GAS METAL ARC WELDING

Gas metal arc welding (GMAW), sometimes referred to by its subtypes as *metal inert gas* (MIG) *welding* or *metal active gas* (MAG) welding, is an electric arc welding process where the heat for welding is produced by an arc between a continuously fed, consumable filler metal electrode and the work. The shielding of the molten weld pool and the arc is obtained from an externally supplied gas or gas mixture.

This course is designed to give you a basic understanding of the GMAW process and equipment, along with the key variables that affect the quality of welds, such as electrode selection, travel speed, welding position, amperage, arc length, and electrode angles. We will also cover core competencies such as setting up welding equipment, preparing weld materials, fitting up weld materials, starting an arc, welding pipes and plates, and repairing welds. And lastly, you will get an understanding of the safety precautions for GMAW and an awareness of the importance of safety in welding.

Although this course is very comprehensive, always refer to the manufacturer’s manuals for specific operating and maintenance instructions.

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

- Describe the process of gas metal arc welding.
- Describe the principles of operation used for gas metal arc welding.
- Describe the equipment associated with gas metal arc welding.
- Describe the processes for installation, setup, and maintenance of equipment for gas metal arc welding.
- State the shielding gas and electrodes for gas metal arc welding.
- Identify the welding applications for gas metal arc welding.
- Describe the welding metallurgy of gas metal arc welding.
- Identify weld and joint designs used for gas metal arc welding.
- Describe the welding procedure variables associated with gas metal arc welding.
- Identify welding procedure schedules used for gas metal arc welding.
- Describe pre-weld preparations for gas metal arc welding.
- Identify defects and problems associated with gas metal arc welding.
- Describe post-weld procedures for gas metal arc welding.
- State the welder training and qualifications associated with gas metal arc welding.
- Describe the welding safety associated with gas metal arc welding.

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1.0.0 INTRODUCTION to the PROCESS

Versatile and widely used, the gas metal arc welding process can be used to weld both ferrous and non-ferrous metals and all thicknesses above thin gage sheet metal. It is the major process used for welding relatively thick sections in the nonferrous metals. The arc and weld pool are clearly visible to the welder. This process sometimes leaves a thin, partial slag covering on the surface of the weld bead, which must be removed. The equipment is generally easy to use because the welder only needs to connect a work lead and the welding gun to the point of welding. The filler metal does transfer across the arc, so there is some weld spatter created (Figure 1).

Figure 1 — Gas metal arc welding.

Efforts were made in the 1920s to shield the atmosphere from the electric arc to improve the properties of welds. The advent of the coated electrode eliminated interest in gas shielded processes at that time. As a matter of fact, coated electrodes utilized the gas produced by the disintegration of the coatings and were thus actually gas shielded welds. The gas tungsten arc welding process, or TIG as it is commonly called, was introduced in the late 1930s and was the forerunner of the current gas shielded processes. It was slow, however, and this led to the development of the gas metal arc welding (GMAW) process in the late 1940s. In this process, the tungsten electrode was replaced by an electrode filler wire which was continuously fed through the center of a torch and surrounded by an inert gas blanket to prohibit atmospheric contamination. The secret of this process was the small diameter electrode wire and the system for automatically maintaining the correct arc length. This process immediately became popular and was used to weld most non-ferrous metals. Research found also that the process could be utilized for welding mild and low alloy steels, but the cost of the inert shielding gas did not allow the MIG process to compete with manual coated electrodes for most applications.

Further welding technology development discovered that the predominant gas evolved from a covered electrode coating was carbon dioxide. This quickly led to the use of carbon dioxide as a shielding gas for use with the gas metal arc welding process when welding on mild and low alloy steel. Early efforts were not too successful, but continuing research did develop the CO_2 welding process. A major problem encountered with CO_2 was porosity caused by low quality gas that contained too much moisture. Because of this, only high purity, welding grade CO_2 could be used.

The CO_2 process became very popular during the 1950s, especially fully automatic installations in the automotive industry. High deposition rates and fast travel speeds were characteristic of the process. It was limited, however, in that it could be used only in the flat position and for making horizontal fillet welds. In addition, the process was so fast that manual travel was difficult, and spatter was sometimes a problem. The shortcomings of the CO_2 process led to further developments.

One development was the improvement of the electrical characteristics of the power sources used for CO_2 welding. This involved the addition of reactance in motor generators to the secondary welding circuit. In this way the short-circuiting currents were limited and the spatter was considerably reduced.

Another area of investigation was the utilization of smaller electrode wires. In utilizing smaller electrode wires, the total heat input into the arc was reduced. However, the current density carried by the electrode wire was greatly increased. The reduced heat input provided a small concentrated arc and a small weld pool. The high current density of the arc provided a very forceful and directional arc which could be controlled and directed. This quickly led to the all position welding process variation known as Microwire which had a short-circuiting type of metal transfer. Originally the gas used to shield micro-wire was 100% CO_2 gas, and this is still the shielding gas predominantly used. However, to soften the arc, argon gas was introduced into the CO_2 and a popular mixture of 75% argon and 25% CO_2 gas is employed for certain applications.

A third development was with different shielding gases which led to "spray arc" welding. This mode employed larger diameter electrode wires and mixtures of argon and small percentages of oxygen for welding steels. This mode produced a smooth weld bead and a directional arc that was easy for the welder to control.

1.1.0 Methods of Application

Gas metal arc welding is widely used in the semiautomatic, mechanized, and automatic modes. Manual welding cannot be done by this process. The most popular method of applying this process is semi-automatically where the welder guides the gun along the joint and adjusts the welding parameters. The wire feeder continuously feeds the filler wire electrode, and the power source maintains the arc length.

The second most popular method of applying this process is automatically where the machinery controls the welding parameters, arc length, joint guidance, and wire feed. The process is only under the observation of the operator.

The mechanized method of welding has only limited popularity. Mechanized welding is where the machine controls the arc length, wire feed, and joint guidance. The operator adjusts the welding parameters.

1.2.0 Advantages and Limitations

The gas metal-arc welding process (GMAW) has revolutionized arc welding. In this process, a consumable electrode (in the form of wire) is fed from a spool through the torch (welding gun) at a preset controlled speed. As the wire passes through the contact tube of the gun, it picks up the welding current. The consumable wire electrode serves two functions: it maintains the arc and provides filler metal to the joint. The method of delivery of the filler metal allows GMAW welding to be basically a one-handed operation which does not require the same degree of skill as Gas Tungsten Arc Welding (GTAW).

The gas metal arc welding process has many advantages over most of the other arc welding processes. These advantages make the process particularly well suited to high production and automated welding applications. Gas metal arc welding has been the process choice for robotic applications. Some of the advantages to gas metal arc welding are the following:

1. It is the only consumable electrode process that can be used to weld most all commercial metals and alloys, ferrous and non-ferrous.
2. A relatively small amount of spatter is produced.
3. The filler metal is fed continuously, so very little time is spent on changing electrodes.
4. It can be used easily in all positions.
5. The arc and weld pool are clearly visible.
6. Little or no slag is produced, resulting in minimal postweld cleaning.
7. A relatively small diameter electrode is used, which gives high current densities.
8. A high percentage of the filler metal is deposited in the weld.
9. Travel speeds and deposition rates are significantly higher than those obtained with shielded metal arc welding and gas tungsten arc welding.
10. Lightweight power sources can be hand carried to the job site.
11. When spray transfer is used, deeper penetration is possible than with shielded metal arc welding, which may permit the use of smaller size fillet welds for equivalent strengths.

Some limitations of the process are:

1. The equipment is more complex, more costly, and less portable than that for shielded metal arc welding.

2. The arc requires protection from wind drafts, which can blow the stream of shielding gas away from the arc.
3. The larger welding gun must be close to the work to ensure proper shielding, and it s less adaptable to welding in difficult to reach areas than shielded metal arc welding.
4. Relatively high levels of radiated heat and arc intensity can result in operator resistance to the process.

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2.0.0 PRINCIPLES of OPERATION

The gas metal arc welding process uses the heat of an electric arc produced between a bare electrode and the part to be welded. The electric arc is produced by electric current passing through an ionized gas. The gas atoms and molecules are broken up and ionized by losing electrons and leaving a positive charge. The positive gas ions then flow from the positive pole to the negative pole, and the electrons flow from the negative pole to the positive pole. About 95% of the heat is carried by the electrons, and the rest is carried by the positive ions. The heat of the arc melts the surface of the base metal and the electrode. The molten weld metal, heated weld zone, and the electrode are shielded from the atmosphere by a shielding gas supplied through the welding gun. The molten electrode filler metal transfers across the arc and into the weld puddle. This process produces an arc with more intense heat than most of the arc welding processes.

The arc is struck by starting the wire feed, which causes the electrode wire to touch the workpiece and initiate the arc. Normally, arc travel along the work is not started until a weld puddle is formed. The gun then moves along the weld joint manually or mechanically so that the adjoining edges are joined. The weld metal solidifies behind the arc in the joint and completes the welding process.

2.1.0 Arc Systems

The gas metal arc welding process may be operated on both constant voltage and constant current power sources. Any welding power source can be classified by its volt-ampere characteristics as either a constant voltage (also called constant potential) or constant current (also called variable voltage) type although there are some machines that can produce both characteristics. Constant voltage power sources are preferred for a majority of gas metal arc welding applications.

In the constant voltage arc system, the voltage delivered to the arc is maintained at a relatively constant level, which gives a flat or nearly flat volt-ampere curve (Figure 2). This type of power source is widely used for the processes that require a continuously fed bare wire electrode. In this system, the arc length is controlled by setting the voltage level on the power source, and the welding current is controlled by setting the wire feed speed.

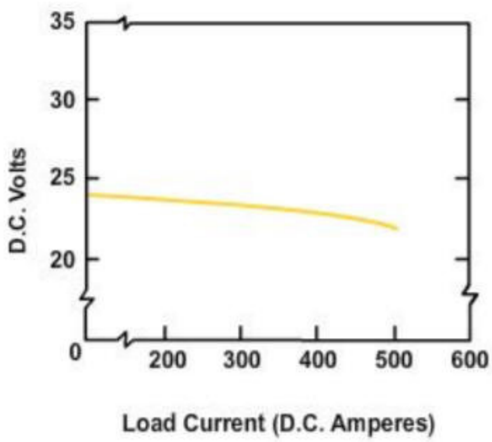

Figure 2 — Volt-amp curve.

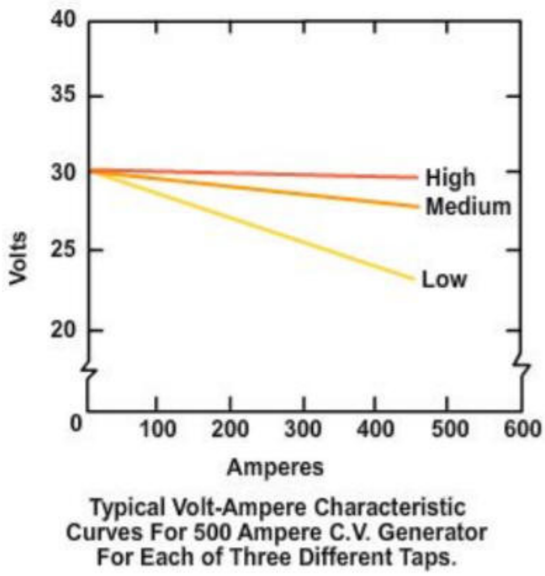

Figure 3 — Volt-amp slopes.

Most machines have a fixed slope that is built in for a certain type of gas metal arc welding. Some constant voltage welding machines are equipped with a slope control that is used to change the slope of the volt-ampere curve. Figure 3 shows different slopes obtained from one power source. The slope has the effect of limiting the amount of short-circuiting current that the power supply can deliver. This is the current available from the power source on the short circuit between the electrode wire and the work.

A slope control is not required but is best when welding with small diameter wire and low current levels. The short-circuit current determines the amount of pinch force available on the electrode. The pinch forces cause the molten electrode tip to neck down so that the droplet will separate from the solid electrode. The flatter the slope of the volt-ampere curve, the higher the short-circuit current and the pinch force. The steeper the slope the lower the short circuit current and pinch force. The pinch force is important because it affects the way the droplet detaches from the tip of the electrode wire, which also affects the arc stability in short-circuiting transfer. When a high short circuit and pinch force are caused by a flat slope, excessive spatter is created. When a very low short circuit current and pinch force are caused by a steep slope, the electrode wire tends to freeze in the weld puddle or pile upon the work piece. When the proper amount of short-circuit current is used, very little spatter with a smooth electrode tip is created.

The inductance of the power supply also has an effect on the arc stability. When loads on the power supply change, the output current will fluctuate, taking time to find its new level. The rate of current change is determined by the inductance of the power supply. The rate of the welding current buildup and pinch force buildup increases with the current, which is also affected by the inductance in the circuit. Increasing the inductance will reduce the rate of current rise and the pinch force. (In short-circuiting welding, increasing the inductance will increase the arc time between short-circuit and decrease the frequency of short-circuiting, thereby reducing the amount of spatter). Increased arc time or inductance produces a flatter and smoother weld bead as well as a more fluid weld puddle. Too much inductance will cause more difficult arc starting.

The constant current (CC) arc system provides a nearly constant welding current to the arc, which gives a drooping volt-ampere characteristic (Figure 4). This arc system is used with the shielded metal arc welding and gas tungsten arc welding processes. The welding current is set by a dial on the machine, and the welding voltage is controlled by the arc length held by the welder. This system is necessary for manual welding because the welder cannot hold a constant arc length, which causes only small variations in the welding current. When gas metal arc welding is done with a constant current system, a special voltage sensing wire feeder is used to maintain a constant arc length.

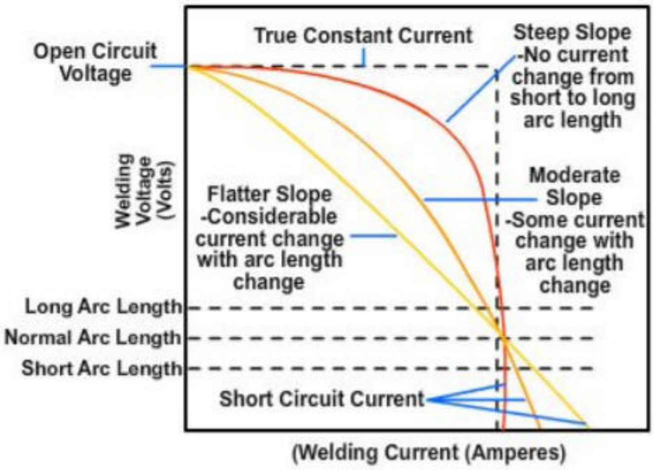

Figure 4 — CC volt-amp curve.

For any power source, the voltage drop across the welding arc is directly dependent on the arc length. An increase in the arc length results in a corresponding increase in the arc voltage, and a decrease in the arc length results in a corresponding decrease in the arc voltage. Another important relationship exists between the welding current and the melt off rate of the electrode. With low current, the electrode melts off slower and the metal is deposited slower. This relationship between welding current and wire feed speed is definite, based on the wire size, shielding gas, and type of filler metal; a faster wire feed speed will give a higher welding current.

In the constant voltage system, instead of regulating the wire to maintain a constant arc length, the wire is fed into the arc at a fixed speed, and the power source is designed to melt off the wire at the same speed. The self-regulating characteristic of a constant voltage power source comes about by the ability of this type of power source to adjust its welding current to maintain a fixed voltage across the arc.

With the constant current arc system with a voltage sensing wire feeder, the welder would change the wire feed speed as the gun is moved toward or away from the weld puddle. Since the welding current remains the same, the burn-off rate of the wire is unable to compensate for the variations in the wire feed speed, which allows stubbing or burning back of the wire into the contact tip to occur. To lessen this problem, a special voltage sensing wire feeder is used which regulates the wire feed speed to maintain a constant voltage across the arc.

The constant voltage system is preferred for most applications, particularly for small diameter wire. With smaller diameter electrodes, the voltage sensing system is often not able to react fast enough to feed at the required burn--off rate, resulting in a higher instance of burnback into the contact tip of the gun.

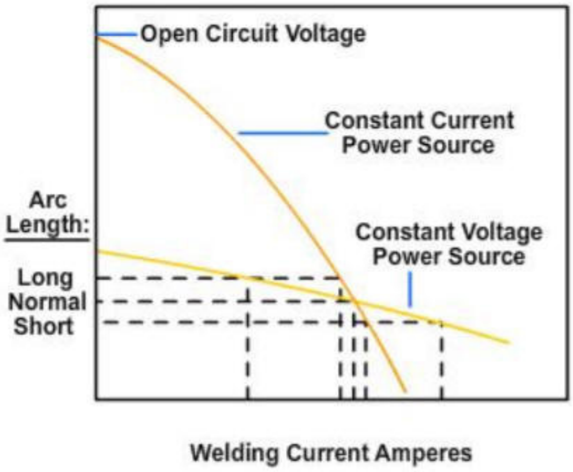

Figure 5 — Volt-amp curves.

Figure 5 shows a comparison of the volt-ampere curves for the two arc systems. This shows that for these particular curves, when a normal arc length is used, the current and voltage level is the same for both the constant current and constant voltage systems. For a long arc length, there is a slight drop in the welding current for the constant current machine and a large drop in the current for a constant voltage machine. For constant voltage power sources, the volt-ampere curve shows that when the arc length shortens slightly, a large increase in welding current occurs. This results in an increased burn-off rate which brings the arc length back to the desired level. Under this system, changes in the wire feed speed caused by the welder are compensated for electrically by the power source. The constant current system is sometimes used, especially for welding aluminum and magnesium because the welder can vary the current slightly by changing the arc length. This varies the depth of penetration and the amount of heat input. With aluminum and magnesium, preheating the wire is not desirable.

2.2.0 Metal Transfer

The types of arcs obtainable and the different modes of gas metal arc welding are determined by the type of metal transfer. The four modes of welding are the short circuiting, globular, spray, and pulsed arc metal transfer. Each mode has its own advantages and applications. The type of metal transfer is determined by the welding current, shielding gas, and welding voltage.

2.2.1 Short Circuiting

Transfer At the beginning of the short-circuiting arc cycle, the end of the electrode wire melts into a small globule which moves toward the weld puddle. When the tip of this globule comes in contact with the workpiece, the arc is momentarily extinguished. When the wire touches the workpiece, the current increases because a short circuit is created. The current increases to the point that the molten globule is pinched off and the arc is re-ignited (Figure 6). This cycle then repeats itself, occurring approximately 20 to 200 times a second depending on the current level and the power supply. The filler metal is transferred to the weld puddle only during the period when the electrode is in contact with the work. No filler metal is transferred across the arc.

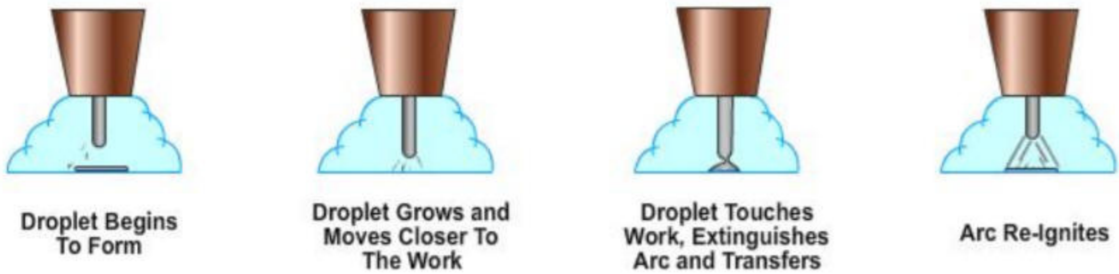

Figure 6 — Short-circuiting transfer.

Short-circuiting transfer applies the lowest welding currents and voltages used with gas metal arc welding, which produces low heat input. The type of shielding gas used has very little effect on this type of transfer but most gas metal arc welding done in this mode employs a CO_2 shielding gas. This type of metal transfer produces a small, fast-freezing weld pool, usually with some small, fine spatter. Because of this, this mode is well suited for joining thin sections of metal by welding in the vertical, horizontal, and overhead positions, and for filling large root openings.

2.2.2 Globular Transfer

The globular transfer cycle starts when a droplet forms on the end of the electrode wire. The molten droplet grows in size until it is larger than the diameter of the electrode. The droplet then detaches from the end of the electrode and transfers across the arc due to the force of gravity. Globular transfer is shown in Figure 7.

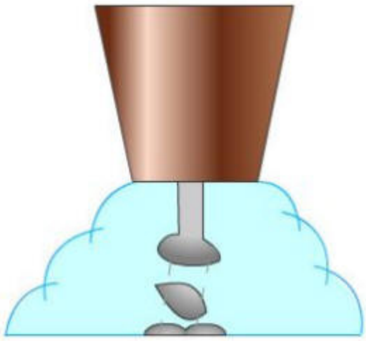

Figure 7 — Globular transfer.

Globular transfer occurs at relatively low operating currents and voltages but higher than those used to obtain short-circuiting transfer. It can occur with all types of shielding gases, but with gases other than CO_2 it generally occurs at current and voltage levels toward the bottom of the operating range. With CO_2 shielding gas, globular transfer will take place at most operating current and voltage levels. Because of the large droplet size and the dependence on gravity to transfer the filler metal, this mode of gas metal arc welding is not suitable for many out-of-position welding applications, especially overhead welding where the droplets tend to fall into the nozzle of the welding gun. Globular transfer is also characterized by a less stable arc and higher amounts of spatter. The arc is less stable because it will shift around and move to the part of the droplet that is closest to the weld puddle, (electric current will always try to take the shortest path). The arc will wave around on the end of the droplet, creating more spatter.

2.2.3 Spray Transfer

The spray transfer cycle begins when the end of the electrode tapers down to a point. Small droplets are formed and electromagnetically pinched off at the tapered point of the electrode tip. The droplets are smaller than the diameter of the electrode and detach much more rapidly than in globular transfer. The rate of transfer can vary from less than one hundred times a second up to several hundred times a second. The arc is also more directional than in the globular mode. Spray transfer is shown in Figure 8.

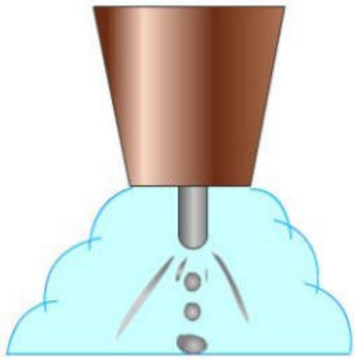

Figure 8 — Spray transfer.

Spray transfer is generally associated with the higher amperage and voltage levels and occurs with argon or argon-rich shielding gases. The spray transfer mode is best adapted for welding thick sections because of the higher welding currents. Spray transfer produces a very stable arc that is well adapted for out-of-position as well as flat position welding. When welding out-of-position, operators need to consider how the high voltage and current levels used may produce a weld puddle that is difficult to control. This mode also produces the least amount of spatter.

2.2.4 Pulsed Current Transfer

To overcome the work thickness and welding position limitations of spray transfer, specially designed power supplies have been developed. These machines produce controlled wave forms and frequencies that "pulse" the welding current at regularly spaced intervals. They provide two levels of current: one a constant, low background current which sustains the arc without providing enough energy to cause drops to form on the wire tip; the other is a superimposed pulsing current with amplitude greater than the transition current necessary for spray transfer. During this pulse, one or more drops are formed and transferred. The frequency and amplitude of the pulses control the energy level of the arc, and therefore the rate at which the wire melts. By reducing the average arc energy and the wire-melting rate, pulsing makes the desirable features of spray transfer available for joining sheet metals and welding thick metals in all positions.

Test Your Knowledge

1. What shielding gas is predominantly used for GMAW?

A. O_2
B. NO_2
C. CO_2
D. He

2. Which is NOT a mode of GMAW metal transfer?

A. Pulsed
B. Spherical
C. Globular
D. Spray

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3.0.0 EQUIPMENT for WELDING

The basic design of a GMAW system is shown in Figure 9 and includes four principal components:

- Power source.
- Wire drive and accessories (drive rolls, guide tubes, reel stand, etc.).
- GMAW gun and cable assembly designed to deliver the shielding gas and the electrode to the arc.
- Shielding gas apparatus and accessories.

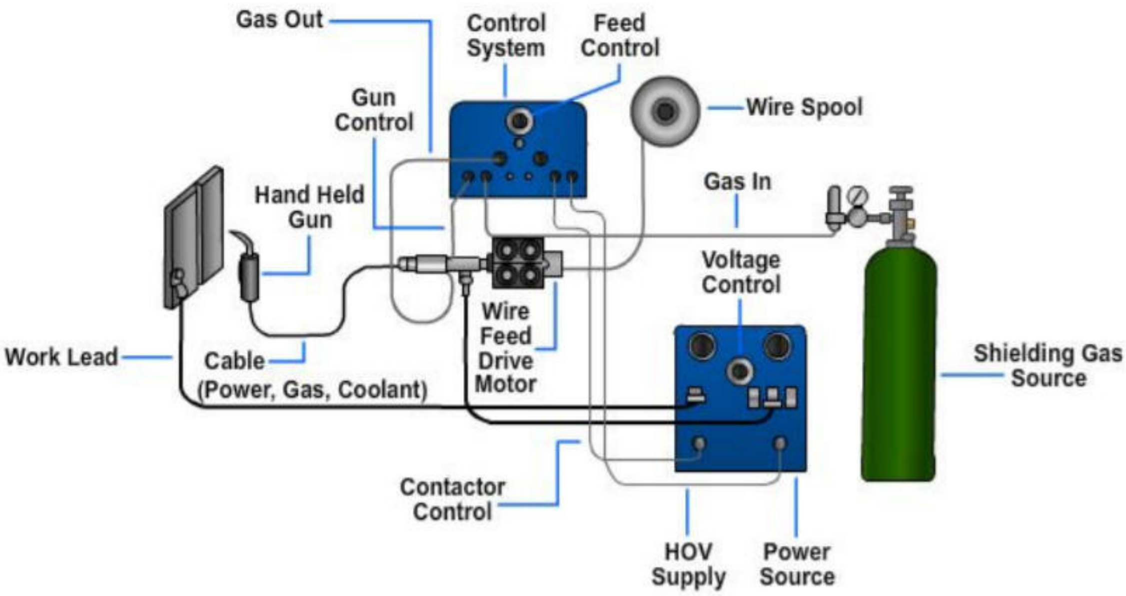

Figure 9 — Equipment for gas metal arc welding.

3.1.0 Power Sources

The purpose of the power source or welding machine is to provide the electric power of the proper current and voltage to maintain a welding arc. Many power sources operate on 200, 230, 460, or 575 volt input electric power. The power sources operate on single-phase or three-phase input power with a frequency of 50 or 60 Hz.

3.1.1 Power Source Duty Cycle

The duty cycle of a power source is defined as the ratio of arc time to total time. Most power sources used for gas metal arc welding have a duty cycle of 100%, which indicates that they can be used to weld continuously. Some machines used for this process have duty cycles of 60%, which means that they can be used to weld six of every ten minutes. In general, these lower duty cycle machines are the constant current type that are used in plants where the same machines are also used for shielded metal arc welding and gas tungsten arc welding. Some of the smaller constant voltage welding machines have a 60% duty cycle.

3.1.2 Types of Current

Most gas metal arc welding is done using steady direct current. Steady direct current can be connected in one of two ways: electrode positive (reverse polarity DCEP) and electrode negative (straight polarity DCEN). The electrically charged particles flow between the tip of the electrode and the work (Figure 10). The electrode positive connection is used for almost all welding applications of this process. It gives better penetration than electrode negative and can be used to weld all metals. Electrode negative is sometimes used when a minimum amount of penetration is desired.

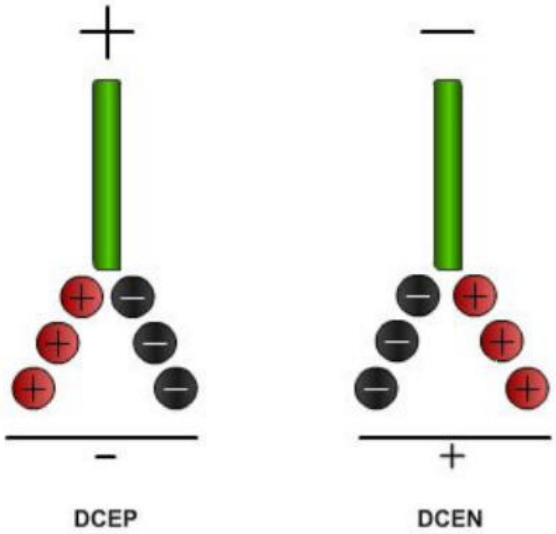

Figure 10 — Particle flow for DCEP and DCEN.

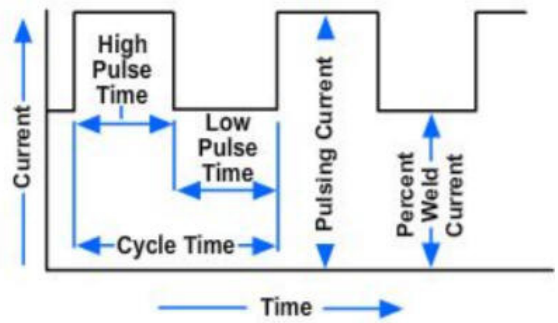

Figure 11 — Pulsed current terminology.

Pulsed direct current is used for applications where good penetration and reduced heat input are required. Pulsed current occurs when the welding current is operated at one level for a set period of time, switches to another level for a time, and then repeats the cycle (Figure 11). The pulsing action can be provided from one power source or combining the outputs of two power sources working at two current levels. The welding current varies from as low as 20 amps at 18 volts up to as high as 750 amps at 50 volts, and the frequency of pulsing can be varied. When using pulsed current, welding thinner sections is more practical than when using steady direct current in the spray transfer mode, because there is less heat input, which reduces the amount of distortion.

3.1.3 Types of Power

Sources Many types of direct current power sources may be used for gas metal arc welding, including engine-driven generators (rotating) and transformer-rectifiers (static). Inverters are included in the static category.

3.1.3.1 Generator Welding Machines

A generator welding machine can be powered by an electric motor for shop use or by an internal combustion engine (gas or diesel) for field use. Engine-driven welders can have either water- or air-cooled engines, and many of them provide auxiliary power as well (Figure 12).

Figure 12 — Engine-driven power source.

Many of the engine-driven generators used for gas metal arc welding in the field are combination constant current-constant voltage types. These are popular for applications such as pipe welding so that both shielded metal arc welding and gas metal arc welding can be done using the same power source. The motor-driven generator welding machines are becoming less popular and are being replaced by transformer-rectifier welding machines. Motor-driven generators produce a very stable arc, but they are noisier and more expensive, consume more power, and require more maintenance than transformer-rectifier machines.

3.1.3.2 Transformer-Rectifier Welding Machines

The more popular welding machines used for gas metal arc welding are the transformer-rectifiers. A method of supplying direct current to the arc other than the use of a rotating generator is by adding a rectifier to a basic transformer circuit. A rectifier is an electrical device which changes alternating current into direct current. These machines are more efficient electrically than motor-generator welding machines, they respond faster when arc conditions change, and they provide quieter operation. There are two basic types of transformer-rectifier welding machines: those that operate on single-phase input power and those that operate on three-phase input power (Figure 13).

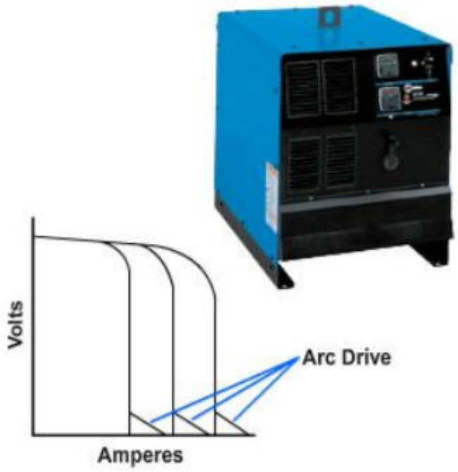

Figure 13 — Three-phase constant voltage.

The single-phase transformer-rectifier machines provide DC current to the arc and a constant current volt-ampere characteristic. These machines are not as popular as three-phase transformer-rectifier welding machines for gas metal arc welding. When using a constant current power source, a special variable speed or voltage sensing wire feeder must be used to keep the current level uniform.

Machines used for shielded metal arc welding and gas tungsten arc welding can be adapted for use with gas metal arc welding. A limitation of the single-phase system is that the power required by the single-phase input power may create an unbalance of the power supply lines, which is objectionable to most power companies. Another limitation is that short-circuiting metal transfer cannot be used with this type of power source. These machines normally have a duty cycle of 60%.

One of the most widely used types of power sources for this process is the three-phase transformer rectifier. These machines produce DC current for the arc and most have a constant voltage volt-ampere characteristic. When using these machines, a constant speed wire feeder is normally employed. This type of wire feeder maintains a constant wire feed speed with slight changes in welding current. The three-phase input power gives these machines a more stable arc than single-phase input power, and avoids the line unbalance that occurs with the single-phase machines. Many of these machines also use solid-state controls for the welding. A solid-state machine will produce the flattest volt-ampere curve of the different constant voltage power sources.

3.1.3.3 Inverter Power Sources

The inverter machine is different from a transformer-rectifier. The inverter will rectify 60 Hz alternating line current, utilize a chopper circuit to produce a high frequency alternating current, reduce that voltage with an AC transformer, and finally rectify that to obtain the required direct current output. Changing that alternating current frequency to a much higher frequency allows a greatly reduced size of transformer and reduced transformer losses as well (Figure 14).

Figure 14 — Inverter power source.

Inverter circuits control the output power using the principle of time ratio control (TRC). The solid-state devices (semiconductors) in an inverter act as switches; they are either switched "on" and conducting, or they are switched "off" and blocking. This operation of switching "on" and "off" is sometimes referred to as switch mode operation. TRC is the regulation of the "on" and "off" time of the switches to control the output. Faster response times are generally associated with the higher switching and control frequencies, resulting in more stable arcs and superior arc performance. However, other variables, such as length of weld cables, must be considered since they may affect the power supply performances.

3.2.0 Controls

The controls for this process are located on the front of the welding machine, on the welding gun, and on the wire feeder or a control box.

The welding machine controls for a constant voltage machine are an on-off switch, a voltage control, and sometimes a switch to select the polarity of direct current. The voltage control can be a single knob, or it can have a top switch for setting the voltage range and a fine voltage control knob. Other controls are sometimes present such as a switch for selecting CC (constant current) or CV (constant voltage) output on combination machines or a switch for a remote control. On the constant current welding machines there is an on-off switch, a current level control knob, and sometimes a knob or switch for selecting the polarity of direct current.

The trigger or switch on the welding gun is a remote control that is used by the welder in semiautomatic welding to stop and start the welding current, wire feed, and shielding gas flow.

For semiautomatic welding, a wire feed speed control is normally part of the wire feeder assembly or close by. The wire feed speed sets the welding current level on a constant voltage machine. For machine or automatic welding, a separate control box is often used to control the wire feed speed. On the wire feeder control box, there may also be switches to turn the control on and off and gradually feed the wire up and down.

Other controls for this process are used for special applications, especially when using a programmable power source. A couple of examples are items such as timers for spot welding and pulsation.

3.3.0 Wire Feeders

The electrode feed unit (wire feeder) provides the power for driving the electrode through the cable and gun and to the work (Figure 15). There are several different electrode feed units available, but the best type of system depends on the application. Most of the electrode feed units used for gas metal arc welding are the constant speed type which are used with constant voltage power sources. This means that the wire feed speed is set before welding. The wire feed speed controls the amount of welding current.

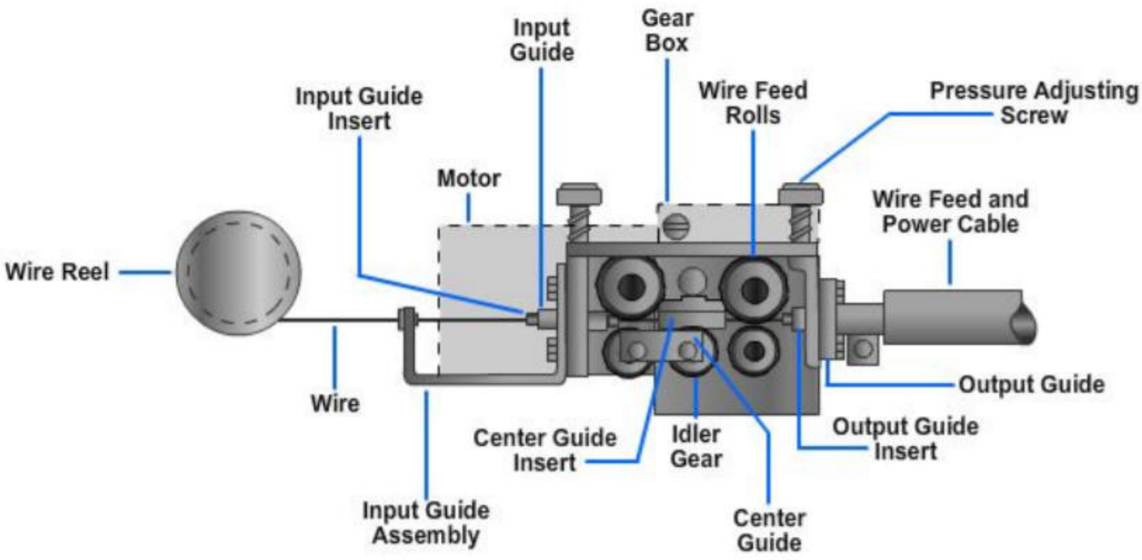

Figure 15 — Wire feed assembly.

Variable speed or voltage sensing wire feeders are used with constant current power sources. With a variable speed wire feeder, a voltage sensing circuit is used to maintain the desired arc length by varying the wire feed speed. Variations in the arc length increase or decrease the wire feed speed. The wire-feed speed is measured in inches per minute (ipm). For a specific amperage setting, a high wire-feed speed results in a short arc, whereas a low speed produces a long arc. Therefore, you would use higher speeds for overhead welding than for flat-position welding.

An electrode feed unit consists of an electric motor connected to a gearbox with drive rolls in it. Systems may have two or four feed rolls in the gearbox. In a four roll system, the lower two rolls drive the wire and have a circumferential "V" groove in them, depending on the type and size of wire being fed. Figure 16 shows several of the most common drive rolls and their uses.

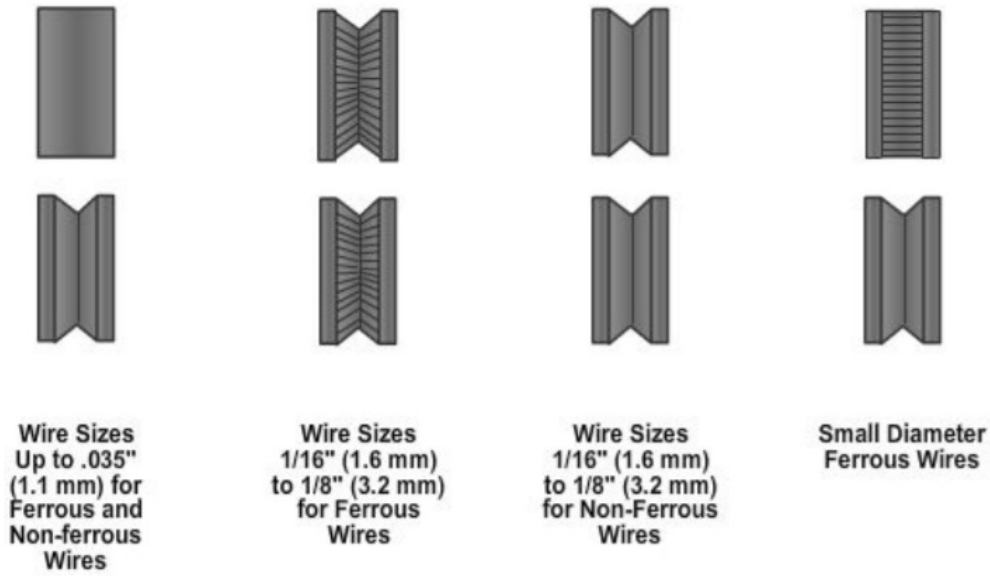

Figure 16 — Common types of drive rolls and their uses.

Wire feed systems may be of the push, pull, or push-pull types depending on the type and size of the electrode wire and the distance between the welding gun and the coil or spool of electrode wire. The push type is the wire feeding system most commonly used for steels. It consists of the wire being pulled from the wire feeder by the drive rolls and then being pushed into the flexible conduit and through the gun. The length of the conduit can be up to about 12 ft. (3.7m) for steel wire and 6 ft. (1.8m) for aluminum wire.

A typical push wire feeder is shown in Figure 17. This solid-state wire feeder has the wire feeder control box and the wire reel support mounted with the wire feed motor and gear box.

Figure 17 — Solid-state control wire feeder and wire support.

Pull type wire feeders have the drive rolls attached to the welding gun. This type of system works best for feeding wires up to about .045 in. (1.1mm) in diameter with a hand-held welding gun. Most machine and automatic welding stations also use this type of system. The push-pull system is particularly well suited for use with low strength wires such as aluminum and when driving wires long distances. This system can use synchronous drive motors to feed the electrode wire, which makes it good for soft wires and long distances. The wire feeding system shown in Figure 18 uses the standard feeder as the drive motor (push) and the gun as a slave motor (pull).

Figure 18 — Standard push-pull wire feeding system.

3.4.0 Welding Guns

A typical GMAW gun is shown in Figure 19. The welding gun transmits the welding current to the electrode. Because the wire is fed continuously, a sliding electrical contact is used. The welding current is passed to the electrode through a copper base alloy contact tube. The contact tubes have various hole sizes, depending on the diameter of the electrode wire. The gun also has a gas supply connection and a nozzle to direct the shielding gas around the arc and weld puddle.

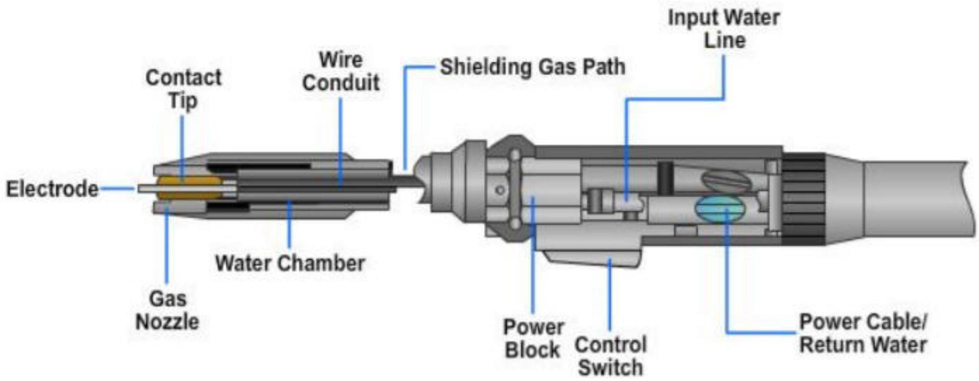

Figure 19 — Cross-sectional view of a welding gun.

To prevent overheating of the welding gun, cooling is required to remove the heat generated. Shielding gas or water circulating in the gun, or both are used for cooling. An electrical switch is used to start and stop the electrode feeding, welding current, and shielding gas flow. This is located on the gun in semiautomatic welding and separately on machine welding heads.

3.4.1 Semiautomatic Guns

The hand-held semiautomatic guns usually have a curved neck, which makes them flexible, and a curved handle that adds comfort and balance. The gun is attached to the service lines which include the power cable, water hose, gas hose, and wire conduit or liner. The guns have metal nozzles, which have orifice diameters from 3/8 to 7/8 in. (10- 22 mm), depending on the welding requirements, to direct the shielding gas to the arc and weld puddle.

Welding guns are either air-cooled or water-cooled. The choice between the guns is based on the type of shielding gas, amount of welding current, voltage, joint design, and the shop practice. A water-cooled gun is similar to an air-cooled gun except that ducts have been added that permit the cooling water to circulate around the contact tube and nozzle. Water-cooled guns provide more efficient cooling of the gun.

Air-cooled guns are employed for applications where water is not readily available. These are actually cooled by the shielding gas. The guns are available for service up to 600 amperes used intermittently with a CO_2 shielding gas. These guns are usually limited to 50% of the CO_2 rating with argon or helium. CO_2 cools the welding gun, where argon or helium do not. Water-cooling permits the gun to operate continuously at the rated capacity with lower heat buildup. Water-cooled guns are generally used for applications requiring between 200 and 750 amperes. Air-cooled guns of the same capacity as water-cooled guns are heavier but they are easier to manipulate in confined spaces or for out-of-position applications because there are fewer cables.

There are three general types of guns available. The one shown in Figure 20 has the electrode wire fed through a flexible conduit from a remote wire feeder. The conduit is generally 10 to 15 feet due to the wire feeding limitations of a push type wire feeding system.

Figure 20 — Semi-automatic.

Figure 21 — Spool gun.

Figure 21 shows the second type of welding gun, which has a self-contained wire feeding mechanism and electrode wire supply. This wire supply is in the form of a 1 lb. (.45 kg) spool. This gun employs a pull type wire feed system and is particularly good for feeding aluminum and other softer electrode wires which tend to jam in long conduits. The third type of gun has a wire feed motor on the gun, and the wire is fed through a conduit from a remote wire feed supply. This system has a pull type wire feeder and can use longer length conduits.

3.4.2 Machine Welding Guns

The machine welding guns use the same basic design principles and features as the semiautomatic welding guns. These guns have capacities up to 1200 amperes and are generally water-cooled because of the higher amperages and duty cycles required. The gun is mounted directly below the wire feeder. Large diameter wires up to 1/4 in. (6.4 mm) are often used. Figure 22 shows a GMAW control panel for a machine welding gun system.

Figure 22 — Control panel.

3.5.0 Shielding Gas Equipment

The shielding gas system used in gas metal arc welding consists of a gas supply source, a gas regulator, a flowmeter, control valves, and supply hoses to the welding gun.

The shielding gases are supplied in liquid form when they are in storage tanks with vaporizers or in a gas form in high-pressure cylinders. An exception to this is carbon dioxide. When put in high-pressure cylinders, it exists in both the liquid and gas forms. The bulk storage tank system is used when there are large numbers of welding stations using the same type of shielding gas in large quantities. For applications where there are large numbers of welding stations but relatively low gas usage, a manifold system is often used. This consists of several high-pressure cylinders connected to a manifold which then feeds a single line to the welding stations. Individual high-pressure cylinders are used when the amount of gas usage is low, when there are few welding stations, or when portability is required.

You should use the same type of regulator and flowmeter for gas metal-arc welding that you use for gas tungsten-arc welding. The gas flow rates vary, depending on the types and thicknesses of the material and the joint design. At times it is necessary to connect two or more gas cylinders (manifold) together to maintain higher gas flow.

For most welding conditions, the gas flow rate is approximately 35 cubic feet per hour (cfh). This flow rate may be increased or decreased, depending upon the particular welding application. Final adjustments usually are made on a trial-and-error basis. The proper amount of gas shielding results in a rapid crackling or sizzling arc sound. Inadequate gas shielding produces a popping arc sound and results in weld discoloration, porosity, and spatter.

Regulators and flowmeters are designated for use with specific shielding gases and should be used only with the gas for which they were designed (Figure 23).

The hoses are normally connected to solenoid valves on the wire feeder to turn the gas flow on and off with the welding current. A hose is used to connect the flowmeter to the welding gun. The hose is often part of the welding gun assembly.

Figure 23 — Regulator and flowmeter.

3.6.0 Welding Cables

Welding cables, normally made of copper or aluminum, and connectors connect the power source to the electrode holder and to the work. They consist of hundreds of wires enclosed in an insulated casing of natural or synthetic rubber. The cable that connects the power source to the welding gun is called the electrode lead. In semiautomatic welding, this cable is often part of the cable assembly, which also includes the shielding gas hose and the conduit through which the electrode wire is fed. For machine or automatic welding, the electrode lead is normally separate. The cable that connects the work to the power source is called the work lead; it is usually connected to the work by a pincer clamp or a bolt.

Table 1 shows recommended cable sizes for use with different welding currents and cable lengths. A cable too small, or too long, for the current load will become too hot to handle during welding.

Table 1 — Recommended cable sizes for different currents and cable lengths.

Weld Type	Weld Current	Length of Cable Circuit in Feet – Cable Size AWG.					
		60'	100'	150'	200'	300'	400'
Manual (Low Duty Cycle)	100	4	4	4	2	1	1/0
	150	2	2	2	1	2/0	3/0
	200	2	2	1	1/0	3/0	4/0
	250	2	2	1/0	2/0		
	300	1	1	2/0	3/0		
	350	1/0	1/0	3/0	4/0		
	400	1/0	1/0	3/0			
	450	2/0	2/0	4/0			
	500	2/0	2/0	4/0			
Automatic (High Duty Cycle)	400	4/0	4/0				
	800	4/0 (2)	4/0 (2)				
	1200	4/0 (3)	4/0 (3)				

Three factors determine the size of welding cable to use: the duty cycle of the machine, its amperage rating, and the distance between the work and the machine. If either amperage or distance increases, the cable size also must increase. Cable sizes range from the smallest at AWG No.8 to AWG No. 4/0 with amperage ratings of 75 amperes and upward.

3.7.0 Other Equipment

A good ground clamp is essential to producing quality welds. Without proper grounding, the circuit voltage fails to produce enough heat for proper welding, and there is the possibility of damage to the welding machine and cables. Three basic methods are used to ground a work lead. You can fasten the ground cable to the workbench with a C-clamp, attach a spring-loaded clamp directly onto the workpiece, or bolt or tack-weld the end of the ground cable to the welding bench or workpiece. For a workbench, the third way creates a permanent common ground.

3.7.1 Water Circulators

When a water-cooled gun is used, a water supply must be included in the system. This can be supplied by a water circulator or directly from a hose connection to a water tap. The water is carried to the welding torch through hoses that may or may not go through a valve in the welding machine. A water circulator is shown in Figure 24.

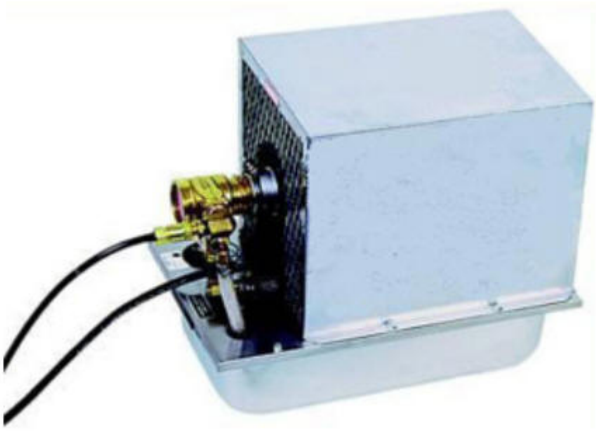

Figure 24 — Water circulator.

3.7.2 Motion Devices

Motion devices are used for machine and automatic welding. These motion devices can be used to move the welding head, workpiece, or gun depending on the type and size of the work and the preference of the user. Motor driven carriages that run on tracks or directly on the workpiece are commonly used. Carriages can be used for straight line contour, vertical, or horizontal welding. Side beam carriages, supported on the vertical face of a flat track, can be used for straight line welding. Welding head manipulators may be used for longitudinal welds and, in conjunction with a rotary weld positioner, for circumferential welds. These welding head manipulators come in many boom sizes and can also be used for semiautomatic welding with mounted welding heads. Oscillators are optional equipment used to oscillate the gun for surfacing, vertical-up welding, and other welding operations that require a wide bead. Oscillator devices can be either mechanical or electromagnetic.

3.7.3 Accessories

Accessory equipment used for gas metal arc welding consists of items used for cleaning the weld bead and cutting the electrode wire. In many cases cleaning is not required, but when slag is created by the welding, a chipping hammer or grinder is used to remove it. Wire brushes and grinders are sometimes used for cleaning the weld bead, and wire cutters and pliers are used to cut the end of the electrode wire between stops and starts.

Test Your Knowledge

3. What type of current is predominantly used for GMAW?

   A. Alternating
   B. Direct
   C. Negative
   D. Positive

4. Of what material are welding cables most commonly made?

   A. Stainless steel
   B. Copper
   C. Bronze
   D. Silver alloy

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4.0.0 INSTALLATION, SETUP, AND MAINTENANCE of EQUIPMENT

Learning to arc weld requires you to possess many skills. Among these skills are the abilities to set up, operate, and maintain your welding equipment.

In most factory environments, the work is brought to the welder. In the Seabees, the majority of the time the opposite is true. You will be called to the field for welding on buildings, earthmoving equipment, well drilling pipe, ship to shore fuel lines, pontoon causeways, and the list goes on. To accomplish these tasks, you have to become familiar with your equipment and be able to maintain it in the field. It would be impossible to give detailed maintenance information here because of the many different types of equipment found in the field; therefore, only the highlights will be covered.

You should become familiar with the welding machine that you will be using. Study the manufacturer's literature and check with your senior petty officer or chief on the items that you do not understand. Machine setup involves selecting current type, polarity, and current settings. The current selection depends on the size and type of electrode used, position of the weld, and the properties of the base metal.

Cable size and connections are determined by the distance required to reach the work, the size of the machine, and the amperage needed for the weld.

Operator maintenance depends on the type of welding machine used. Transformers and rectifiers require little maintenance compared to engine-driven welding machines. Transformer welders require only to be kept dry and to be given a minimal amount of cleaning. Internal maintenance should be done only by electricians due to the possibilities of electrical shock. Engine-driven machines require daily maintenance. In most places you will be required to fill out and turn in a daily inspection form called a “hard card” before starting the engine. This form is a list of items, such as oil level, water level, visible leaks, and other things, that affect the operation of the machine.

After all of these items have been checked, you are now ready to start welding.

Listed below are some additional welding rules that should be followed.

- Clear the welding area of all debris and clutter.
- Do not use gloves or clothing that contains oil or grease.
- Check that all wiring and cables are installed properly.
- Ensure that the machine is grounded and dry.
- Follow all manufacturers’ directions on operating the welding machine.
- Have on hand a protective screen to protect others in the welding area from flash burns.
- Always keep fire-fighting equipment on hand.
- Clean rust, scale, paint, and dirt from the joints that are to be welded.

4.1.0 Power Source Connections

As a safety precaution, turn the power switches on the wire feeder and the power source to the off position before checking electrical connections. Also, always wear your safety glasses when you are in the welding area.

Check all electrical connections to make sure they are tight, and check cables for cracks and exposed wire.

On power sources that are set up for electrode positive (reverse polarity), the positive terminal that supplies welding voltage and amperage is connected to the wire feeder.

The gun trigger takes its power from a connection on the wire feeder.

The work lead is connected to the negative terminal; it should be attached to the work or to the welding table.

4.2.0 Gun Cable Assembly

To remove the gun cable assembly: disconnect the gun trigger lead, loosen the retaining knob on the wire feeder, and pull the gun cable out of the wire feeder with a twisting motion. Check the O-rings for damage (Figure 25). Check the gun to make sure it is in good condition. Clean the nozzle. Use a nozzle cleaner or a pair of needle nose pliers to remove spatter from the nozzle. A dirty or damaged nozzle may interrupt the flow of shielding gas, causing porosity. Inspect the contact tube and gas diffuser (Figure 26). Clean spatter from the contact tube with a pair of needle nose pliers.

Figure 25 — O-ring inspection.

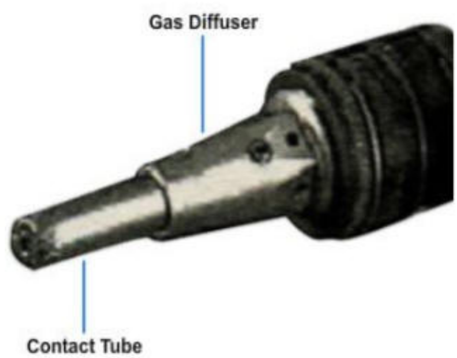

Figure 26 — Contact tube and gas diffuser inspection

Note

Replace the contact tube if the opening is worn into an oval shape.

Check the gas diffuser for blockage, and clean it if necessary.

Clean the liner:

1. Remove the contact tube and outlet guide.
2. Stretch the cable straight.
3. Blow shop air through the liner.

Note

You should clean the liner each time you change wire to prevent dirt buildup.

You should replace the liner if it is kinked or shows signs of excessive wear, such as an enlarged or oval opening. Install a new liner according to manufacturer's specification. Insert the liner into the gun cable slowly to avoid kinking it.

4.3.0 Wire Installation

1. Remove the contact tube.
2. Open the feed roll assembly (Figure 27).

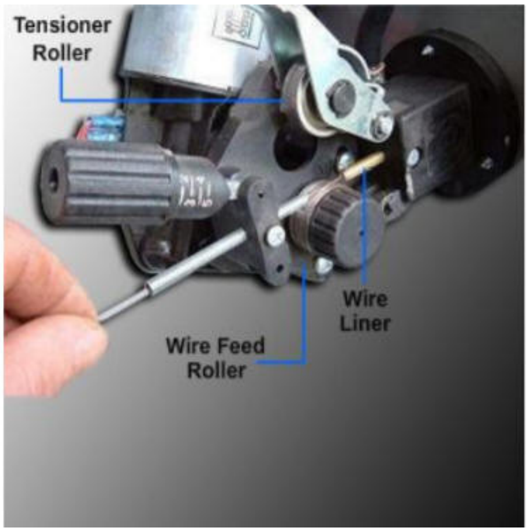

Figure 27 — Wire installation.

3. Remove the spool retaining ring.
4. Slide the spool onto the spool hub so the wire feeds from bottom.
5. Replace the spool retaining ring.
6. Keep hand pressure on the wire to prevent the spool from uncoiling as you feed the wire through the inlet guide, across the bottom wire feed roller, and into the outlet guide.
7. Close the feed roll assembly.
8. Test tension by pressing the "jog" button until the wire feeds through the gas diffuser.
9. Replace the contact tube and nozzle.
10. Clip the wire to a 1/4 to 3/8 in. stick-out.

The correct amount of electrode extension or wire stick-out is important because it influences the welding current of the power source. Since the power source is self-regulating, the current output is automatically decreased when the wire stick-out increases. Conversely, when the stick-out decreases, the power source is forced to furnish more current. Too little stick-out causes the wire to fuse to the nozzle tip, which decreases the tip life.

For most GMAW, the wire stick-out should measure from 3/8 to 3/4 inch. For smaller (micro) wires, the stick-out should be between 1/4 and 3/8 inch.

Note

Make sure the drive rolls and contact tube are matched to the diameter of the wire.

4.4.0 Gas Cylinder Installation

Transport a cylinder on the proper cart, chain it in place, and remove the cap.

To clear dirt from the valve opening, open and quickly close the cylinder valve.

Install the pressure regulator and flow meter assembly.

When installing 100% CO_2, insert a nonmetallic washer inside the regulator connection so the regulator does not frost (Figure 28). To prevent freezing for flow rates greater than 25 cubic feet per hour (cfh), use a line heater or manifold system.

Figure 28 — Installation of pressure regulator.

Attach the gas hose to the flowmeter and wire feeder.

Open the valve slowly until pressure registers on the regulator, then open the valve completely to seat it in the fully open position. Press the purge button and adjust the flow meter to the correct flow rate. 4.5.0 Amperage and Voltage Settings Set amperage and voltage to the middle of the range specified in the welding procedure.

Fine tune the settings by performing a series of test welds.

4.6.0 Equipment Shutdown and Clean Up

Completely close the valve on the gas cylinder or gas manifold. Press the purge button to bleed gas from the line. Close the flowmeter finger tight. Power down the wire feeder and power source. Clean up the work area.

4.7.0 Burn Back

Burn back occurs when the molten tip of the electrode fuses to the end of the contact tube.

If burn back occurs, check the following:

- Voltage. If the voltage is too high in relation to the amperage, the electrode melts faster than the wire feeder can deliver wire to the puddle.
- Drive roll tension. The drive rolls could be too loose, causing the wire to slip.
- Liner and contact tube. A damaged liner or restricted contact tube may also cause burn back.

4.8.0 Bird Nests

Bird nests occur when the wire is impeded somewhere between the wire feeder and the work, causing the wire to pile up between the drive rolls and the outlet guide (Figure 29).

Figure 29 — Bird nest.

The most common cause of bird nests is having too much drive roll tension combined with a dirty or damaged liner, a restricted contact tube, or burnback.

To clear a bird nest:

1. Clip the wire behind the inlet and outlet guides, and remove the tangle of wire.
2. Remove the gun cable assembly, nozzle, and contact tube.
3. Extract the wire from the back of the gun cable.
4. Rethread the wire.
5. Replace the contact tube and nozzle.

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5.0.0 SHIELDING GAS AND ELECTRODES

The shielding gas is an important consumable of gas metal arc welding; its main purpose is to shield the arc and the molten weld puddle from the atmosphere. The electrodes used for this process are also consumable and provide the filler metal to the weld. The chemical composition of the electrode wire in combination with the shielding gas will determine the weld metal composition and mechanical properties of the weld.

5.1.0 Shielding Gases

Air in the weld zone is displaced by a shielding gas in order to prevent contamination of the molten weld puddle. This contamination is caused mainly by nitrogen, oxygen, and water vapor present in the atmosphere.

As an example, nitrogen in solidified steel reduces the ductility and impact strength of the weld and can cause cracking. In large amounts, nitrogen can also cause weld porosity.

Excess oxygen in steel combines with carbon to form carbon monoxide (CO). This gas can be trapped in the metal, causing porosity. In addition, excess oxygen can combine with other elements in steel and form compounds that produce inclusions in the weld metal.

When hydrogen, present in water vapor and oil, combines with either iron or aluminum, porosity will result, and "underbead" weld metal cracking may occur.

To avoid these problems associated with contamination of the weld puddle, three main gases are used for shielding: argon, helium, and carbon dioxide. In addition, small amounts of oxygen, nitrogen, and hydrogen have proven beneficial for some applications. Of these gases, only argon and helium are inert gases.

Both inert and active gases may be used for gas metal arc welding. When welding the non-ferrous metals, inert shielding gases are used because they do not react with the metals. The inert gases used in gas metal arc welding are argon, helium, and argon-helium mixtures.

Active or inert gases may be employed when welding the ferrous metals. Active gases such as carbon dioxide, mixtures of carbon dioxide, or oxygen-bearing shielding gases are not chemically inert and can form compounds with the metals.

Compensation for the oxidizing tendencies of other gases is made by special wire electrode formulations. Argon, helium, and carbon dioxide can be used alone, in combinations, or mixed with others to provide defect-free welds in a variety of weld applications and weld processes.

The basic properties of shielding gases that affect the performance of the welding process include the following:

- Thermal properties at elevated temperatures
- Chemical reaction of the gas with the various elements in the base plate and welding wire
- Effect of each gas on the mode of metal transfer

The thermal conductivity of the gas at arc temperatures influences the arc voltage as well as the thermal energy delivered to the weld. As thermal conductivity increases, greater welding voltage is necessary to sustain the arc. For example, the thermal conductivity of helium and CO_2 is much higher than that of argon; because of this, they deliver more heat to the weld. Therefore, helium and CO_2 require more welding voltage and power to maintain a stable arc. The compatibility of each gas with the wire and base metal determines the suitability of the various gas combinations.

Carbon dioxide and most oxygen-bearing shielding gases should not be used for welding aluminum, as aluminum oxide will form. However, CO_2 and O_2 are useful at times and even essential when MIG welding steels. They promote arc stability and good fusion between the weld puddle and base material. Oxygen is a great deal more oxidizing than CO_2. Consequently, oxygen additions to argon are generally less than 12 percent by volume, whereas 100 percent CO_2 can be used for GMAW mild steels. Steel wires must contain strong deoxidizing elements to suppress porosity when used with oxidizing gases, particularly mixtures with high percentages of CO_2 or O_2 and especially 100 percent CO_2.

Shielding gases also determine the mode of metal transfer and the depth to which the workpiece is melted (depth of penetration). Table 2 summarizes recommended shielding gases for various materials and metal transfer types. Spray transfer is not obtained when the gas is rich in CO_2. For example, mixtures containing more than about 20 percent CO_2 do not exhibit true spray transfer. Rather, mixtures up to 30 percent CO_2 can have a "spray-like" shape to the arc at high current level but are unable to maintain the arc stability of lower CO_2 mixtures. Spatter levels will also tend to increase when mixtures are rich in CO_2.

Table 2 — Use of different shielding gases for gas metal arc welding.

Type of Gas	Typical Mixtures	Primary Uses
Argon		Non-ferrous metals
Helium		Aluminum, magnesium, and copper alloys
Carbon dioxide		Mild and low alloy steel
Argon-helium	20-80%	Aluminum, magnesium, copper and nickel alloys
Argon-oxygen	1-2% O_2 3-5% O_2	Stainless steel Mild and low alloy steels
Argon-carbon dioxide	20-50% CO_2	Mild and low alloy steels
Helium-argon-carbon dioxide	90%He-7 1/2%Ar-2 1/2%CO_2 60-70%He-25-35%Ar-5%CO_2	Stainless steel Low alloy steels
Nitrogen		Copper alloys

Several factors are usually considered in determining the type of shielding gas to be used, including the following:

- Type of metal to be welded
- Arc characteristics and type of metal transfer
- Speed of welding
- Tendency to cause undercutting
- Penetration, width, and shape of the weld bead
- Availability
- Cost of the gas
- Mechanical property requirements

5.1.1 Argon

Argon shielding gas is chemically inert and used primarily on the non-ferrous metals. This gas is obtained from the atmosphere by the liquification of air. Argon may be supplied as a compressed gas or a liquid, depending on the volume of use.

Argon shielding gas promotes spray type metal transfer at most current levels. Because argon is a heavier gas than helium, lower flow rates are used because the gas does not leave the welding area as fast as it does with helium. Another advantage of argon is that it gives better resistance to drafts. For any given arc length and welding current, the arc voltage is less when using argon than when using helium or carbon dioxide. This means that there is less arc energy, which makes argon preferable for welding thin metal and for metals with poor thermal conductivity.

Argon is less expensive than helium and has greater availability. It also gives easier arc starting, quieter and smoother arc action, and good cleaning action.

5.1.2 Helium

Helium shielding gas is chemically inert and is used primarily on aluminum, magnesium, and copper alloys. Helium is a light gas obtained by separation from natural gas. It may be distributed as a liquid but it is more often used as compressed gas in cylinders.

Helium shielding gas is lighter than air and because of this, high gas flow rates must be used to maintain adequate shielding. Typically, the gas flow rate is 2 to 3 times of that used for argon when welding in the flat position. Helium is often preferred in the overhead position because the gas floats up and maintains good shielding, while argon tends to float down. Globular metal transfer is usually obtained with helium, but spray transfer may be obtained at the highest current levels. Because of this, more spatter and a poorer weld bead appearance will be produced, as compared to argon. For any given arc length and current level, helium will produce a hotter arc, which makes helium good for welding thick metal and metals like copper, aluminum, and magnesium, which have a high thermal conductivity. Helium generally gives wider weld beads and better penetration than argon.

5.1.3 Carbon Dioxide

Carbon dioxide is manufactured from fuel gases given off by the burning of natural gas, fuel oil, or coke. It is also obtained as a by-product of calcination operation in lime kilns, from the manufacturing of ammonia, and from the fermentation of alcohol. The carbon dioxide given off by manufacturing ammonia and the fermenting alcohol is almost 100% pure. Carbon dioxide is made available to the user in either cylinder or bulk containers with the cylinder being more common. With the bulk system, carbon dioxide is usually drawn off as a liquid and heated to the gas state before going to the welding torch. The bulk system is normally used only when supplying a large number of welding stations.

In the cylinder, the carbon dioxide is in both a liquid and a vapor form, with the liquid carbon dioxide occupying approximately two thirds of the space in the cylinder. By weight, this is approximately 90% of the content of the cylinder. Above the liquid it exists as a vapor gas. As carbon dioxide vapor is drawn from the cylinder, it is replaced with carbon dioxide that vaporizes from the liquid in the cylinder, and therefore the overall pressure will be indicated by the pressure gage.

When the pressure in the cylinder has dropped to 200 psi (1.4 MPa), the cylinder should be replaced with a new cylinder. A positive pressure should always be left in the cylinder in order to prevent moisture and other contaminants from backing up into the cylinder. The normal discharge rate of the CO_2 cylinder is from about 4 to 35 cubic feet per hour (1.9 to 17 liters per minute). However, a maximum discharge rate of 25 cfh (12 l/min) is recommended when using a single cylinder for welding.

As the vapor pressure drops from the cylinder pressure to discharge pressure through the CO_2 regulator, it absorbs a great deal of heat. If flow rates are set too high, this absorption of heat can lead to freezing of the regulator and flow meter, which interrupts the gas shielding. When flow rates higher than 25 cfh (12 l/min) are required, normal practice is to manifold two CO_2 cylinders in parallel or to place a heater between the bottle and gas regulator, pressure regulator, and flowmeter. Figure 30 shows a manifold system used for connecting several cylinders together. Excessive flow rates can also result in drawing liquid from the cylinder.

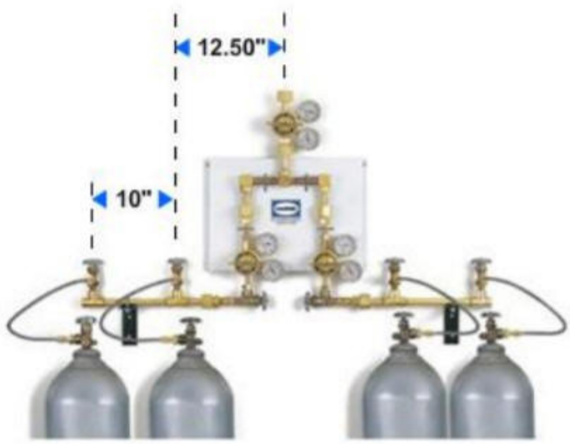

Figure 30 — Manifold system for carbon dioxide.

Carbon dioxide has become widely used for welding mild and low alloy steels. Most active gases cannot be used as shielding, but carbon dioxide offers several advantages for use in welding steel:

- Better joint penetration
- Higher welding speeds
- Lower welding costs (the major advantage)

Carbon dioxide produces short-circuiting transfer at low current levels and globular transfer at the higher current levels. Because carbon dioxide is an oxidizing gas, most electrode wires available for welding steel contain deoxidizers to prevent porosity in the weld. The surface of the weld bead is usually slightly oxidized even when there is no porosity.

The major disadvantage of carbon dioxide is that it produces a harsh arc and higher amounts of spatter. A short arc length is usually desirable to keep the amount of spatter to a minimum. Another problem with carbon dioxide is that it adds some carbon to the weld deposit. This does not affect mild steels, but it tends to reduce the corrosion resistance of stainless steel and reduce the ductility and toughness of the weld deposit in some of the low alloy steels.

5.1.4 Argon-Helium Mixtures

Regardless of the percentage, argon-helium mixtures are used for non-ferrous materials such as aluminum, copper, nickel alloys, and reactive metals. These gases used in various combinations increase the voltage and heat of GTAW and GMAW arcs while maintaining the favorable characteristics of argon. Generally, the heavier the material the higher the percentage of helium you would use. Small percentages of helium, as low as 10%, will affect the arc and the mechanical properties of the weld. As helium percentages increase, the arc voltage, spatter, and penetration will increase while minimizing porosity. A pure helium gas will broaden the penetration and bead, but depth of penetration could suffer. However, arc stability also increases. The argon percentage must be at least 20% when mixed with helium to produce and maintain a stable spray arc.

Argon-25% He (HE-25) – This little used mixture is sometimes recommended for welding aluminum where an increase in penetration is sought and bead appearance is of primary importance.

Argon-75% He (HE-75) – This commonly used mixture is widely employed for mechanized welding of aluminum greater than one inch thick in the flat position. HE-75 also increases the heat input and reduces porosity of welds in ¼-and 1/½-in. thick conductivity copper.

Argon-90% He (HE-90) – This mixture is used for welding copper over ½ in. thick and aluminum over 3 in. thick. It has an increased heat input, which improves weld coalescence and provides good X-ray quality. It is also used for short circuiting transfer with high nickel filler metals.

5.1.5 Argon-Oxygen Mixtures

Argon-oxygen gas mixtures usually contain 1%, 2% or 5% oxygen. The small amount of oxygen in the gas causes the gas to become slightly oxidizing, so the filler metal used must contain deoxidizers to help remove oxygen from the weld puddle and prevent porosity. Pure argon does not always provide the best arc characteristics when welding ferrous metals. In pure argon shielding, the filler metal has a tendency not to flow out to the fusion line.

The addition of small amounts of O_2 to argon greatly stabilizes the weld arc, increases the filler metal droplet rate, lowers the spray arc transition current, and improves wetting and bead shape. The weld puddle is more fluid and stays molten longer, allowing the metal to flow out towards the toe of the weld. This reduces undercutting and helps flatten the weld bead. Occasionally, small oxygen additions are used on non-ferrous applications. For example, it has been reported by NASA that .1% oxygen has been useful for arc stabilization when welding very clean aluminum plate.

Argon-1% O_2 – This mixture is primarily used for spray transfer on stainless steels. One percent oxygen is usually sufficient to stabilize the arc, improve the droplet rate, provide coalescence, and improve appearance.

Argon-2% O_2 – This mixture is used for spray arc welding on carbon steels, low alloy steels and stainless steels. It provides additional wetting action over the 1% O_2 mixture. Mechanical properties and corrosion resistance of welds made in the 1 and 2% O_2 additions are equivalent.

Argon-5% O_2 – This mixture provides a more fluid but controllable weld pool. It is the most commonly used argon-oxygen mixture for general carbon steel welding. The additional oxygen also permits higher travel speeds.

Argon-8-12% O_2 – Originally popularized in Germany, this mixture has recently surfaced in the U.S. in both the 8% and 12% types. The main application is single pass welds, but some multi-pass applications have been reported. The higher oxidizing potential of these gases must be taken into consideration with respect to the wire alloy chemistry. In some instances a higher alloyed wire will be necessary to compensate for the reactive nature of the shielding gas. The higher puddle fluidity and lower spray arc transition current of these mixtures could have some advantage on some weld applications.

Argon-12-25% O_2 – Mixtures with very high O_2 levels have been used on a limited basis, but the benefits of 25% O_2 versus 12% O_2 are debatable. Extreme puddle fluidity is characteristic of this gas. A heavy slag/scale layer over the bead surface can be expected, which is difficult to remove. With care and a deoxidizing filler metal, sound welds can be made at the 25% O_2 level with little or no porosity. Removal of the slag/scale before subsequent weld passes is recommended to ensure the best weld integrity.

5.1.6 Argon-Carbon Dioxide Mixtures

The argon-carbon dioxide mixtures are mainly used on carbon and low alloy steels with limited application on stainless steels. The argon additions to CO_2 decrease the spatter levels usually experienced with pure CO_2 mixtures. Small CO_2 additions to argon produce the same spray arc characteristics as small O_2 additions. The difference lies mostly in the higher spray arc transition currents of argon-CO_2 mixtures. In GMAW welding with CO_2 additions, a slightly higher current level must be reached in order to establish and maintain stable spray transfer of metal across the arc. Oxygen additions reduce the spray transfer transition current. Above approximately 20% CO_2, spray transfer becomes unstable, and random short circuiting and globular transfer occur.

Argon-3-10% CO_2 – These mixtures are used for spray arc and short circuiting transfer on a variety of carbon steel thicknesses. Because the mixtures can successfully utilize both arc modes, this gas has gained much popularity as a versatile mixture. A 5% mixture is very commonly used for pulsed GMAW of heavy section low alloy steels being welding out-of-position. The welds are generally less oxidizing than those with 98 Ar-2% O_2. Improved penetration is achieved with less porosity when using CO_2 additions as opposed to O_2 additions. In the case of bead wetting, it requires about twice as much CO_2 to achieve the same wetting action as identical amounts of O_2. From 5 to 10% CO_2 the arc column becomes very stiff and defined. The strong arc forces that develop give these mixtures more tolerance to mill scale and a very controllable puddle.

Argon-11-20% CO_2 – This mixture range has been used for various narrow gap, out-of-position sheet metal and high speed GMAW applications. Most applications are on carbon and low alloy steels. By mixing the CO_2 within this range, maximum productivity on thin gauge materials can be achieved. This is done by minimizing burn through potential while at the same time maximizing deposition rates and travel speeds. The lower CO_2 percentages also improve deposition efficiency by lowering spatter loss.

Argon-21-25% CO_2 – Used almost exclusively with short circuiting transfer on mild steel, it was originally formulated to maximize the short circuit frequency on .030- and .035- in. diameter solid wires, but through the years it has become the de facto standard for most diameter solid wire welding and has been commonly used with flux cored wires. This mixture also operates well in high current applications on heavy materials and can achieve good arc stability, puddle control, and bead appearance as well as high productivity.

Argon-50% CO_2 – This mixture is used where high heat input and deep penetration are needed. Recommended material thicknesses are above 11/8 in., and welds can be made out-of-position. This mixture is very popular for pipe welding using the short circuiting transfer. Good wetting and bead shape without excessive puddle fluidity are the main advantages for the pipe welding application. Welding on thin gauge materials has more of a tendency to burn through, which can limit the overall versatility of this gas. In welding at high current levels, the metal transfer is more like welding in pure CO_2 than previous mixtures, but some reduction in spatter loss can be realized due to the argon addition.

Argon-75% CO_2 – A 75% CO_2 mixture is sometimes used on heavy wall pipe and is the optimum in good side-wall fusion and deep penetration. The argon constituent aids in arc stabilization and reduced spatter.

5.1.7 Helium-Argon-Carbon Dioxide Mixtures

Three-part shielding gas blends continue to be popular for carbon steel, stainless steel, and, in restricted cases, nickel alloys. For short-circuiting transfer on carbon steel, the addition of 40% helium to argon and CO_2 as a third component to the shielding gas blend provides a broader penetration profile.

Helium provides greater thermal conductivity for short-circuiting transfer applications on carbon steel and stainless steel base materials. The broader penetration profile and increased sidewall fusion reduces the tendency for incomplete fusion.

For stainless steel applications, three-part mixes are quite common. Helium additions of 55% to 90% are added to argon and 2.5% CO_2 for short-circuiting transfer. They are favored for reducing spatter, improving puddle fluidity, and providing a flatter weld bead shape.

Common Ternary (tur-nuh-ree) Gas Shielding Blends:

90% Helium + 7.5% Argon + 2.5% CO_2 — This is the most popular of the short-circuiting blends for stainless steel applications. The high thermal conductivity of helium provides a flat bead shape and excellent fusion. This blend has also been adapted for use in pulsed spray transfer applications, but it is limited to stainless or nickel base materials greater than .062–in. (1.6 mm) thick. It is associated with high travel speeds on stainless steel applications.

55% Helium + 42.5% Argon + 2.5% CO_2 — Although less popular than the 90% helium mix discussed above, this blend features a cooler arc for pulsed spray transfer. It also lends itself very well to the short-circuiting mode of metal transfer for stainless and nickel alloy applications. The lower helium concentration permits its use with axial spray transfer.

38% Helium + 65% Argon + 7% CO_2 — This tertiary blend is for use with short-circuiting transfer on mild and low alloy steel applications. It can also be used on pipe for open root welding. The high thermal conductivity broadens the penetration profile and reduces the tendency to cold lap.

5.1.8 Nitrogen

Nitrogen is occasionally used as a shielding gas when welding copper and copper alloys. Nitrogen has characteristics similar to helium because it gives better penetration than argon and tends to promote globular metal transfer. Nitrogen is used where the availability of helium is limited, such as in Europe. It can be mixed with argon for welding aluminum alloys.

5.2.0 Shielding Gas Flow Rate

The shielding gas flow rate should be high enough to maintain adequate shielding for the arc and weld puddle but should not be so high that it causes turbulence in the weld puddle. The gas flow rate is primarily dependent on the type of shielding gas, position of welding, and amount of electrode extension or stick-out. Higher flow rates are required for helium than for carbon dioxide and argon. These are often twice those used for carbon dioxide and argon because helium is a very light gas that floats away from the weld puddle quicker than the heavier carbon dioxide and argon gases.

In welding in the overhead position, slightly higher flow rates are often used with the heavier shielding gases because they tend to fall away from the weld puddle. The last item that affects the gas flow rate is the amount of electrode extension used. For a long electrode extension, higher gas flow rates are required to provide adequate shielding because of the greater distance between the tip of the nozzle and the weld puddle.

5.3.0 Electrodes

One of the most important factors to consider in GMAW welding is the correct filler wire selection. The electrode used in gas metal arc welding is bare, solid, consumable wire. In many cases, the electrode wires are chosen to match the chemical composition of the base metal as closely as possible. In some cases, electrodes with a somewhat different chemical composition will be used to obtain maximum mechanical properties or better weldability. Almost all electrodes used for gas metal arc welding of steels have deoxidizing or other scavenging elements added to minimize the amount of porosity and improve the mechanical properties. The use of electrode wires with the right amount of deoxidizers is most important when using oxygen- or carbon dioxide-bearing shielding gases.

The filler wire, in combination with the shielding gas, will produce the deposit chemistry that determines the resulting physical and mechanical properties of the weld. Five major factors influence the choice of filler wire for GMAW welding:

- Base plate chemical composition
- Base plate mechanical properties
- Shielding gas employed
- Type of service or applicable specification requirements
- Type of weld joint design

However, long experience in the welding industry has generated American Welding Society Standards to greatly simplify the selection. Wires have been developed and manufactured that consistently produce the best results with specific plate materials. Although there is no industry-wide specification, most wires conform to an AWS standard (Table 3).

Table 3 — AWS filler metal specifications for gas metal arc welding.

AWS Specification	Metal
A5.7	Copper and copper alloys
A5.9	Stainless steel
A5.10	Aluminum and aluminum alloys
A5.14	Nickel and nickel alloys
A5.16	Titanium and titanium alloys
A5.18	Carbon steel
A5.19	Magnesium alloys
A5.24	Zirconium and zirconium alloys
A5.28	Low alloy steel

5.3.1 Classification

The classification system for bare, solid wire electrodes used throughout industry in the United States was devised by the American Welding Society. Because of the wide variety of metals that can be welded by this process, there are numerous classifications and many are the same as those used to classify filler rods for gas tungsten arc welding.

Most classifications of GMAW electrodes are based on the chemical composition of the weld deposit. A major exception to this is the classification of electrodes used for welding steel, which are classified by both the chemical composition of the wire and mechanical properties produced in the weld.

A typical steel classification is ER70S-6.

- The E indicates the filler wire is an electrode that may be used for gas metal arc welding. The R indicates it may also be used as a filler rod for gas tungsten arc or plasma arc welding.
- The next two (or three) digits indicate the nominal tensile strength of the filler wire.
- The letter to the right of the digits indicates the type of filler metal. An S stands for a solid wire and a C stands for a metal-cored wire which consists of a metal powder core in a metal sheath.
- The digit or letters and digit in the suffix indicate the special chemical composition of the filler metal and the other mechanical properties required.

For example, an ER90S-B3 classification indicates that the filler metal may be used as an electrode or a filler rod, produces a weld metal tensile strength of 90,000 psi (620 MPa), is a solid electrode wire, and produces a weld deposit with specific chemical compositions and mechanical properties. These are shown in Tables 10-4 and 10-5, taken from the AWS Filler Metal Specifications A5.18 and A5.28 respectively.

Table 4 — Chemical composition of bare solid electrodes and deposited weld metal for composite cored electrodes for carbon and low alloy steels (AWS A5.18, A5.28).

	C	Mn	Si	P	S	Ni	Cr	Mo	Cu	Other
					CARBON STEELS					
ER70S-2	.07	.90-1.40	.40-.70	.025	.035				.50	Ti Zr Al
ER70S-3	.06-15	.90-1.40	.45-.70	.025	.035				.50	
ER70S-4	.07-.15	1.00-1.50	.65-.85	.025	.035				.50	
ER70S-5	.07-.19	.90-1.40	.30-.60	.025	.035				.50	Al
ER70S-6	.07-15	1.40-1.85	.80-1.15	.025	.035				.50	
ER70S-7	.07-.15	1.50-2.00	.50-.80	.025	.035				.50	
ER70S-G		No Chemical Requirements								
					CHROMIUM-MOLYBDENUM STEELS					
ER80S-B2	.07-.12	.40-.70	.40-.70	.025	.025	.20	1.2-1.5	.40-.65	.35	
ER80S-B2L	.05	.40-.70	.40-.70	.025	.025	.20	1.2-1.5	.40-.65	.35	
ER90S-B3	.07-.12	.40-.70	.40-.70	.025	.025	.20	2.3-2.7	.90-1.20	.35	
ER90S-B3L	.05	.40-.70	.40-.70	.025	.025	.20	2.3-2.7	.90-1.20	.35	
E80C-B2L	.05	.40-1.00	.25-.60	.025	.030	.20	1.00.. 1.5	.40-.65	.35	
E80C-B2	.07-.12	.40-1.00	.25-.60	.025	.030	.20	1.0-1.50	.40-.65	.35	
E90C-B3L	.05	.40-1.00	.25-.60	.025	.030	.20	2.0-2.5	.90-1.20	.35	
E90C-B3	.07-.12	.40-1.00	.25-.60	.025	.030	.20	2.0-2.5	.90-1.20	.35	
					NICKEL STEELS					
ER80S-Ni1	.12	1.25	.40-.80	.025	.025	.80-l.10	.15	.15	.35	V
ER80S-Ni2	.12	1.25	.40-.80	025	.025	2.00-2.75			.35	
ER80S-Ni3	.12	1.25	.40-.80	.025	.025	3.00-3.75			.35	
E80C-Ni1	.12	1.25	.60	.025	.030	.80-1.10		.65	.35	V
E80C-Ni2	.12	1.25	.60	.025	.030	2.00-2.75			.35	
E80C-Ni3	.12	1.25	.60	.025	.030	3.00-3.75			.35	
					MANGANESE-MOLYBDENUM STEELS					
ER80S-D2	.07-.12	1.60-2.10	.50-.80	.025	.025	.15		.40-.60	.50	
					OTHER LOW ALLOY STEEL ELECTRODES					
ER100S-1	.08	1.25-1.80	.20-.50	.010	.010	1.40-2.10	.30	.25-.55	.25	V Ti Zr Al
ER100S-2	.12	1.25-1.80	.20-.60	.010	.010	.80-l.25	.30	.20-.55	.35-.65	V Ti Zr Al
ERII0S-1	.09	1.40-1.80	.20-.55	.010	1.90-2.60		.50	.25-.55	.25	V Ti Zr Al
ER120S-1	.10	1.40-1.80	.25-.60	.010	2.00-2.80		.60	.30-.65	.25	V Ti Zr Al
ERXXS-G		No Chemical Requirements								
EXXC-G		No Chemical Requirements								

Table 5 — Tension and impact test of weld metal deposits of carbon steel electrodes.

Tension Test Requirements (As Welded)

AWS Classification	Shielding Gas	Tensile Strength (minimum) psi	Tensile Strength (minimum) Mpa	Yield Strength (minimum) psi	Yield Strength (minimum) Mpa	Elongation Percent (minimum)
ER70S-2 ER70S-3 ER70S-4 ER70S-5 ER70S-6 ER70S-7	CO_2	70,000	480	58,000	400	22
ER70S-G	d	70,000	480	58,000	400	22
E70C-3X E70C-6X	75-80% Ar/balance CO_2	70,000	480	58,000	400	22
E70C-G(X)	d	70,000	480	58,000	400	22
E70C-GS(X)	d	70,000	480	Not Specified		Not Specified

a. The final X shown in the classification represents. "C" or "M" which corresponds to the shielding gas with which the electrode is classified. The use of "C" designates 100% CO_2, shielding; "M" designates 75·80% Ar/balance CO_2. For E70C-GQ and E70C-GS. The final "C" or "M" may be omitted.

b. Yield strength at 0.2% offset and elongation in 2 in. (51 mm) gage length.

c. CO_2 = carbon dioxide shielding gas. The use of CO_2 for classification purposes shall not be construed to preclude the use of Ar/CO_2 or Ar/O_2 shielding gas mixtures. A filler metal tested with gas blends such as Ar/O_2 or Ar/CO_2 may result in weld metal having higher strength and lower elongation.

d. Shielding gas shall be as agreed to between purchaser and supplier.

Impact test requirements (as welded)

AWS Classification	Average Impact Strength (minimum)
ER70-2	20 ft lbf at -20°F(27J@-29°C)
ER70-3	20 ft lbf at 0°F(27J@-18°C)
ER70-4	Not Required
ER70-5	Not Required
ER70-6	20 ft lbf at -20°F(27J@-29°C)
ER70-7	20 ft lbf at -20°F(27J@-29°C)
ER70S-G	As agreed between supplier and purchaser
ER70S-G(X)	As agreed between supplier and purchaser
E70C-3X	20 ft lbf at 0°F(27J@-18°C)
E70C-6X	20 ft lbf at -20°F(27J@-29°C)
E70C-GS(X)	Not Required

a. Both the highest and lowest of the five test values obtained shall be disregarded in computing the impact strength. Two of the remaining three values shall equal or exceed 20 ft-lbf; one of the three remaining values may be lower than 20 ft-lbl but not lower than 15 ft-lbf. The average of the three shall not be less than the 20 ft-lbf specified.

b. For classifications with the "N" (nuclear) designation, three additional specimens shall be tested at room temperature. Two of the three shall equal or exceed. 75 ft-lbf (102J), and the third shall not be lower than 70 ft-lbf (95J). Average of the three values shall equal or exceed 75 ft lbf (102J).

Filler metals for other base metals are classified according to the chemical compositions of the weld metal produced. Some examples are the stainless steel classifications shown in Table 6, the aluminum classifications shown in Table 7, the copper classifications shown in Table 8, the magnesium classifications shown in Table 9, and the nickel classifications shown in Table 10.

Table 6 — Chemical composition of bare stainless steel welding electrodes and rods (AWS A5.9).

AWS	UNS	Composition, Wt%[a,b]										Other Elements	
Classification[c,d]	Number[e]	C	Cr	Ni	Mo	Mn	Si	P	S	N	Cu	Element	Amount
ER209	S20980	0.05	20.5-24.0	9.5-12.0	1.5-3.0	4.0-7.0	0.90	0.03	0.03	0.10-0.30	0.75	V	0.10-0.30
ER218	S21880	0.10	16.0-18.0	8.0-9.0	0.75	7.0-9.0	3.5-4.5	0.03	0.03	0.08-0.18	0.75		
ER219	S21980	0.05	19.0-21.5	5.5-7.0	0.75	8.0-10.0	1.00	0.03	0.03	0.10-0.30	0.75		
ER240	S24080	0.05	17.0-19.0	4.0-6.0	0.75	10.5-13.5	1.00	0.03	0.03	0.10-0.30	0.75		
ER307	S30780	0.04-0.14	19.5-22.0	8.0-10.7	0.5-1.5	3.3-4.75	0.30-0.65	0.03	0.03		0.75		
ER308	S30880	0.08	19.5-22.0	9.0-11.0	0.75	1.0-2.5	0.30-0.65	0.03	0.03		0.75		
ER308H	S30880	0.04-0.08	19.5-22.0	9.0-11.0	0.50	1.0-2.5	0.30-0.65	0.03	0.03		0.75		
ER308L	S30883	0.03	19.5-22.0	9.0-11.0	0.75	1.0-2.5	0.30-0.65	0.03	0.03		0.75		
ER308Mo	S30882	0.08	18.0-21.0	9.0-12.0	2.0-3.0	1.0-2.5	0.30-0.65	0.03	0.03		0.75		
ER308LMo	S30886	0.04	18.0-21.0	9.0-12.0	2.0-3.0	1.0-2.5	0.30-0.65	0.03	0.03		0.75		
ER308Si	S30881	0.08	19.5-22.0	9.0-11.0	0.75	1.0-2.5	0.65-1.00	0.03	0.03		0.75		
ER308LSi	S30888	0.03	19.5-22.0	9.0-11.0	0.75	1.0-2.5	0.65-1.00	0.03	0.03		0.75		
ER309	S30980	0.12	23.0-25.0	12.0-14.0	0.75	1.0-2.5	0.30-0.65	0.03	0.03		0.75		
ER309L	S30983	0.03	23.0-25.0	12.0-14.0	0.75	1.0-2.5	0.30-0.65	0.03	0.03		0.75		
ER309Mo	S30982	0.12	23.0-25.0	12.0-14.0	2.0-3.0	1.0-2.5	0.30-0.65	0.03	0.03		0.75		
ER309LMo	S30986	0.03	23.0-25.0	12.0-14.0	2.0-3.0	1.0-2.5	0.30-0.65	0.03	0.03		0.75		
ER309Si	S30981	0.12	23.0-25.0	12.0-14.0	0.75	1.0-2.5	0.65-1.00	0.03	0.03		0.75		
ER309LSi	S30988	0.03	23.0-25.0	12.0-14.0	0.75	1.0-2.5	0.65-1.00	0.03	0.03		0.75		
ER310	S31080	0.08-0.15	25.0-28.0	20.0-22.5	0.75	1.0-2.5	0.30-0.65	0.03	0.03		0.75		
ER312	S31380	0.15	28.0-32.0	8.0-10.5	0.75	1.0-2.5	0.30-0.65	0.03	0.03		0.75		
ERJ16	S31680	0.08	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	0.30-().65	0.03	0.03		0.75		
ER316H	S31680	0.04-0.08	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	0.30-().65	0.03	0.03		0.75		
ER316L	S31683	0.03	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	0.30-0.65	0.03	0.03		0.75		
ER316Si	S31681	0.08	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	0.65-1.00	0.03	0.03		0.75		
ER316LSi	S31688	0.03	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	0.65-1.00	0.03	0.03		0.75		
ERJ17	S31780	0.08	18.5-20.5	13.0-15.0	3.0-4.0	1.0-2.5	0.30-0.65	0.03	0.03		0.75		
ER317L	S31783	0.03	18.5-20.5	13.0-15.0	3.0-4.0	1.0-2.5	0.30-0.65	0.03	0.03		0.75		
ER318	S31980	0.08	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	0.30-0.65	0.03	0.03		0.75	Cb[g]	8xC min/1.0 m
ERJ20	N08021	0.07	19.0-21.0	32.0-36.0	2.0-3.0	2.5	0.60	0.03	0.03		3.0-4.0	Cb[g]	8xC min/1.0 m
ER320LR	N08022	0.025	19.0-21.0	32.0-36.0	2.0-3.0	1.5-2.0	0.15	0.015	0.02		3.0-4.0	Cb[g]	8xC min/0.40 r
ER321	S32180	0.08	18.5-20.5	9.0-10.5	0.75	1.0-2.5	0.30-0.65	0.03	0.03		0.75	Ti	9xC min/1.0 m
ER330	N0S331	0.18-0.25	15.0-17.0	34.0-37.0	0.75	1.0-2.5	0.30-0.65	0.03	0.03		0.75		
ER347	S34780	0.08	19.0-21.5	9.0-11.0	0.75	1.0-2.5	0.30-0.65	0.03	0.03		0.75	Cb[g]	10xC min/1.0 r
ER347Si	S34788	0.08	19.0-21.5	9.0-11.0	0.75	1.0-2.5	0.65-1.00	0.03	0.03		0.75	Cb[g]	10xC min/1.0 r
ER383	N08028	0.025	26.5-28.5	30.0-33.0	3.2-4.2	1.0-2.5	0.50	0.02	0.03		0.70-1.5		
ER385	N08904	0.025	19.5-21.5	24.0-26.0	4.2-5.2	1.0-2.5	0.50	0.02	0.03		1.2-2.0		
ER409	S40900	0.08	10.5-13.5	0.6	0.50	0.8	0.8	0.03	0.03		0.75	Ti	10xC min/1.0 r
ER409Cb	S40940	0.08	10.5-13.5	0.6	0.50	0.8	1.0	0.04	0.03		0.75	Cb[g]	10xC min/1.0 r
ER410	S41080	0.12	11.5-13.5	0.6	0.75	0.6	0.5	0.03	0.03		0.75		
ER410NiM0	S41086	0.06	11.0-12.5	4.0-5.0	0.4-0.7	0.6	0.5	0.03	0.03		0.75		
ER420	S42080	0.25-0.40	12.0-14.0	0.6	0.75	0.6	0.5	0.03	0.03		0.75		
ER430	S43080	0.10	15.5-17.0	0.6	0.75	0.6	0.5	0.03	0.03		0.75		
ER446LM0	S44687	0.015	25.0-27.5	f	0.75-1.50	0.4	0.4	0.02	0.02	0.015	f		
ER502[h]	S50280	0.10	4.6-6.0	0.6	0.45-0.65	0.6	0.5	0.03	0.03		0.75		
ER505[h]	S50480	0.10	8.0-10.5	0.5	0.8-1.2	0.6	0.5	0.03	0.03		0.75		
ER630	S17480	0.05	16.0-16.75	4.5-5.0	0.75	0.25-0.75	0.75	0.03	0.03		3.25-4.00	Cb[g]	0.15-0.30
ER19-10H	S30480	0.04-0.08	18.5-20.0	9.0-11.0	0.25	1.0-2.0	0.30-0.65	0.03	0.03		0.75	Cb[g] Ti	0.05 0.05
ER16-8-2	S16880	0.10	14.5-16.5	7.5-9.5	1.0-2.0	1.0-2.0	0.30-0.65	0.03	0.03		0.75		
ER2209	S39209	0.03	21.5-23.5	7.5-9.5	2.5-3.5	0.50-2.0	0.90	0.03	0.03	0.08-0.20	0.75		
ER2553	S39553	0.04	24.0-27.0	4.5-6.5	2.9-3.9	1.5	1.0	0.04	0.03	0.10-0.25	1.5-2.5		
ERJ556	RJ0556	0.05-0.15	21.0-23.0	19.0-22.5	2.5-4.0	0.50-2.00	0.20-0.80	0.04	0.015	0.10-0.30		Co W Cb Ta Al Zr La B	16.0-21.0 2.0-3.5 0.30 0.30-1.25 0.10-0.50 0.001-0.10 0.005-0.10 0.02

Notes for Table 6

a. Analysis shall be made for the elements for which specific values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total, excluding iron, does not exceed 0.50 percent.

b. Single values shown are maximum percentages.

c. In the designator for composite. stranded, and strip electrodes, the "R" shall be deleted. A designator "C" shall be used for composite and stranded electrodes and a designator "0" shall be used for strip electrodes. For example, ERXXX designates a solid wire and EQXXX designates a strip electrode of the same general analysis, and the same UNS number. However, ECXXX designates a composite metal cored or stranded electrode and may not have the same UNS number. Consult ASTM/SAE Uniform Numbering System for the proper UNS Number.

d. For special applications, electrodes and rods may be purchased with less than the specified silicon content.

e. ASTM/SAE Unified Numbering System for Metals and Alloys.

f. Nickel + copper equals 0.5 percent maximum.

g. Cb(Nb) may be reported as Cb(Nb) + Ta.

h. These classifications also will be included in the next revision of ANSI/AWS AS.2B, Specification for Low Alloy Steel Filler Metals for Gas Shielded Metal Arc Welding. They will be deleted from ANSI/ AWS AS.9 in the final revision following publication of the revised ANSI/AWS AS.2B document.

Table 7 — Chemical composition of bare aluminum and aluminum alloy welding electrodes and rods (AWS A5.10).

		Weight Percent[a,b]											
											Other Elements		
AWS Classification	UNS Number[c]	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Each	Total	Al
ER1100	A91100	d	d	0.05-0.20	0.05				0.10		0.05[e]	0.15	99.0 min[f]
R1100	A91100	d	d	05-0.20	0.05				0.10		0.05[e]	0.15	99.0 min[f]
ER1188[g]	A91188	0.06	0.06	0.005	0.01	0.01			0.03	0.01	0.01[e]		99.88 min[f]
R1188[g]	A91188	0.06	0.06	0.005	0.01	0.01			0.03	0.01	0.01[e]		99.88 min[f]
ER2319[h]	A92319	0.20	0.30	5.8-6.8	0.20-0.40	0.02			0.10	0.10-0.20	0.05[e]	0.15	Remainder
R2319[h]	A92319	0.20	0.30	5.8-6.8	0.20-0.40	0.02			0.10	0.10-0.20	0.05[e]	0.15	Remainder
ER4009	A94009	4.5-5.5	0.20	1.0-1.5	0.10	0.45-0.6			0.10	0.20	0.05[e]	0.15	Remainder
R4009	A94009	4.5-5.5	0.20	1.0-1.5	0.10	0.45-0.6			0.10	0.20	0.05[e]	0.15	Remainder
ER4010	A94010	6.5-7.5	0.20	0.20	0.10	0.30-0.45			0.10	0.20	0.05[e]	0.15	Remainder
R4010	A94010	6.5-7.5	0.20	0.20	0.10	0.30-0.45			0.10	0.20	0.05[e]	0.15	Remainder
R4011[k]	A94011	6.5-7.5	0.20	0.20	0.10	0.45-0.7			0.10	0.04-0.20	0.05	0.15	Remainder
ER4043	A94043	4.5-6.0	0.8	0.30	0.05	0.05			0.10	0.20	0.05[e]	0.15	Remainder
R4043	A94043	4.5-6.0	0.8	0.30	0.05	0.05			0.10	0.20	0.05[e]	0.15	Remainder
ER4047	A94047	11.0-13.0	0.8	0.30	0.15	0.10			0.20		0.05[e]	0.15	Remainder
R4047	A94047	11.0-13.0	0.8	0.30	0.15	0.10			0.20		0.05[e]	0.15	Remainder
ER4145	A94145	9.3-10.7	0.8	3.3-4.7	0.15	0.15	0.15		0.20		0.05[e]	0.15	Remainder
R4145	A94145	9.3-10.7	0.8	3.3-4.7	0.15	0.15	0.15		0.20		0.05[e]	0.15	Remainder
ER4643	A94643	3.6-4.6	0.8	0.10	0.05	0.10-0.30			0.10	0.15	0.05[e]	0.15	Remainder
R4643	A94643	3.6-4.6	0.8	0.10	0.05	0.10-0.30			0.10	0.15	0.05[e]	0.15	Remainder
ER5183	A95183	0.40	0.40	0.10	0.50-1.0	4.3-5.2	0.05-0.25		0.25	0.15	0.05[e]	0.15	Remainder
R5183	A95183	0.40	0.40	0.10	0.50-1.0	4.3-5.2	0.05-0.25		0.25	0.15	0.05[e]	0.15	Remainder
ER5356	A95356	0.25	0.40	0.10	0.05-0.20	4.5-5.5	0.05-0.20		0.10	0.06-0.20	0.05[e]	0.15	Remainder
R5356	A95356	0.25	0.4	0.1	0.05-0.20	4.5-5.5	0.05-0.20		0.1	0.06-0.20	0.05[e]	0.15	Remainder
ER5554	A95554	0.25	0.40	0.10	0.50-1.0	2.4-3.0	0.05-0.20		0.25	0.05-0.20	0.05[e]	0.15	Remainder
R5554	A95554	0.25	0.40	0.10	0.50-1.0	2.4-3.0	0.05-0.20		0.25	0.05-0.20	0.05[e]	0.15	Remainder
ER5556	A95556	0.25	0.40	0.10	0.50-1.0	4.7-5.5	0.05-0.20		0.25	0.05-0.20	0.05[e]	0.15	Remainder
R5556	A95556	0.25	0.40	0.10	0.50-1.0	4.7-5.5	0.05-0.20		0.25	0.05-0.20	0.05[e]	0.15	Remainder
ER5654	A95654	i	i	0.05	0.01	3.1-3.9	0.15-0.35		0.20	0.05-0.15	0.05[e]	0.15	Remainder
R5654	A95654	i	i	0.05	0.01	3.1-3.9	0.15-0.35		0.20	0.05-0.15	0.05[e]	0.15	Remainder
R-206.0[j]	A02060	0.10	0.15	4.2-5.0	0.20-0.50	0.15-0.35		0.05	0.10	0.15-0.30	0.05	0.15	Remainder
R-C355.0	A33550	4.5-5.5	0.2	1.0-1.5	0.1	0.40-0.6			0.1	0.2	0.05	0.15	Remainder
R-A356.0	A13560	6.5-7.5	0.20	0.20	0.10	0.25-0.45			0.10	0.20	0.05	0.15	Remainder
R-357.0	A03570	6.5-7.5	0.15	0.05	0.03	0.45-0.6			0.05	0.20	0.05	0.15	Remainder
R-A357.0[k]	A13570	6.5-7.5	0.20	0.20	0.10	0.40-0.7			0.10	0.04-0.20	0.05	0.15	Remainder

Notes for Table 7

a. The filler metal shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that they do not exceed the limits specified for "Other Elements".

b. Single values are maximum. except where otherwise specified.

c. SAE/ASTM Unified Numbering System for Metals and Alloys.

d. Silicon plus iron shall not exceed 0.95 percent.

e. Beryllium shall not exceed 0.0008 percent.

f. The aluminum content for unalloyed aluminum is the difference between 100.00 percent and the sum of all other metallic elements present in amounts of 0.010 percent or more each, expressed to the second decimal before determining the sum.

g. Vanadium content shall be 0.05 percent maximum. Gallium content shall be 0.03 percent maximum.

h. Vanadium content shall be 0.05-0.15 percent. Zirconium content shall be 0.10-0.25 percent.

i. Silicon plus iron shall not exceed 0.45 percent.

j. Tin content shall not exceed 0.05 percent.

k. Beryllium content shall be 0.04-0.07 percent

Table 8 — Chemical composition of copper and copper alloy bare welding electrodes and rods (AWS A 5.7).

AWS Classification	UNS Number[d]	Common name	Cu Including Ag	Zn	Sn	Mn	Fe	Si	Ni Including Co	P	Al	Pb	Ti	Total other elements
			Composition weight percent[abc]											
ERCu	C18980	Copper	98.0 min		1.0	0.50		0.50		0.15	0.01	0.02		0.50
ERCuSi-A	C6S600	Silicon bronze (copper-silicon)	Remainder	1.0	1.0	1.5	0.50	2.8- 4.0			0.01	0.02		0.50
ERCuSn-A	C51800	Phosphor bronze (copper-tin)	Remainder		4.0- 6.0					0.10- 0.35	0.01	0.02		0.5
ERCuNi[e]	C71S80	Copper-nickel	Remainder			1.00	0.40- 0.75	0.25	29.0- 32.0	0.02		0.02 to 0.50	0.20	0.50
ERCuAl-Al	C61000		Remainder	0.20		0.50		0.10			6.0- 8.5	0.02		0.50
ERCuAl-A2	C61800	Aluminum bronze	Remainder	0.02		1.5		0.10			8.5- 11.0	0.02		0.50
ERCuAl-A3	C62400		Remainder	0.10			2.0- 4.5	0.10			10.0- 11.5	0.02		0.50
ERCuNiAl	C63280	Nickel-aluminum bronze	Remainder	0.10		0.60- 3.50	3.0- 5.0	0.10	4.0- 5.50		8.50 9.50	0.02		0.50
ERCuMnNiAl	C63380	Manganese-nickel aluminum bronze	Remainder	0.15		11.0- 14.0	2.0- 4.0	0.10	1.5- 3.0		7.0- 8.5	0.02		0.50

a. Analysis shall be made for the elements for which specific values are shown in this table. However. the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements is not present in excess of the: limits specified for 'Total other elements' in the last column in this table.
b. Single values shown are maximum, unless otherwise noted.
c. Classifications RBCuZn-A, RCuZn-B, RCuZn-C, and RBCuZn-D now are included in A5.27-78, *Specification/or Copper and Copper Alloy Gas Welding Rods.*

d. ASTM-SAE Unified Numbering System for Metals and Alloys.

e. Sulfur shall be 0.01 percent maximum for the ERCuNi classification.

Table 9 — Chemical composition of magnesium alloy welding

AWS Classi-fication	UNS Number'	Mg	Al	Be	Mn	Zn	Zr	Rare Earth	Cu	Fe	Ni	Si	Other Elements Total
		Weight Percentab											
ERAZ61A RAZ61A	M11611	Remainder	5.8 to 7.2	0.0002 to 0.0008	0.15 to 0.5	0.40 to 1.5			0.05	0.005	0.005	0.05	0.30
ERAZ92A RAZ92A	M11922	Remainder	8.3 to 9.7	0.0002 to 0.0008	0.15 to 0.5	1.7 to 2.3			0.05	0.005	0.005	0.05	0.30
ERAZ101A RAZ101A	M11101	Remainder	9.5 to 10.5	0.0002 to 0.0008	0.15 to 0.5	0.75 to 1.25			0.05	0.005	0.005	0.05	0.30
EREZ33A REZ33A	M12331	Remainder		0.0008		2.0 to 3.1	0.45 to 1.0	2.5 to 4.0					0.30

a. The filler metal shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limits specified for I<Other Elements, Total".
b. Single values are maximum.
c. SAE/ASTM Unified Numbering System for Metals and Alloys.

Table 10 — Chemical compositions of nickel and nickel alloy bare welding electrodes and rods (AWS A5.14).

Weight percent[ab]

AWS Classification	UNS Number[c]	C	Mn	Fe	P	S	Si	Cu	Ni[d]	Co	Al	Ti	Cr	Cb plus Ta	Mo	V	W	Other Elements Total
ERNi-1	N02061	0.15	1.0	1.0	0.01	0.015	0.75	0.25	93.0 min		1.5	2.0 to 3.5						0.50
ERNiCu-7	N04060	0.15	4.0	2.5	0.02	0.015	1.25	Rem	62.0 to 69.0		1.25	1.5 to 3.0						0.50
ERNiCr-3	N06082	0.10	2.5 to 3.5	3.0	0.03	0.015	0.50	0.50	67.0 min	e		0.75	18.0 to 22.0	2.0 to 3.0[f]				0.50
ERNiCrFe-5	N06062	0.08	1.0	6.0 to 10.0	0.03	0.015	0.35	0.50	70.0 min	e			14.0 to 17.0	1.5 to 3.0[f]				0.50
ERNiCrFe-6	N07092	0.08	2.0 to 2.7	8.0	0.03	0.015	0.35	0.50	67.0 min			2.5 to 3.5	14.0 to 17.0					0.50
ERNiFeCr-1	N08065	0.05	1.0	22.0 min.	0.03	0.03	0.50	1.50 to 3.0	38.0 to 46.0		0.20	0.60 to 1.2	19.5 to 23.5		2.5 to 3.5			0.50
ERNiFeCr-2[g]	N07718	0.08	0.35	Rem	0.015	0.015	0.35	0.30	50.0 to 55.0		0.20 to 0.80	0.65 to 1.15	17.0 to 21.0	4.75 to 5.50	2.80 to 3.30			0.50
ERNiMo-1	N10001	0.08	1.0	4.0 to 7.0	0.025	0.03	1.0	0.50	Rem	2.5			1.0		26.0 to 30.0	0.20 to 0.40	1.0	0.50
ERNiMo-2	N10003	0.04 to 0.08	1.0	5.0	0.015	0.02	1.0	0.50	Rem	0.20			6.0 to 8.0		15.0 to 18.0	0.50	0.50	0.50
ERNiMo-3	N10004	0.12	1.0	4.0 to 7.0	0.04	0.03	1.0	0.50	Rem	2.5			4.0 to 6.0		23.0 to 26.0	0.60	1.0	0_50
ERNiMo-7	N10665	0.02	1.0	2.0	0.04	0.03	0.10	0.50	Rem	1.0			1.0		26.0 to 30.0		1.0	0.50
ERNiCrMo-1	N06007	0.05	1.0 to 2.0	18.0 to 21.0	0.04	0.03	1.0	1.5 to 2.5	Rem	2.5			21.0 to 23.5	1.75 to 2.50	5.5 to 7.5		1.0	0.50
ERNiCrMo-2	N06002	0.05 to 0.15	1.0	17.0 to 20.0	0.04	0.03	1.0	0.50	Rem	0.50 to 2.5			20.5 to 23.0		8.0 to 10.0		0.20 to 1.0	0.50
ERNiCrMo-3	N06625	0.10	0.50	5.0	0.02	0.015	0.50	0.50	58.0 min		0.40	0.40	20.0 to 23.0	3.15 to 4.15	8.0 to 10.0			0.50
ERNiCrMo-4	N10276	0.02	1.0	4.0 to 7.0	0.04	0.03	0.08	0.50	Rem	2.5			14.5 to 16.5		15.0 to 17.0	0.35	3.0 to 4.5	0.50
ERNiCrMo-7	N06455	0.015	1.0	3.0	0.04	0.03	0.08	0.50	Rem	2.0		0.70	14.0 to 18.0		14.0 to 18.0		0.50	0.50
ERNiCrMo-8	N06975	0.03	1.0	Rem	0.03 0	0.03	1.0	0.7 to 1.20	47.0 to 52.0			0.70 to 1.50	23.0 to 26.0		5.0 to 7.0			0.50
ERNiCrMo-9	N06985	0.015	1.0	18.0 to 21.0	0.04	0.03	1.0	1.5 to 2.5	Rem	5.0			21.0 to 23.5	0.50	6.0 to 8.0		1.5	0.50

Notes for Table 10

a. The filler metal shall be analyzed for the specific elements for which values are shown in this table. In the course of this work, if the presence of other elements is indicated, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for "Other Elements, Total" in the last column of the table.

b. Single values are maximum, except where otherwise specified.

c. SAE/ASTM Unified Numbering System for Metals and Alloys.

d. Includes incidental cobalt.

e. Cobalt—0.12 maximum. when specified.

f. Tantalum--0.30 maximum. when specified.

g. Boron is 0.006 percent maximum.

h. Beryllium content shall be 0.04-0.07 percent

5.3.2 Sizing

The electrodes used for gas metal arc welding are generally small in diameter when compared to the other arc welding processes. Wire diameters ranging from .030 to 1/16 in. (.8-1.6mm) are the used most widely. Wire diameters as small as .020 in. (.5mm) and up to 1/8 in. (3.2mm) are sometimes used. The electrodes are provided in a long, continuous strand of wire which is normally packaged in a coil or spool. Spools of wire normally range in weight from 2 to 60 lbs. (.9-27 kg) and coils normally weigh 60 lbs. (27 kg).

The electrodes' melting rates normally range from about 100 to 600 in./min. (40-255 mm/s) due to the small electrode wire sizes and the relatively high welding current levels used. Because of the small size of the electrode wire, which gives it a high surface to volume ratio, cleanliness of the wire is very important. Drawing compounds, rust, oil, or other foreign matter on the surface of the electrode wire tends to be in high proportion relative to the amount of metal present, and these items can cause weld metal defects such as porosity and cracking.

5.4.0 Electrode Selection

The type of metal being welded and the specific chemical and mechanical properties desired are the major factors in determining the choice of a filler metal. Identification of the base metal is absolutely required to select the proper filler metal. If the type of base metal is not known, tests can be made based on appearance, weight, magnetic check, chisel tests, flame tests, fracture tests, spark tests, and chemistry tests.

The selection of the proper filler metal for a specific job application is quite involved but can be based on the following factors:

- Base Metal Strength Properties - This is done by choosing a filler metal to match the tensile or yield strength of the base metal. This is usually the most important factor with low carbon and low alloy steels, as well as with some aluminum and magnesium welding applications.
- Base Metal Chemical Compositions - The chemical composition of the base metal should be known. Closely matching the filler metal composition to the base metal composition is needed when corrosion resistance, color match, creep resistance, and electrical or thermal conductivity are important considerations. The filler metal for non-ferrous metals, stainless steels, and many alloy steels are chosen by matching the chemical compositions.
- Thickness and Shape of Base Metal Weldments - The workpiece may include thick sections or complex shapes, which may require maximum ductility to prevent weld cracking. Filler metal that gives the best ductility should be used.
- Service Conditions and/or Specifications - When weldments are subjected to severe service conditions such as low temperatures, high temperatures, or shock, a filler metal that closely matches the base metal composition, ductility, and impact resistance properties should be used.

5.5.0 Conformances and Approvals

The electrodes used for gas metal arc welding must conform to the specifications or be approved by code-making organizations for many applications of the process. Some of the code-making organizations that issue specifications or approvals are the American Welding Society (AWS), American Society of Mechanical Engineers (ASME), American Bureau of Shipping (ABS), and the Federal Bureau of Roads. The American Welding Society (AWS) provides specifications for bare solid wire electrodes. The electrodes manufactured must meet specific requirements in order to conform to a specific electrode classification. Many code-making organizations such as the American Society of Mechanical Engineers (ASME) and the American Petroleum Institute (API) recognize and use the AWS specifications. Some of the code-making organizations such as the American Bureau of Shipping (ABS) and the Military must directly approve the electrodes before they can be used for welding on a project that is covered by that code. These organizations send inspectors to witness the welding and testing and to approve the classification of the solid wire electrodes.

To conform to the AWS specifications for low carbon and low alloy filler metals, the electrodes must produce a weld deposit that meets specific mechanical and chemical requirements. For the non-ferrous and stainless steel filler metal, the electrodes must produce a weld deposit with a specific chemical composition. The requirements will vary depending on the class of the electrode.

Test Your Knowledge

5. Which inert gas is primarily used on non-ferrous metals?

A. Argon
B. Nitrogen
C. Oxygen
D. Carbon dioxide

6. One of the most important factors to consider in GMAW welding is the correct filler wire selection.

A. True
B. False

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6.0.0 WELDING APPLICATIONS

Gas metal arc welding is very adaptable to many different applications. It provides the ability to weld thick metals and allows you to take your welding machine to remote locations. As you will see GMAW has become a very accepted method of welding in all industries.

6.1.0 Industries

Gas metal arc welding is becoming more popular for many different welding applications. When this process is used semi-automatically, higher deposition and production rates can be obtained than with the manual arc welding processes. This process is also versatile because it can be used to weld ferrous and most non-ferrous metals in all positions. It is often the only welding process practical for welding thick sections in non-ferrous metals. Gas metal arc welding lends itself easily to machine and automatic welding which are often used for producing consistent, high quality welds at the fastest travel speeds possible. This process is used extensively in the automotive industry where high production rates are required, but it is also used in the field because the equipment is relatively light and portable compared to the other continuous electrode wire processes. For this reason, gas metal arc welding is widely used in field welding of cross-country transmission pipelines and for many construction and maintenance applications.

6.1.1 Pressure Vessels

Gas metal arc welding is one of the more commonly used processes for welding on pressure vessels. It is used in the manufacture of plain carbon, low alloy, and stainless steel vessels as well as non-ferrous vessels. Low heat input is important on pressure vessels. Multi-layer welds are generally built up in relatively thin layers which produce better ductility and impact resistance than larger welds. Gas metal arc welding has several advantages because it produces small weld beads at much faster travel speeds than shielded metal arc welding. It also has some advantages over submerged arc welding because it can be used in all positions and the arc is not hidden beneath a flux layer. The short-circuiting and pulsed arc modes are used for out-of-position welding to reduce the heat input. Figure 31 shows gas metal arc welding being used to weld a large mild steel vessel for an industrial refrigeration system. This process is often used for welding all passes, but sometimes it is used for welding the root passes only (Figure 32). Submerged arc welding is then employed for making the fill and cover passes.

Figure 31 —GMAW pressure vessel welding.

Figure 32 —GMAW root pass weld.

6.1.2 Industrial Piping

Gas metal arc welding also has application in the industrial piping industry. This process is widely used for welding of carbon steel, stainless steel, aluminum, copper, and nickel piping. The main advantage over shielded metal arc welding is the higher deposition rates obtained. Small diameter electrode wires are the most popular, and the short-circuiting mode of metal transfer is widely employed. Tack welds must be carefully prepared because inadequate penetration can occur if proper variables and techniques are not used. For critical applications, skilled welders and close attention to details are required to produce complete fusion, especially on heavy parts. Thin weld layers should be avoided for this type of welding. Carbon dioxide and argon-carbon dioxide gas mixtures are used as shielding on carbon steel pipe. Open root joints in the pipe are welded in the vertical-down position when the pipe is horizontal. The rest of the weld passes may be welded either vertical up or vertical down. Gas metal arc welding is widely used for welding the fill and cover passes over a gas tungsten arc welded root pass because higher deposition rates are obtained as compared to gas tungsten arc welding.

6.1.3 Transmission Pipelines

Gas metal arc welding is widely used in the cross-country transmission pipeline welding industry. Most gas metal arc pipe welding is done in the field using gasoline or diesel engine driven generator-welding machines. Small diameter electrode wires are commonly employed because there is much out-of-position welding. Almost all pipes for transmission pipelines are made of carbon steel, so carbon dioxide and argon-carbon dioxide mixtures are the most popular.

Gas metal arc welding is employed using various procedures. When the process is used, most joints are welded completely with gas metal arc welding. However, some root passes are welded with shielded metal arc welding and then the joint is filled out with gas metal arc welding. A less common procedure is to use gas metal arc welding for the root pass and shielded metal arc welding for the fill and cover passes. Figure 33 shows a root pass being welded in a 48 in. (1.2 mm) diameter natural gas pipeline.

Figure 33 — GMAW root pass of small diameter pipe.

Because the welding is being done in the field, the wind can often deflect the flow of shielding gas away from the arc. This can be prevented by setting up wind shields. An automatic welding system is sometimes employed to improve the consistency and deposition rate of the process. This equipment is normally used with special tracks that clamp on the pipe, but the equipment must be portable enough to handle in the field. When an automatic welding system is used, pipe fitup must be more precise.

6.1.4 Nuclear Power Facilities

Gas metal arc welding is employed but has a limited applicability in the nuclear power plants and components area. It is primarily used for welding components that are not directly part of the reactor. In the nuclear power industry, the quality of the weld deposit is the most important factor for selecting the process. Figure 34 shows gas metal arc welding being used to weld a portion of a nuclear plenum, which is part of a nuclear filtration system. The plenum is fabricated from low carbon steel ranging in thickness from 1/16-1½ in. (1.6 -12.7 mm) and is being welded using .035 in. (.9 mm) diameter low carbon steel electrodes. Nuclear filtration systems are made of carbon or stainless steel. Other items such as piping fittings, vessels, and liquid metal pumps are also common applications

Figure 34 — GMAW of a nuclear plenum.

6.1.5 Structures

The construction industry includes buildings, bridges, and other related structures. Gas metal arc welding is popular for many applications because it can be used in the field and it produces higher deposition rates than shielded metal arc welding. The development of wire feeding systems that can feed the electrode wire greater distances have helped increase the versatility of the process. The field welding applications employ gasoline or diesel engine driven generator-welding machines. The full range of electrode wire diameters is used because of the wide variety of joint designs and metal thicknesses welded.

GMAW is the most popular process for welding aluminum and other non-ferrous structures. Wind shields are often employed for field welding to prevent the loss of shielding gas. Figure 35 shows a shop welding application where brackets are being welded on a steel structural beam. GMAW is also widely used for many multiple pass joints because of the higher deposition rates obtained.

Figure 35 — GMAW of a structural beam.

6.1.6 Ships

Most of the arc welding processes are used in the shipyards, and GMAW has become widespread because of its versatility. Most ships are made of carbon steel, but nonferrous ships are welded also. Gas metal arc welding is popular because it yields higher deposition rates than shielded metal arc welding and lends itself better to welding in all positions than the other continuous wire processes.

In shipbuilding, deposition rate is the most important consideration, and because of the vast amount of welding done on a ship, GMAW is the best process for welding nonferrous metal ships and components.

Other items commonly welded are piping in the ship, non-structural components, and components that require out-of-position welding. Wire feeding systems that allow the welder to move greater distances from the source of the electrode wire are widely used. Figure 36 shows an example of GMAW flat position welding. Portable wire feeders are often used so welders can move from one location to another more easily.

Figure 36 — GMAW vertical weld.

Using .045-in. (1.1 mm) diameter electrode wire, these welds can be produced at three times the rate of shielded metal arc welding. This is a great advantage because a large percentage of the welds made in a ship are vertical fillet welds. In ship members where distortion is a problem, this process is used to get the best deposition rates with the lowest heat input.

6.1.7 Railroads

Gas metal arc welding is used for welding engines and cars in the railroad industry. Rail cars are fabricated from carbon steel, stainless steel, and aluminum. Machine, semiautomatic, and automatic welding are all commonly employed. GMAW and resistance welding are almost exclusively used in the manufacture of aluminum railroad cars. This process is often employed for welding in positions other than flat and for all parts of the engines and cars. Sheet metal covers for cabs, hoods, sides, and roofs are extensively welded. Because rimmed steel is widely used, filler metals of the ER70S-3 and ER70S-6 are employed; they have high amounts of deoxidizers in them to compensate for the rimmed condition of the steel sheet metal. It is used for many sheet metal welding applications because of the fast travel speeds, which help minimize distortion problems. This process can be used for almost all components of the engines and cars, but the primary applications of the process are on thin materials and nonferrous metals, or in locations where the higher deposition rate processes, such as flux cored and submerged arc welding, cannot be used.

6.1.8 Automotive

In the automobile and truck manufacturing industries, both semi-automatic and automatic gas metal arc welding are widely used. It is the major process used in this industry because of the fast travel speeds obtained. Many of these applications are on items such as frames, axle housings, wheels, and body components. This process is used to weld low carbon, low alloy, and stainless steels, as well as many aluminum parts. This process is popular for welding thin sheet metal in the short-circuiting mode because it lessens the heat input and prevents burn through. The high speeds produced by this process make it very good because of the high production rates required. All thicknesses of metal are welded.

Fully automatic welding operations are used for many applications that had formerly been done using shielded metal arc welding and submerged arc welding. Gas metal arc welding has become very popular for automatic welding because it is one of the least difficult processes to fully automate.

Figure 37 shows a subframe being welded. In this application, the part is being rotated automatically, but the welder is providing joint guidance. Carbon dioxide shielding gas and a .035 in. (.9 mm) diameter electrode are being used.

Figure 37 — Automotive welding.

Gas metal arc welding is the only arc welding process being used to weld aluminum automobile body components, truck cabs, and van bodies. Figure 38 shows the welding of an aluminum truck transmission cross-member.

Figure 38 — Aluminum welding.

Gas metal arc spot welding has many applications in the automotive and truck industries for welding the thinner metal gages of carbon steels, stainless steels, and aluminum. This process has several advantages in this industry because accessibility to the weld joint only has to be from one side, whereas resistance spot welding must have accessibility to both sides of the joint. This process is preferred because the spot welds produced have a consistent high quality and the process requires a minimum of operator skill. Typically, semi-automatic equipment is adapted for this process.

6.1.9 Aerospace

GMAW is also used in the aerospace industry for many applications. It is generally employed for welding heavier sections of steel and aluminum, but it is not as widely used as gas tungsten arc welding in this industry. Gas metal arc welding allows faster travel speeds to be used, which helps minimize weld distortion and the size of the heat affected zone. Machine or automatic welding has many applications in the manufacture of in-flight refueling tanks for jet aircraft and aluminum fuel tanks for rocket motor fuel. The use of semi-automatic welding has generally been limited to less critical aircraft components. An exception to this is shown in Figure 39 where the ribbing for an aileron is being welded with a small diameter electrode wire. Gas metal arc welding is used because it can weld thin metal in all positions at high production rates.

Figure 39 — Welding an aileron.

6.1.10 Heavy Equipment

Farm equipment manufacturers are major users of gas metal arc welding. It is used in the manufacture of tractors, combines, plows, tobacco harvesters, grain silos, and many other items. Other heavy equipment manufactured includes mining equipment, earthmoving equipment, and many other products. These types of equipment are generally made of mild and low carbon steels. High deposition rates are desired, so large diameter electrode wires are employed when possible. Because of this, spray and globular transfer welding are used for much of the flat position welding, but GMAW is also widely employed for producing welds in out-of position joints.

6.2.0 Variations of the Process

Of the numerous variations of the GMAW process, two of the most notable are arc spot welding and narrow gap welding.

6.2.1 Arc Spot Welding

The gas metal arc spot welding process is used for making small localized fusion welds by penetrating through one sheet and into the other. The differences between this process and normal gas metal arc welding are that there is no movement of the welding gun and the welding takes place for only a few seconds or less. The equipment for arc spot welding usually consists of a special gun nozzle and arc timer added to a standard semi-automatic welding setup. Gas metal arc spot welding is commonly applied to mild steel, stainless steel, and aluminum, but can be used on all the metals welded by gas metal arc welding. On steel, CO_2 shielding is used to get the best penetration.

The advantages of this process over resistance spot welding are the following:

- The gun is light and portable and can be taken to the weldment.
- Spot welding can be done in all positions more easily.
- Spot welds can be made when there is accessibility only to one side of the joint.
- Spot-weld production is faster for many applications.
- Joint fitup is not as critical.

The major disadvantage of this process is that the consistency of weld strength or size is not as good as with resistance spot welding.

The weld is made by placing the welding gun on the joint. Pulling the trigger initiates the shielding gas and after a pre-flow interval, starts the arc and the wire feed. When the pre-set weld time is finished, the arc and wire feed are stopped, followed by the gas flow. The longer the weld time, the greater the penetration obtained and the higher the weld reinforcement becomes. The rest of the welding variables affect the spot weld size and shape the same way they affect a normal weld. Vertical and overhead arc spot welds can be made in metal up to .05-in. (1 .3 mm) thick. For other than flat position welding, the short-circuiting mode of transfer must be used.

Many different weld joint types are made including lap, corner, and plug. The best results are obtained when the arc side member is equal to or thinner than the other. When the top plate is thicker than the bottom one, a plug weld should be made. Incomplete fusion is a common defect with this type of weld. A copper backing bar is used to prevent excessive penetration through the bottom of the weld. Another advantage of gas metal arc spot welding over resistance spot welding is that the strength can be determined from a visual examination of the weld nugget size, whereas a resistance spot weld would have to be tested to determine the strength.

6.2.2 Narrow Gap Welding

Narrow gap welding is another variation of the GMAW process in which square-groove or V-groove joints with small groove angles are used in thick metal sections. Root openings normally range from ¼ to 3/8 in. (6.4-9.5 mm). Narrow gap welding is generally done on ferrous metals, with the use of specially designed welding guns (Figure 40), but some narrow gap welding has been done on aluminum.

Figure 40 — Narrow gap weld.

Two small electrode wires are normally used in tandem with the wire being fed through 1 or 2 contact tubes. Each of the electrodes is fed so that the weld bead is directed toward each groove face. The special welding guns have water-cooled contact tubes and nozzles that provide shielding gas from the surface of the plate. Spray transfer is the most commonly used mode of the process, but pulsed current transfer is sometimes employed. High travel speeds are used, resulting in a low heat input and small weld puddles with narrow heat affected zones. This low heat input produces weld puddles which are easy to control in out-of position welding. Welds are normally made from one side of the plate.

The major problem encountered in narrow gap welding is incomplete fusion because of the low heat input in thick metal, but careful placement of the electrode wires and removing slag islands between passes to prevent slag inclusions can avoid any problems.

When used for welding metal thicknesses over 2 in. (51 mm), narrow gap welding is competitive with the other automatic arc welding processes. This type of welding has several advantages:

- Welding costs are lower because less filler metal is required.
- Lower residual stresses and less distortion are produced.
- Better welded joint properties are obtained.
- The main disadvantages are the following:
- It is more prone to defects.
- Defects are more difficult to remove.
- Fitup of the joint must be more precise.
- Placement of the welding gun must be more precise.

Test Your Knowledge

7. What development has improved the field versatility of GMAW by increasing the distance between the gun and the welding machine?

A. Stiffer welding electrodes
B. Portability
C. Lighter welding guns
D. Water cooling systems

8 What is the major disadvantage of gas metal arc spot welding compared to resistance spot welding?

A. Weld size
B. Weld strength
C. Amount of spatter
D. Directionality of the weld

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7.0.0 WELDING METALLURGY

Knowing the basics of welding metallurgy will provide a firm foundation for understanding the chemical and physical changes that occur on metal when using the GMAW process.

7.1.0 Properties of the Weld

A weld has the following properties:

- Chemical composition
- Mechanical strength and ductility
- Microstructure

These items will determine the quality of the weld. The chemical properties are affected by the types of materials used. The mechanical properties and microstructure of the weld are determined by the heat input of welding as well as by the chemical composition of the materials.

7.1.1 Chemical and Physical Properties

The chemical and physical properties such as the chemical composition, melting point, and thermal conductivity have a great influence on the weldability of a metal. These three items influence the amount of preheating and postheating used, as well as the welding parameters. Preheating and postheating are used to prevent the weld and adjacent area from becoming brittle and weak.

In welding a metal, the chemical composition of the base metal and filler metal will affect corrosion and oxidation resistance, creep resistance, high and low temperature strength, and the mechanical properties and the microstructure. For welding stainless steels and non-ferrous metals, the chemical composition of the weld is often the most important property. When corrosion resistance, thermal and electrical conductivity, and appearance are major considerations, the chemical composition of the weld must match the composition of the base metal.

Preheating reduces the cooling rate of the weld to prevent cracking. The amount of preheat needed depends on the type of metal being welded, the metal thickness, and the amount of joint restraint. In steels, those with higher carbon contents need more preheating than those with lower carbon equivalents. For the non-ferrous metals, the amount of preheat will often depend on the melting points and thermal conductivity of the metal. Table 11 shows typical preheat values for different metals welded by GMAW.

Another major factor that determines the amount of preheat needed is the thickness of the base metal. Thicker base metals usually need higher preheat temperatures than thinner base metals because of the larger heat sinks that thicker metals provide. Thick metal draws the heat away from the welding zone quicker because there is a large mass of metal to absorb the heat. This would increase the cooling rate of the weld if the same preheat temperature was used as is used on thinner base metals.

The third major factor for determining the amount of preheating needed is the amount of joint restraint. Joint restraint is the resistance of a joint configuration to moving or relieving the stresses due to welding during the heating and cooling of the weld zone. Where there is high resistance to moving or high joint restraint, large amounts of internal stresses build up and higher preheat temperatures are needed as the amount of joint restraint increases. Slower cooling rates reduce the amount of internal stresses that build up as the weld cools.

Table 11 — Typical Recommended Preheats for Various Metals.

Type of Metal	Preheat
Low-Carbon Steel	Room Temperature or up to 200°F (93°C)
Medium-Carbon Steel	400-500°F (205-260°C)
High-Carbon Steel	500-600°F (260-315°C)
Low Alloy Nickel Steel	
-Less than ¼-inch (6.4 mm) thick	Room Temperature
-More than ¼-inch (6.4 mm) thick	500°F (260°C)
Low Alloy Nickel-Chrome Steel	
-Carbon content below .20%	200-300°F (93-150°C)
-Carbon content .20% to .35%	600-800°F (315-425°C)
-Carbon content above .35%	900-1100°F (480-595°C)
Low Alloy Manganese Steel	400-600°F (205-315°C)
Low Alloy Chrome Steel	Up to 750°F (400°C)
Low Alloy Molybdenum Steel	
-Carbon content below .15%	Room Temperature
-Carbon content above .15%	400-650°F (205-345°C)
Low Alloy High Tensile Steel	150-300°F (66-150°C)
Austenitic Stainless Steel	Room Temperature
Ferritic Stainless Steel	300-500°F (66-260°C)
Martensitic Stainless Steel	400-600°F (66-150°C)
Cast Irons	700-900°F (370-480°C)
Copper	500-800°F (260-425°C)
Nickel	200-300°F (93-150°C)
Aluminum	Room Temperature or up to 300°F (150°C)

Note: The actual preheat needed may depend on several other factors such as the thickness of the base metal, the amount of joint restraint, and whether or not low-hydrogen types of electrodes are used. This chart is intended as general information; the specifications of the job should be checked for the specific

preheat temperature used.

The melting point of the base metal is a major consideration in determining the weldability of a metal. Metals with very low melting points are difficult to weld because the intense heat of the welding arc will melt them too quickly to join them easily. These metals must be brazed because welding is not practical.

Another property that affects the weldability is the thermal conductivity. The thermal conductivity is the rate at which heat is conducted by the metal, and it determines the rate at which heat will leave the welding area. Metals that have a high thermal conductivity often require higher preheats and welding currents to avoid cracking. Metals that have very low thermal conductivity may require no preheat and lower welding currents to prevent overheating an area, which can cause distortion, warpage, and changes in mechanical properties.

7.1.2 Mechanical Properties

The most important mechanical properties in the weld are the following:

- tensile strength
- yield strength
- elongation
- reduction of area
- impact strength

The first two are measures of the strength of the material, the next two are a measure of the ductility, and the last is a measure of the impact toughness. These properties are often important in GMAW, especially for welding steel and the non-ferrous alloys that have been developed to give maximum strength, ductility, and toughness.

The toughness and ductility of the heat affected zone produced by this process are sometimes slightly less than those produced by many of the other welding processes. This is caused because of the relatively quick cooling rates commonly associated with gas metal arc welding, which produce a more brittle heat affected zone. Quicker cooling rates occur because of the fast travel speeds used and the use of shielding gas, which does not slow the cooling rate as well as a slag layer. One advantage of the quicker cooling rate is that distortion is less of a problem.

The yield strength, ultimate tensile strength, elongation, and reduction of area are all measured from a .505-in. (12.B mm) diameter machined testing bar. The metal is tested by pulling it in a tensile testing machine. Figure 41 shows a tensile bar before and after testing. The yield strength of the metal is the stress at which the material is pulled beyond the point where it will return to its original length. The tensile strength is the maximum load that can be carried by the metal. This is also measured in psi (MPa). Elongation is a measure of ductility that is also measured on the tensile bar. Two points are marked on the bar 2 in. (51 mm) apart before testing. After testing, the distance between the two points is measured again and the percent of change in the distance between them, or percent elongation, is measured.

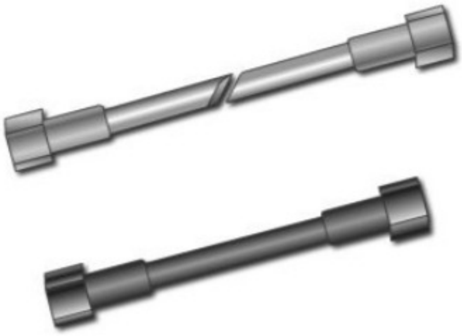

Figure 41 — Tensile strength testing bars.

Reduction of area is another method of measuring ductility. The original area of the cross section of the testing bar is .505 sq. in (104 sq. mm). During the testing the diameter of the bar reduces as it elongates. When the bar finally breaks, the diameter of the bar at the breaking point is measured, which is then used to determine the area. The percent reduction of this cross-sectional area is called the reduction of area.

Impact tests are used to measure the toughness of a metal. The toughness of a metal is the ability of a metal to absorb mechanical energy by deforming before breaking. The Charpy V-notch test is the most commonly used method of making impact toughness tests. Figure 42 shows some typical Charpy V-notch test bars. These bars are usually 10 mm square and have V-notches ground or machined in them. They are put in a machine where they are struck by a hammer attached to the end of a pendulum. The energy that it takes to break these bars is known as the impact strength and it is measured in foot-pounds (Joules).

Figure 42 — Charpy V-notch bars.

7.1.3 Microstructure

There are three basic microstructural areas within a weldment: the weld metal, the heat affected zone, and the base metal. The weld metal is the area that was molten during welding. This is bounded by the fusion line, which is the maximum limit of melting. The heat affected zone is the area where the heat from welding had an effect on the microstructure of the base metal. The limit of visible heat affect is the outer limit of this area. The base metal zone is the area that was not affected by the welding. Figure 43 shows a cross section of a weld indicating the different areas.

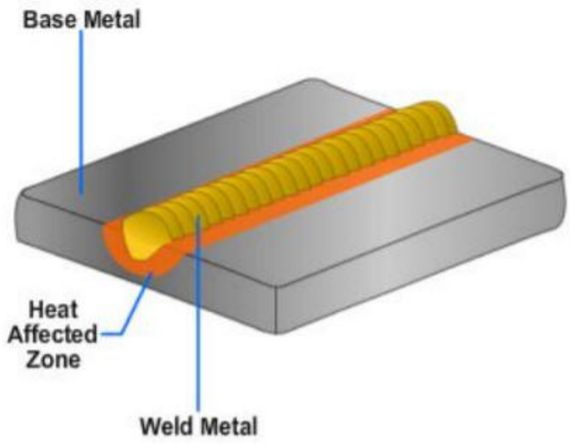

Figure 43 — Cross section of a weld.

The extent of change of the microstructure is dependent on four factors:

- Maximum temperature that the weld metal reached
- Time that the weld spent at that temperature
- Chemical composition of the base metal
- Cooling rate of the weld

The weld metal zone, which is the area that is melted, usually has the coarsest grain structure of the three areas. Generally, a fairly fine grain size is produced in most metals on cooling, but in some metals, especially refractory metals, rapid grain growth in the weld metal can become a problem.

Large grain size is undesirable because it gives the weld poor toughness and poor cracking resistance. The solidification of the weld metal starts at the edge of the weld puddle next to the base metal. The grains that form at the edge, called dendrites, grow toward the molten center of the weld. Figure 44 shows the solidification pattern of a weld. These dendrites give the weld metal its characteristic columnar grain structure. The grains that form in the weld zone are similar to the grains that form in castings.

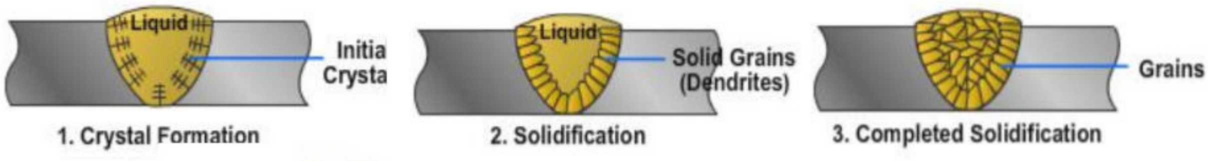

Figure 44 — Solidification pattern of a weld.

Deoxidizers and scavengers are often added to filler metal to help refine the grain size in the weld. The greater the heat input to the weld and the longer that it is held at high temperatures, the larger the grain size. A fast cooling rate will produce a smaller grain size than a slower cooling rate. Preheating will give larger grain sizes, but is often necessary to prevent the formation of a hard, brittle microstructure.

The heat affected zone is the area where changes occur in the microstructure of the base metal; the area closest to the weld metal usually undergoes grain growth. Other parts of the heat affected zone will go through grain refinement, while still other areas may be annealed and considerably softened. Because of the changes due to the heat input, areas of the heat affected zone can become embrittled and become the source of cracking. A large heat input during welding will cause a larger heat affected zone, which is often not desirable, so the welding parameters used can help influence the size of the heat affected zone.

7.2.0 Metals Weldable

The GMAW process can be used to weld most metals and their alloys, the most common of which are aluminum, copper, magnesium, nickel, mild steel, low alloy steel, stainless steel, and titanium.

7.2.1 Aluminum and Aluminum Alloys

GMAW is one of the most widely used processes for welding aluminum and its alloys. The major alloying elements used in aluminum are copper, manganese, silicon, magnesium, and zinc. Table 12 shows how the aluminum alloys are classified according to their alloy content. Aluminum alloys are also classified into heat treatable and non-heat treatable categories; alloys of the 2XXX, 6XXX, and 7XXX series are heat treatable.

Table 12 — Aluminum Alloy Classifications.

Aluminum Classification	Major Alloying Element
1XXX	Commercially pure
2XXX	Copper
3XXX	Manganese
4XXX	Silicon
5XXX	Magnesium
6XXX	Silicon + Magnesium
7XXX	Zinc
8XXX	Other

Gas metal arc welding is used to weld all metal thicknesses, but welding is most commonly done on thicknesses greater than 1/8-in. (3.2 mm). This process is the best method for the thicker metals because it produces higher deposition rates and travel speeds than gas tungsten arc welding. Aluminum as thin as .030-in. (.8 mm) can be welded using pulsed current. High welding speeds may be obtained with this process and when welding aluminum, high welding speeds are desirable to prevent overheating. Argon shielding gas is preferred for welding the thinner metal. Argon-helium mixtures are preferred for welding thicker metal because of the better penetration obtained. Argon-oxygen and argon-helium-oxygen mixtures are sometimes used to improve the arc stability and make out-of-position welding easier.

Most GMAW applications are done with the spray transfer method, but pulsed current is used for aluminum to reduce the heat input and use larger diameter electrode wires. Larger electrode wires are less expensive and are easier to feed. Globular and short-circuiting transfer are rarely used when welding aluminum.

The filler metal used for welding aluminum is generally of the non-heat treatable type. Consequently, when welding some of the higher strength heat treatable alloys, the weld deposit will be weaker than the base metal. Using heat treatable filler metal often causes weld cracking, so non-heat treatable filler is preferred. Choosing the type of filler metal to use for welding a specific aluminum alloy is based on ease of welding, corrosion resistance, strength, ductility, elevated temperature service, and color match with the base metal after welding. Table 13 shows a filler metal selection chart based on the specific properties desired. Table 14 shows a filler metal selection chart for welding different grades of aluminums together.

The typical oxide layer on the surface of aluminum makes it more difficult to weld than many other types of metals. This oxide layer has a very high melting point compared to the melting temperature of the aluminum itself. Direct current electrode positive gives the welding arc an oxide-cleaning action which breaks the oxide layer so that welding can take place. Before welding, the surface of the base metal should be cleaned to prevent oxide inclusions and hydrogen entrapment

Table 13 — Aluminum Filler Metal Selection.

Type of base metal	Property Desired				
	Strength	Ductility	Color match after anodizing	Corrosion resistance	Least cracking tendency
1100	4043	1100	1100	1100	4043
2219	2319	2319	2319	2319	2319
3003	4043	1100	1100	1100	4043
5052	5356	5654	5356	5554	5356
5083	5183	5356	5183	5193	5356
5086	5356	5356	5356	5356	5356
5454	5356	5554	5554	5554	5356
5456	5556	5356	5556	5556	5356
6061	5356	5356	5654	4043	4043
6063	5356	5356	5356	4043	4043
7005	5039	5356	5036	5039	5356
7039	5039	5356	5039	5039	5356

A preheat is used on aluminum only when the temperature of the parts is below 15°F (- 10°C), or when a large mass of metal is being welded, which will draw the heat away very quickly. Aluminum has a high thermal conductivity, so heat is drawn away from the welding area. Because aluminum has a relatively low melting point and a high thermal conductivity, overheating can be a problem, especially on thin metal; therefore, preheating is seldom used. The maximum preheat normally used on aluminum is 300° F (150° C). Rather than use preheating, it is usually preferable to increase the voltage and current levels to obtain adequate heat input. Alloys such as 5083, 5086, and 5456 should not be preheated to between 200 and 400° F (95-205°C) because their resistance to stress corrosion cracking will be reduced due to high magnesium contents.

Table 14 — Aluminum Filler Metal Selection Chart.

Base Metal	201.0 206.0 224.0	319.0, 333.0 354.0, 355.0 C355.0	356.0, A356.0 357.0, A357.0 413.0, 443.0 A444.0	511.0 512.0 513.0 514.0 535.0	7004, 7005 7039, 710.0 712.0	6009 6010 6070	6005, 6061 6063, 6101 6151, 6201 6351, 6951	5456	5454
1060, 1070, 1080, 1350	ER4145	ER4145	ER4043ab	ER5356cd	ER5356cd	ER4043ab	ER4043ab	ER5356d	ER4043bd
1100, 3003, Alc 3003	ER4145	ER4145	ER4043ab	ER5356cd	ER5356cd	ER4043ab	ER4043ab	ER5356d	ER4043bd
2014, 2036	ER4145e	ER4145e	ER4145			ER4145	ER4145		
2219	ER2319a	ER4145e	ER4145bc	ER4043	ER4043	ER4043ab	ER4043ab		ER4043b
3004, Alc3004		ER4043b	ER4043b	ER5356f	ER5356f	ER4043b	ER4043bf	ER5356d	ER5356f
5005 5050		ER4043b	ER4043b	ER5356f	ER5356f	ER4043b	ER4043bf	ER5356d	ER5356f
5052 5652		ER4043b	ER4043f	ER5356f	ER5356f	ER4043b	ER5356cf	ER5356f	ER5356f
5083			ER5356cd	ER5356d	ER5183d		ER5356d	ER5183d	ER5356d
5086			ER5356cd	ER5356d	ER5356d		ER5356d	ER5356d	ER5356d
5154, 5254			ER4043f	ER5356f	ER5356f		ER5356f	ER5356f	ER5356f
5454		ER4043b	ER4043f	ER5356f	ER5356f	ER4043b	ER5356ef	ER5356f	ER5554cf
5456			ER5356cd	ER5356d	ER5556d		ER5356d	ER5556d	
6005, 6061, 6063 6101, 6151, 6201 6351, 6951	ER4145	ER4145bc	ER4043bfg	ER5356f	ER5356cf	ER4043abg	ER4043bfg		
6009, 6010, 6070	ER4145	ER4145bc	ER4043abg	ER4043	ER4043	ER4043abg			
7004, 7005, 7039 710.0, 712.0		ER4043b	ER4043bf	ER5356f	ER5356d				
511.0, 512.0, 513.0 514.0, 535.0			ER4043f	ER5356f					
356.0, A356.0, 357.0 A357.0, 413.0 443.0, A444.0	ER4145	ER4145bc	ER4043bh						
319.0, 333.0 354.0, 355.0 C355.0	ER4145e	ER4145bch							
201.0, 206.0, 224.0	ER2319ah								

Base Metal	5154 5254	5086	5083	5052 5652	5005 5050	3004 Alc.3004	2219	2014 2036	1100 3003 Alc.3003	1060 1070 1080 1350
1060, 1070,1080, 1350	ER5356cd	ER5356d	ER5356d	ER4043bd	ER1100bc	ER4043bd	ER4145bc	ER4145	ER1001bc	ER1188bchj
1100, 3003, Alc3003	ER5356cd	ER5356d	ER5356d	ER4043bd	ER1100bc	ER4043bd	ER4145bc	ER4145	ER1001bc	
2014, 2036					ER4145	ER4145	ER4145e	ER4145e		
2219	ER4043			ER4043b	ER4043ab	ER4043ab	ER2319a			
3004, Alc3004	ER5356f	ER5356d	ER5356d	ER5356cf	ER5356cf	ER5356cf				
5005	ER5356f	ER5356d	ER5356d	ER5356cd	ER5356cf					
5052, 5652i	ER5356f	ER5356d	ER5356d	ER5354cfi						
5083	ER5356d	ER5356d	ER5183d							
5086	ER5356d	ER5356d								
5154 5254i	ER5356fi									

Notes for Table 14 above

1. Service conditions such as immersion in fresh or salt water, exposure to specific chemicals or a sustained high temperature (over 150°F (66 °C)) may limit the choice of filler metals. Filler metals ER5IS3, ER5356, ER5556, and ER5654 are not recommended for sustained elevated temperature service.
2. Recommendations in this table apply to gas shielded arc welding processes. For oxyfuel gas welding, only ER118S, ER1100, ER4043, ER4047, and ER4145 filler metals are ordinarily used.
3. Where no filler metal is listed, the base metal combination is not recommended for welding.
   a. ER4145 may be used for some applications.
   b. ER4047 may be used for some applications.
   c. ER4043 may be used for some applications.
   d. ER5183, ER5356, or ER5556 may be used.
   e. ER2319 may be used for some applications. It can supply high strength when the weldment is postweld solution heat treated and aged.
   f. ER5183, ER5356, ER5554, ER5556, and ER5654 may be used. In some cases, they provide:
      i. improved color match after anodizing treatment,
      ii. highest weld ductility, and
      iii. higher weld strength. ER5554 is suitable for sustained elevated temperature service.
   g. ER4643 will provide high strength in 1/2 in. (12 mm) and thicker groove welds in 6XXX hase alloys when postweld solution heat treated and aged.
   h. Filler metal with the same analysis as the base metal is sometimes used. The following wrought filler metals possess the same chemical composition limits as cast filler alloys: ER4009 and R4009 as R-C355.0: ER4010 and R4010 as R-A356.0: and R4011 as R-A357.0.
   i. Base metal alloys 5254 and 5652 are used for hydrogen peroxide service. ER5654 filler metal is used for welding both alloys for service temperatures below 150°F (66°C).
   j. ER 1100 may he used for some applications.

7.2.2 Copper and Copper Alloys

Gas metal arc welding is well suited for welding copper and copper alloys because of the intense arc generated by this process. This is advantageous because copper has a very high thermal conductivity and the heat is conducted away from the weld zone very rapidly. An intense arc is important in completing the fusion with minimum heating of the surrounding base metal.

The main alloying elements used in copper are zinc (brasses), phosphorous (phosphor bronzes), aluminum (aluminum bronzes), beryllium (beryllium coppers), nickel (nickel silvers), silicon (silicon bronzes), tin and zinc (tin brasses), and nickel and zinc (nickel silvers). All of these are weldable with this process but some are easier than others. The best are the deoxidized coppers, aluminum bronzes, silicon bronzes, and copper nickels. The alloys having the poorest weldability are those with the highest zinc contents, which have a high cracking tendency, and electrolytic tough pitch copper, which gives problems with porosity. Care must be taken when welding beryllium coppers because the fumes given off are dangerous to the welder's health. For this reason, extra special precautions should be taken. Table 15 shows the relative ease of welding copper and copper alloys.

Table 15 — Weldability Ratings of Coppers and Copper Alloys. (1=excellent, 2=good, 3=fair)

Type	Weldability Rating
Oxygen-free copper	2
Electrolytic tough pitch copper	3
Deoxidized copper	1
Beryllium copper	2
Low-zinc brass	2
High-zinc brass	3
Tin brasses	3
Nickel silvers	3
Phosphor bronzes	2
Aluminum bronzes	2
Silicon bronzes	1
Copper nickels	1

Most applications of this process are for welding metal thicknesses greater than 1/8 in. (3.2 mm). For thicknesses less than this, the gas tungsten arc welding process is more popular. GMAW is the most practical process to use on thicknesses greater than 1/2 in. (12.7) because of the higher deposition rates obtained. Generally, preheating is not used on the thinner sections, but it is often used on sections thicker than 1/8 in. (3.2 mm) so that the heat does not leave the weld area as quickly. A temperature of 500- 800° F (260-425° C) is typical when preheat is used. Welding currents used for copper are often 50-75% higher than those used for aluminum.

Most welding of copper and copper alloys is done in the flat position, but when welding has to be done in other positions, the gas metal arc welding process is preferred over gas tungsten arc welding and shielded metal arc welding. Out-of-position welding uses small diameter electrodes, lower currents, and short-circuiting transfer, and is generally done on the less fluid alloys such as the aluminum bronzes, silicon bronzes, and copper nickels.

The shielding gases most commonly used for welding copper are argon and helium. Argon has the lowest energy output but produces spray transfer and the least amount of spatter. Helium produces globular transfer with heavy spatter. This gas produces more heat, so the penetration patterns are broader and more uniform in depth than those produced by argon. Nitrogen is occasionally used, but spatter is particularly heavy. Mixtures of argon and helium are often used to get the stable arc characteristics of argon and the deep penetration of helium.

The filler metal is usually selected so the chemical composition of the filler rod closely matches the base metal. When welding copper and copper alloys, a deoxidized electrode is required; this is often necessary to obtain a strong weld joint in some of the copper alloys. For example, a silicon bronze filler metal is used with silicon bronze base metal. A filler metal with a different chemical composition than the base metal may be selected when welding some of the weaker alloys to give the weld joint added strength. The best choice of filler metal depends primarily on the type of copper alloy being welded with the application also being considered.

7.2.3 Magnesium and Magnesium Alloys

Gas metal arc welding is widely used for welding magnesium alloys. The major alloying elements used in magnesium are aluminum, zinc, and thorium (thawr-ee-uh m). Most magnesium alloys are weldable with this process but the weldability will vary with the alloy. Table 16 shows the main alloying elements used and the relative weldability of the alloys. The rating is based mainly on the susceptibility to cracking. Aluminum contents up to about 10% help the weldability because it promotes grain size refinement. Zinc contents above about 1% will increase the tendency towards hot cracking. Alloys that have high zinc content are very susceptible to cracking and have poorer weldability. Thorium alloys generally have excellent weldability. Magnesium forms an oxide similar to aluminum oxide, which gives these two metals similar welding characteristics.

GMAW can be used to weld all thicknesses of magnesium; it is the most popular process for welding thicknesses greater than 3/8 in. (9.5 mm). The higher deposition rates and the faster travel speeds used, which reduce distortion, are primary reasons for the popularity of this process. Welding is generally done in the flat, horizontal, and vertical-up positions if possible, because of the higher deposition rates and the more fluid weld puddle produced compared to gas tungsten arc welding.

Inert gases must be used for welding magnesium alloys because the base metal will react chemically with an active gas. Argon is generally used as the shielding, but occasionally, mixtures of argon and helium are used to give better filler metal flow and heat input. Helium is not recommended because it produces globular transfer and more spatter.

The three types of metal transfer useful for welding magnesium alloys are the short-circuiting, spray, and pulsed arc methods. The pulsed arc mode is used in current ranges between the short-circuiting mode and the spray mode to avoid the highly unstable globular transfer mode.

Preheating is often used on thin sections and highly restrained joints to prevent weld cracking. Thicker sections generally do not require preheating unless there is a high degree of joint restraint.

If the filler metal has been selected properly, the GMAW-produced welds are often stronger than the base metal.

Electrodes with lower melting points and a wider freezing range than the base metal are often used to avoid cracking. Electrodes for gas metal arc welding magnesium alloys consist of four different types (refer again to Figure 59). The type of electrode used is governed by the chemical composition of the base metal.

Table 16 — Magnesium Alloy Classification, Weldability and Filler Selection. (1=excellent, 2=good, 3=fair, 4 =poor

Magnesum Alloy Wrought	Major Alloying Elements Alloys	Weldability Rating	Filler Metal
AZ10A	Aluminum,Zinc	1	AZ61A,AZ92A
AZ31B	Aluminum,Zinc	1	AZ61AAZ92A
AZ31C	Aluminum,Zinc	1	AZ61AAZ92A
AZ61A	Aluminum,Zinc	2	AZ61A,AZ92A
AZ80A	Aluminum,Zinc	2	AZ61AAZ92A
HK31A	Thorium,Zirconium	1	EZ33A
HM21A	Thorium,Manganese	1	EZ33A
HM31A	Thorium,Manganese	1	EZ33A
LA141A	Lithium,Aluminum	2	LA141A,EZ33A
M1A	Manganese	1	AZ61A,AZ92A
ZE10A	Zinc,Rare Earths	1	AZ61A,AZ92A
ZK21A	Zinc,Zirconium	2	AZ61A,AZ92A
ZK60A	Zinc,Zirconium	4	EZ33A
CastAlloys			
AM100A	Aluminum,Manganese	2	AZ101A,AZ92A
AZ63A	Aluminum,Zinc	3	AZ101A,AZ92A
AZ81A	Aluminum,Zinc	2	AZ101A,AZ92A
AZ91C	Aluminum,Zinc	2	AZ101A,AZ92A
AZ92A	Aluminum,Zinc	2	AZ101A
EK41A	Rare Earths,Zirconium	2	EZ33A
EZ33A	Rare Earths,Zinc	1	EZ33A
HK31A	Thorium,Zirconium	2	EZ33A
HZ32A	Thorium,Zinc	2	EZ33A
K1A	Zirconium	1	EZ33A
QE22A	Silver,Rare Earths	2	EZ33A
ZE41A	Zinc,Rare Earths	2	EZ33A
ZH62A	Zinc,Thorium	3	EZ33A
ZK51A	Zinc,Zirconium	4	EZ33A
ZK61A	Zinc,Zirconium	4	EZ33A

7.2.4 Nickel and Nickel Alloys

Gas metal arc welding is one of the major processes used for welding nickel and nickel alloys. The major alloying elements used in nickel are iron, chromium, copper, molybdenum, and silicon. Trade names are widely used, but a classification system is shown in Table 17. This process is used for welding the solid-solution strengthened alloys; the precipitation-hardening alloys are more readily welded by gas tungsten arc welding because it is difficult to transfer hardening elements across the arc. Many of the cast alloys, especially ones with high silicon contents, are more difficult to weld.

Table 17 — Classifications of nickel and nickel alloys.

Series	Alloy Group
200	Nickel, solid solution
300	Nickel, precipitation-hardenable
400	Nickel-copper, solid solution (Monel)
500	Nickel-copper, precipitation-hardenable (Monel)
600	Nickel-chromium, solid solution (Inconel)
700	Nickel chromium, precipitation-hardenable (Inconel)
800	Nickel-iron-chromium solid solution (Incoloy)
900	Nickel-iron-chromium, precipitation-hardenable (Incoloy)

One of the most important factors in welding nickel and nickel alloys is the cleanliness of the base metal. These metals are susceptible to embrittlement caused by sulfur, phosphorous, and lead. Therefore, the surface of the metal to be welded should be cleaned of any grease, oil, paint, dirt, and processing chemicals. Another welding characteristic of nickel is that the weld puddle is not very fluid; therefore, it is more difficult to get complete fusion.

Short-circuiting, globular, or spray transfer may be used depending on the welding heat input and the thickness of the metal being welded. The pulsed arc method is also used.

Argon shielding gas is widely used and normally recommended for welding in the spray and pulsed arc modes. Argon-helium mixtures are used to produce wider and flatter beads and are generally used with the short-circuiting mode. This process is employed for welding most thicknesses of nickel and nickel alloys. The filler metals used for welding of these metals are generally similar in composition to the base metal being welded.

The filler metals are alloyed to resist hot cracking and porosity in the weld metal.

7.2.5 Steels

GMAW is widely used for welding steels. In general, steels are classified according to the carbon content, such as low carbon, medium carbon, or high carbon steels. In addition, steels are also classified according to the types of alloy used, such as chromemoly, nickel-manganese, etc. For discussion purposes in this course, steels will be classified according to their welding characteristics.

In welding steel, the hardness and hardenability of the weld metal are influenced by the carbon and any other alloy content, which in turn influences the amount of preheat needed. The two terms, hardness and hardenability, are not the same. The maximum hardness of steel is primarily a function of the amount of carbon in the steel. Hardenability is a measure of how easily a martensite structure is formed when the steel is quenched. Martensite is the phase or metallurgical structure in steel where the maximum hardness of the steel can be obtained. Steels with low hardenability must have very high cooling rates after welding to form martensite, where steels with high hardenability will form martensite even when they are slow cooled in air. Hardenability will determine to what extent a steel will harden during welding. The carbon equivalent formula is one of the best methods of determining the weldability of steels. This value is determined by the amounts of the alloying elements. There are several different formulas used; one of the most popular is as follows:

$$\text{Carbon Equivalent} = \%C + \frac{\%Cr}{10} + \frac{\%Mn}{6} + \frac{\%Mo}{10} + \frac{\%Ni}{20} + \frac{\%Cu}{40}$$

Steels with lower carbon equivalents generally are more readily weldable and require fewer precautions such as the use of preheat and postheat. Steels with higher carbon equivalents are generally more difficult to weld. In welding some of the steels, it is more important to match the mechanical properties than the chemical compositions of the filler metal to the base metal. Often, filler metal with a lower carbon content than the base metal is used because the weld metal absorbs carbon from the base metal. This is done to minimize the tendency for weld cracking.

7.2.5.1 Low Carbon and Mild Steels

Low carbon and mild steels generally have low carbon contents and are the most readily weldable. They are the most widely used type of steel for industrial fabrication and include the high strength structural steels.

Low carbon steels have carbon contents up to .14%; mild steels have carbon contents ranging from .15 to .29%. For many applications, preheating is not required except on thick sections and highly restrained joints, or where codes require preheating, but other precautions such as interpass temperature control and postheating are sometimes used. With thicker sections and highly restrained joints, preheating, interpass temperature control, and postheating are usually required to prevent cracking. Electrodes of the ER70S class are employed with carbon dioxide, inert gas, or carbon dioxide-inert gas mixtures, and all types of metal transfer are used. Carbon dioxide is the most widely used gas because it is the least expensive and provides good penetration. The filler metal should be chosen to match the tensile strength of the base metal. A filler metal with sufficient amounts of deoxidizers must be chosen to prevent porosity when welding rimmed steels, which have a silicon content of less than .05%. This precaution is not necessary for welding steels containing more than .05% silicon.

The high strength structural steels are steels whose yield strength falls between 45,000 psi (310M Pa) and 70,000 psi (483 MPa) and their carbon content is generally below .25%. These steels have relatively small amounts of alloying elements. Some common examples of these steels are the ASTM designations of A242, A441, A572, A588, A553, and A537.

7.2.5.2 Low Alloy Steels

The low alloy steels discussed here will be those steels that are low carbon and have alloy additions less than 5%. This includes the quenched and tempered steels, heat treated low alloy steels, and the low nickel alloy steels. Elements such as nickel, chromium, manganese, and molybdenum are the main alloying elements used.

These steels have a higher hardenability than mild steels, and this factor is the principal complication in welding. Low alloy steels have good weldability but are not as easily weldable as the mild steels. This higher hardenability permits martensite to form at lower cooling rates. As the alloy content and the carbon content increase, the hardenability also increases.

In general, as the hardenability of the material increases, the ability to weld it decreases. One of the best methods for determining the weldability of a low alloy steel is the use of the carbon equivalent formula. Steels that have carbon equivalents below about .40% usually do not require the use of preheating and postheating in the welding procedure and generally have the best weldability. Steels with carbon equivalents higher than .40% require more precautions for welding.

Typically, the higher the carbon equivalent, the more difficult the steel is to weld. Except in the case of the low nickel alloys, the selection of electrodes for welding steel is usually based on the desired strength and mechanical properties of the weld rather than on matching chemical compositions. Short-circuiting, globular, and spray metal transfers may be used. The most commonly used shielding gases are carbon dioxide or argoncarbon dioxide mixtures.

The quenched and tempered heat treated steels have yield strengths ranging from 50,000 psi (345 MPa) to very high yield strengths, and have carbon contents ranging to .25%. Some common examples of these types of steel are the ASTM designations A533 Grade B, A537 Grade B, A514, A517, A543, and A553. The .25% carbon limit is used to provide fairly good weldability. These steels provide high tensile and yield strength along with good ductility, notch toughness, corrosion resistance, fatigue strength, and weldability. The presence of hydrogen is always bad in steel, but it is even more critical in these types of steels compared to mild steels. Low hydrogen electrodes should be used when welding these steels. Preheat is generally not used on thinner sections, but it is used on thicker or highly restrained sections. Postweld heat treatment is generally not used because the shielded metal arc welds have good toughness. The steels are generally used in the welded or stress relieved conditions.

The nickel alloy steels included in these low alloy steel groups are those with less than 5% nickel contents. The 2 1/4% and 3 1/2% nickel steels are usually welded with covered electrodes that have the same general chemical composition as the base metal. Preheating is required with highly restrained joints.

7.2.5.3 Heat Treatable Steels

The heat treatable steels are the medium and high carbon steels and medium carbon steels that have been alloyed. This group includes the steels quenched and tempered after welding, normalized or annealed steels, and medium and high carbon steels. These steels are more difficult to weld than the other types of steels already mentioned in this course. The most important factor for selecting the type of covered electrode to be used is matching the chemical compositions of the base metal and the filler metal.

Medium carbon steels are those that have carbon contents ranging from .30% to .59%, and high carbon steels have carbon contents ranging from .60% to about 1.0%. When medium and high carbon steels are welded, precautions should be included in the welding procedure because of the hardness that can occur in the weld joint. As the carbon content increases up to .60%, the hardness of the fully hardened structure (or martensite) increases to a maximum value. When the carbon content is above .60%, the hardness of the fully hardened structure does not increase, so these steels can be welded using about the same welding procedures as the medium carbon steels.

Martensite, which is the phase that steel is in at its fullest hardness, is harder and more brittle in high carbon steel than it is in low carbon steel. A high carbon martensitic structure can have a tendency to crack in the weld metal and heat affected zone during cooling. Welding procedures that lower the hardness of the heat affected zone and the weld metal will reduce the tendency to crack. This can be done by using a procedure that requires lower carbon content in the filler metal and by slowing the cooling rate. The procedure would include preheating, interpass temperature control, and postheating.

The procedures used for welding medium carbon steels can be simpler than the one just mentioned, but that depends on the specific applications. Medium carbon steels can be welded with the ER70S-ER90S classifications. High carbon steels should be welded with the ER80S-ER120S using the electrode of the proper tensile strength to match the tensile strength of the base metal. Generally, high carbon steels are not used in welded production work. These steels are usually welded only in repair work. Mild steel electrodes may also be used, but the deposited weld metal absorbs carbon from the base metal and thus loses a considerable amount of ductility. Stainless steel electrodes of the austenitic type are sometimes used, but the fusion zone may still be hard and brittle. A preheat and/or postheat will help eliminate the brittle structure.

Steels quenched and tempered after welding have carbon contents ranging from about .25% to .45%, which distinguishes them from the steels that are quenched and tempered before welding. These steels also have small additions of alloying elements. Some common examples of these steels are the AISI designations 4130, 4140, and 4340. Because of the higher carbon contents, the steels in this group can be heat treated to extremely high levels of strength and hardness. Some of these steels have enough alloy content to give them high hardenability. Because of this combination of carbon and alloy content, the steels must be preheated before welding. Their weldability is also influenced by the purity of the steels. High amounts of sulfur and phosphorous in the steel increase the sensitivity to cracking and reduce the ductility. Gas metal arc welding is often used for welding these steels, and a filler metal of the same chemical composition as the base metal is required to obtain the maximum strength.

7.2.5.4 Chromium-Molybdenum Steels

The low chromium molybdenum steels in this section are those with alloy contents of about 6% or less. These steels are in the low carbon range, generally up to .15%, and are readily weldable. The chromium and molybdenum alloying elements provide these steels with good oxidation resistance and high temperature strength. The chromium is mainly responsible for the resistance, and the molybdenum is mainly responsible for the high temperature strength.

The higher chrome-moly steels contain about 6-10% chromium and .5-1% molybdenum. These steels are limited to a maximum carbon content of about .10% to limit the hardness because these steels are very sensitive to air hardening. For the welding of these steels, preheating, interpass temperature control, slow cooling, and postweld heat treatment are required to make a weld with good mechanical properties. These steels generally do not require preheating except when welding thick sections or highly restrained joints. Postheating is usually not required on chromium molybdenum steels that contain less than 2 1/4% Cr and 1% Mo.

Gas metal arc welding is one of the most common methods of welding the chromium molybdenum steels. Short-circuiting or spray transfer is generally used. The steels with less than 6% chromium are welded with a carbon dioxide or argon-carbon dioxide mixture, depending on the type of metal transfer desired. For the steels with 6% chromium or more, argon, argon-helium mixtures, and argon with small additions of oxygen or carbon dioxide are used. Pulsed arc transfer is often employed to fill the gap between short-circuiting and spray transfer to avoid globular transfer. The filler metal is chosen to match the chemical composition of the base metal as closely as possible to give good corrosion resistance.

7.2.5.5 Free Machining Steels

Free machining steels are steels that have additions of sulfur, phosphorous, selenium, or lead in them to make these steels easier to machine. Except for the high sulfur, lead, or phosphorous, these steels have chemical compositions similar to mild, low alloy, and stainless steels. The addition of these elements makes these steels nearly unweldable because lead, phosphorous, and sulfur have melting points much lower than the melting point of the steel. As the weld solidifies, these elements remain liquid much longer than the steel, so they coat the grain boundaries, causing hot cracking in the weld. Hot cracking is cracking that occurs before the weld has had a chance to cool. Because of this hot cracking problem, free machining steels cannot be welded easily. High manganese filler metal and low base metal dilution will help give the best results possible.

7.2.5.6 Stainless Steels

Most types of stainless steels can be welded by GMAW. The types that are very difficult to weld are types such as 303, 416, 416 Se, 430 F, and 430 FSe, which have high sulfur and selenium contents, and Type 440, which has a high carbon content. The major alloying element which distinguishes stainless steels from the other types of steel is the chromium. Steels that have chromium contents greater than 11% are considered stainless steels. The high chromium content gives these steels very good corrosion and oxidation resistance. The three major groups of stainless steels that are welded are the austenitic, martensitic, and ferritic types.

The austenitic types of stainless steels are generally the easiest to weld. In addition to the high chromium content of about 16-26%, these types have high nickel contents ranging from 6-22%. These steels are designated by the AISI as the 300 series. The 200 series, which have high manganese contents to replace some of the nickel, are also austenitic. Nickel and manganese are strong austenite formers and maintain an austenitic structure at all temperatures. This structure gives these steels good toughness and ductility but also makes them non-hardenable. A major problem when welding these types of steels is carbide precipitation or sensitization, which occurs only in the austenitic structure. This occurs when the temperature of the steel is between approximately 1000-1600° F (540-870° C) and can greatly reduce the corrosion resistance. There are several methods for preventing this problem:

1. Fast cooling rate after welding through this temperature range. This is a major reason why preheating is usually not used and why these steels require a relatively low maximum interpass temperature on multiple pass welds.
2. Use of extra low carbon base and filler metal (.03% carbon max). Examples are 304L and 316L.
3. Use of a stabilized alloy containing columbium, tantalum (tan-tl-uh m), or titanium. Examples are 347 and 321.
4. Use of a solution heat treatment to redissolve the carbides after welding.

Martensitic stainless steels are not as easy to weld as the austenitic stainless steels. These stainless steels have approximately 11-18% chromium, which is the major alloying element, and are designated by the AISI as the 400 series. Some examples are 403, 410, 420, and 440. These types of stainless steel are heat treatable because they generally contain higher carbon contents and a martensitic structure. Stainless steels with higher carbon contents are more susceptible to cracking and some, such as Type 440, have carbon contents so high that they are often considered unweldable. A stainless steel with a carbon content greater than .10% will often need preheating, usually in the range of 400-600° F (205-315°C) to avoid cracking. For steels containing carbon contents greater than .20%, a postweld heat treatment such as annealing is often required to improve the toughness of the weld produced.

Ferritic stainless steels are also more difficult to weld than austenitic stainless steels because they produce welds having lower toughness than the base metal. These stainless steels form a ferritic grain structure and are also designated by the AISI as the 400 series. Some examples are types 405, 430, 442, and 446. These types are generally less corrosion resistant than austenitic stainless steel. To avoid a brittle structure in the weld, preheating and postheating are often required. Typical preheat temperatures range from 300-500° F (150-260° C). Annealing is often used after heat treatment welding to increase the toughness of the weld.

GMAW is well suited for welding stainless steel. Lower current levels may be desirable for welding stainless steel compared to welding mild steel because of the higher thermal expansion, lower thermal conductivity, and lower melting point of stainless steel. The lower thermal conductivity and higher thermal expansion cause more distortion and warpage for a given heat input. All of the different modes of metal transfer are used when welding stainless steel. Pulsed arc welding is popular because it helps reduce distortion and warpage. An argon-oxygen mixture of 99% Ar-1 % O_2, or 98% Ar-2% O_2, or pure argon is used to obtain spray transfer. The argon-oxygen mixtures are used to improve arc stability and weld puddle wetting. Helium-argon-carbon dioxide mixtures are used to obtain short-circuiting transfer. Argon-carbon dioxide mixtures are sometimes used. Carbon dioxide causes a loss of silicon and manganese, and an increase in carbon in the low carbon stainless steels. Carbon dioxide is restricted for welding many of the stainless steels, especially austenitic grades, because corrosion resistance may be reduced due to the carbon the gas adds to the weld. GMAW may be used on most thicknesses of stainless steel

The filler metal for welding stainless steel is generally chosen to match the chemical composition of the base metal. For the 200 series austenitic stainless steels, a 300 series austenitic filler metal is usually used due to lack of an available 200 series filler metal. This weld joint will generally be weaker than the surrounding base metal. 300 series filler metal is used on 300 series base metal.

Type 410 and 420 electrodes are the only martensitic stainless steel types recognized by the AWS. This limitation is often the reason why austenitic stainless steel filler metal is often used when welding martensitic stainless steel. Austenitic filler metal provides a weld with lower strength but higher toughness and eliminates the need for preheating and postheating. For welding ferritic stainless steels, both ferritic and austenitic filler metal may be used. Ferritic filler metal is used when higher strength and an annealing postheat are required. Austenitic filler metal is used when higher ductility is required. Table 18 shows filler metal selection for stainless steels.

Table 18 — Filler metal selection for welding stainless steel.

No.	C%	Mn%	Si%	Cr%	Ni%	Other Elements	Filler Metal Selection
201	0.15 max	5.5-7.5	1.00	16.00-18.00	3.50-5.50	N 0.25 max	308
202	0.15 max	7.5-10.0	1.00	17.00-19.00	4.00-6.00	N 0.25 max	308
301	0.15 max	2.00	1.00	16.00-18.00	6.00-8.00	-	308
302	0.15 max	2.00	1.00	17.00-19.00	8.00-10.00	-	308
3028	0.15 max	2.00	2.00-3.00	17.00-19.00	8.00-10.00	-	308
304	0.08 max	2.00	1.00	18.00-20.00	8.00-12.00	-	308
304L	0.03 max	2.00	1.00	18.00-20.00	8.00-12.00	-	308L
305	0.12 max	2.00	1.00	17.00-19.00	10.00-13.00	-	308 310
308	0.08 max	2.00	1.00	19.00-21.00	10.00-12.00	-	308
309	0.20 max	2.00	1.00	22.00-24.00	12.00-15.00	-	309
309S	0.08 max	2.00	1.00	22.00-24.00	12.00-15.00	-	309
310	0.25 max	2.00	1.50	24.00-26.00	19.00-22.00	-	310
310S	0.08 max	2.00	1.50	24.00-26.00	19.00-22.0	-	310
314	0.25 max	2.00	1.50-3.00	23.00-26.00	19.00-22.00	-	310 312
316	0.08 max	2.00	1.00	16.00-18.00	10.00-14.00	Mo 2.00-3.00	316
316L	0.03 max	2.00	1.00	16.00-18.00	10.00-14.00	Mo 2.00-3.00	316L
317	0.08 max	2.00	1.00	18.00-20.00	11.00-15.00	Mo 2.00-3.00	317
321	0.08 max	2.00	1.00	17.00-19.00	9.00-12.00	Ti 5xCmin	347
330	0.35 max	2.00	2.50	13.00-17.00	33.00-37.00	-	330
347	0.08 max	2.00	1.00	17.00-19.00	9.00-13.00	Cb+Ta 10xC min	347
348	0.08 max	2.00	1.00	18.00-19.00	9.00-13.00	Cb+Ta 10 C min.Ta 0.10	347 348
403	0.15 max	1.00	0.50	11.50-13.00	-	-	410 309 310
410	0.15 max	1.00	1.00	11.50-13.50	-	-	410 309 310
414	0.15 max	1.00	1.00	11.50-13.50	1.25-2.50	-	410 309 310
420	Over 0.15	1.00	1.00	12.00-14.00	-	-	410 420
431	0.20 max	1.00	1.00	15.00-17.00	1.25-2.50	-	430 309 310
501	Over 0.10	1.00	1.00	4.00-6.00	-	Mo 0.40-0.65	502
502	0.10 max	1.00	1.00	4.00-6.00	-	Mo 0.40-0.65	502
405	0.08 max	1.00	1.00	11.50-14.50	-	Al0.10-0.30	410 309 310
430	0.12 max	1.00	1.00	14.00-18.00	-	-	430 309 310
442	0.20 max	1.00	1.00	18.00-23.00	-	-	309 310
446	0.20 max	1.50	1.00	23.00-27.00	-	N20.25max	309 310

7.2.6 Titanium and Titanium Alloys

Titanium and many of the titanium alloys are welded by GMAW. The major alloying elements contained in titanium alloys are aluminum, tin, zirconium, vanadium and molybdenum. There are four basic groups of this metal:

1. Unalloyed titanium
2. Alpha alloys
3. Alpha-beta alloys
4. Beta alloys

The unalloyed titanium and alpha alloys are all weldable. The weakly beta-stabilized alpha-beta alloys are weldable but strongly beta-stabilized alpha-beta alloys are embrittled by welding. Most beta alloys can be welded, but proper heat treatment must be used to prevent the welds from becoming brittle.

In general, titanium requires the same welding techniques used for welding stainless steel with two exceptions: titanium requires greater cleanliness and an auxiliary shielding gas. The molten weld puddle reacts with most materials, and contamination from the atmosphere or from material on the surface of the metal can cause embrittlement in the weld zone and a loss of corrosion resistance. The surface of the metal to be welded must be cleaned thoroughly to avoid these problems. Argon or helium shielding gases are almost exclusively used for welding titanium. The only other shielding gas used is an argon-helium mixture. Welding titanium requires a shielding gas on the backside of the root pass also. In many cases, welding is done in an inert gas filler chamber. For out of chamber welding, a trailing shielding gas is used behind the torch to protect the hot metal until it cools below about 600°F (315°C). A leading shield is also used to prevent oxidation of any spatter that may be remelted into the weld puddle. GMAW is used for welding metal thicknesses greater than 1/8 in. (3.2mm), but gas tungsten arc welding is often preferred instead, even when welding thicker metal, because of the weld spatter and arc instability, which can occur in GMAW, thus reducing the weld quality. Preheating is rarely used except when removing moisture from the surface of the metal.

Electrodes of the same chemical composition as the base metal are usually used. Sometimes electrodes with a yield point lower than the base metal are used to improve the joint ductility when welding higher strength titanium alloys. The electrode wire must also be very clean because it can also cause contamination of the weld metal.

Test Your Knowledge

9. What are the grains called that form on the edge of a weld?

   A. Deoxidizers
   B. Dendrites
   C. Slag
   D. Dross

10. Why is preheating used when welding titanium?

   A. To increase base metal temperature.
   B. To remove moisture from the base metal.
   C. To soften the base metal.
   D. To increase the hardenability of the base metal.

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8.0.0 WELD AND JOINT DESIGN

The weld joint design used for gas metal arc welding is determined by the design of the workpiece, metallurgical considerations, and codes or specifications.

Joints are designed for accessibility and economy during construction. The purpose of a joint design is to obtain the required strength and highest quality at the lowest possible cost. A weld joint consists of a specific weld made in a specific joint. A joint is defined as being the junction of members who are to be, or have been, joined. Figure 45 shows the five basic joint types. Each of the different joints may be joined by many different types of welds. Figure 45 shows the most common types of welds. The type of weld made is governed by the joint configuration, and each of the different welds has its own specific advantages. Figure 45 lists the nomenclature used for groove and fillet welds.

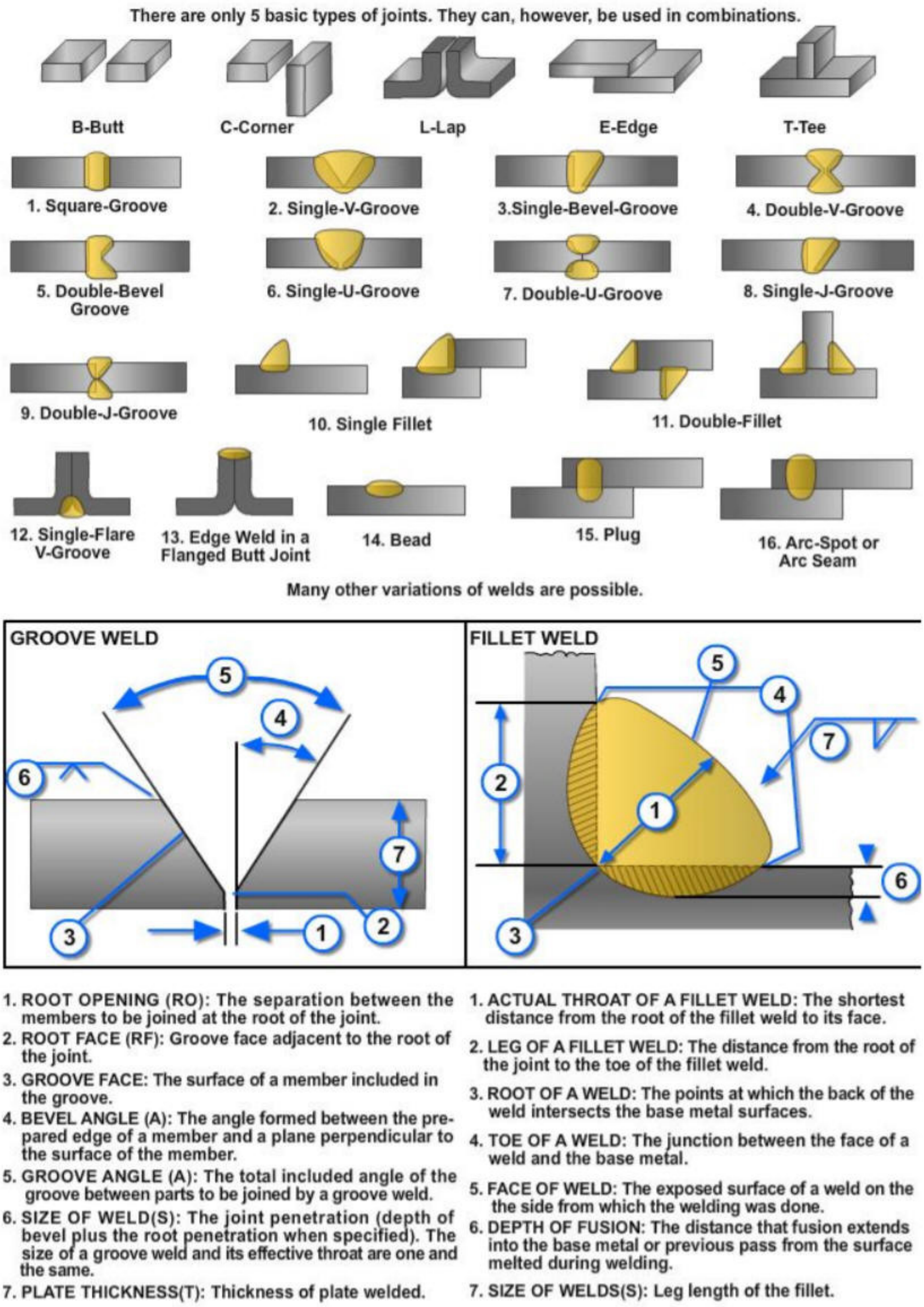


Figure 45 — Weld nomenclature.

Several factors influence the joint design to be used:

- Strength required
- Welding position
- Metal thickness
- Joint accessibility
- Type of metal being welded

The edge and joint preparation are important because they will affect both the quality and cost of welding. The cost items to be considered are the amount of filler metal required, the method of preparing the joint, the amount of labor required, and the level of quality required. Difficult to weld joints will often have more repair work necessary than those that are the easier to weld.

GMAW is applicable to all five basic joint types, with butt and tee joints the most commonly welded. Lap joints have the advantage of not requiring much preparation other than squaring off the edges and making sure the metal is in close contact. Edge joints are widely used on thin metal. Corner joints generally use similar edge preparations to those used on tee joints.

In some cases, the joint designs used for gas metal arc welding are similar to shielded metal arc welding, but there are often differences due to the different characteristics of the process. Gas metal arc welding has some characteristics that are different from many other processes, which will sometimes affect the joint design. One of the main items is that the joint must be designed so the welder can obtain good access to the joint to be able to manipulate the electrode properly. In addition, a joint must not be located so it creates an excessive distance between the root of the joint and the nozzle of the welding gun. A large nozzle-to-work distance may prevent adequate root penetration and adequate gas shielding.

8.1.0 Strength

The strength required of a weld joint is a major factor governing weld joint design. Weld joints may be either full or partial penetration depending on the strength required of the joint. Full or complete penetrating welds are those that have weld metal through the full cross section of the joint; partial penetrating welds are those that have an unfused area in the joint. Welds subject to cyclic, impact, or dynamic loading require complete penetration welds. This is even more important for applications that require low temperature service.

Partial penetration welds may be adequate for joints where loading is static only, and they are easier to prepare and require less filler metal than full penetration joints.

The amount of penetration obtained will be affected by the root opening and root face used. A root opening is used to allow good access to the root of the joint and is usually used in full penetrating weld joints. A root opening is usually not used in partial penetration weld joints because access to the root is not necessary and parts are easier to fit together without a root opening. The size of the root face is also affected. A larger root face is used for partial penetration welds than for complete penetration welds because less penetration is required.

Because GMAW uses relatively small diameter electrode wire, the arc produced is more intense than the arcs produced by shielded metal arc welding and gas tungsten arc welding. Slightly larger root faces are needed because of the greater penetrating characteristics of the gas metal arc welding process, especially when using carbon dioxide shielding gas. Smaller root openings may also be used to keep the weld metal from falling through the root of the joint. These differences apply to the globular, spray, and pulsed arc modes only. Because lower welding current values are used with the short-circuiting mode of metal transfer, joint designs used are similar to those used for shielded metal arc welding. The short-circuiting mode requires larger root openings and smaller root faces. This metal transfer mode is widely used for welding thin metal and for depositing the root pass in thick metal, while the rest of the groove may be filled using the spray or globular transfer modes. Smaller groove angles are required with GMAW because of the relatively small electrode diameter used, which allows better access to the root of the joint.

8.2.0 Position

GMAW may be used in all welding positions. The position in which welding is done often affects the joint configuration. A diagram of the welding position capabilities (also the welding test positions) is shown in Figure 46. Good quality welding in the flat, horizontal, vertical, and overhead positions depends on the skill of the welder and the mode of metal transfer. Welding positions are classified by a set of numbers and letters. The four basic welding positions are designated by the numbers 1 for flat, 2 for horizontal, 3 for vertical, and 4 for overhead. F designations are used for fillet welds and G designations are used for groove welds. The 5G and 6G positions are used in pipe welding.

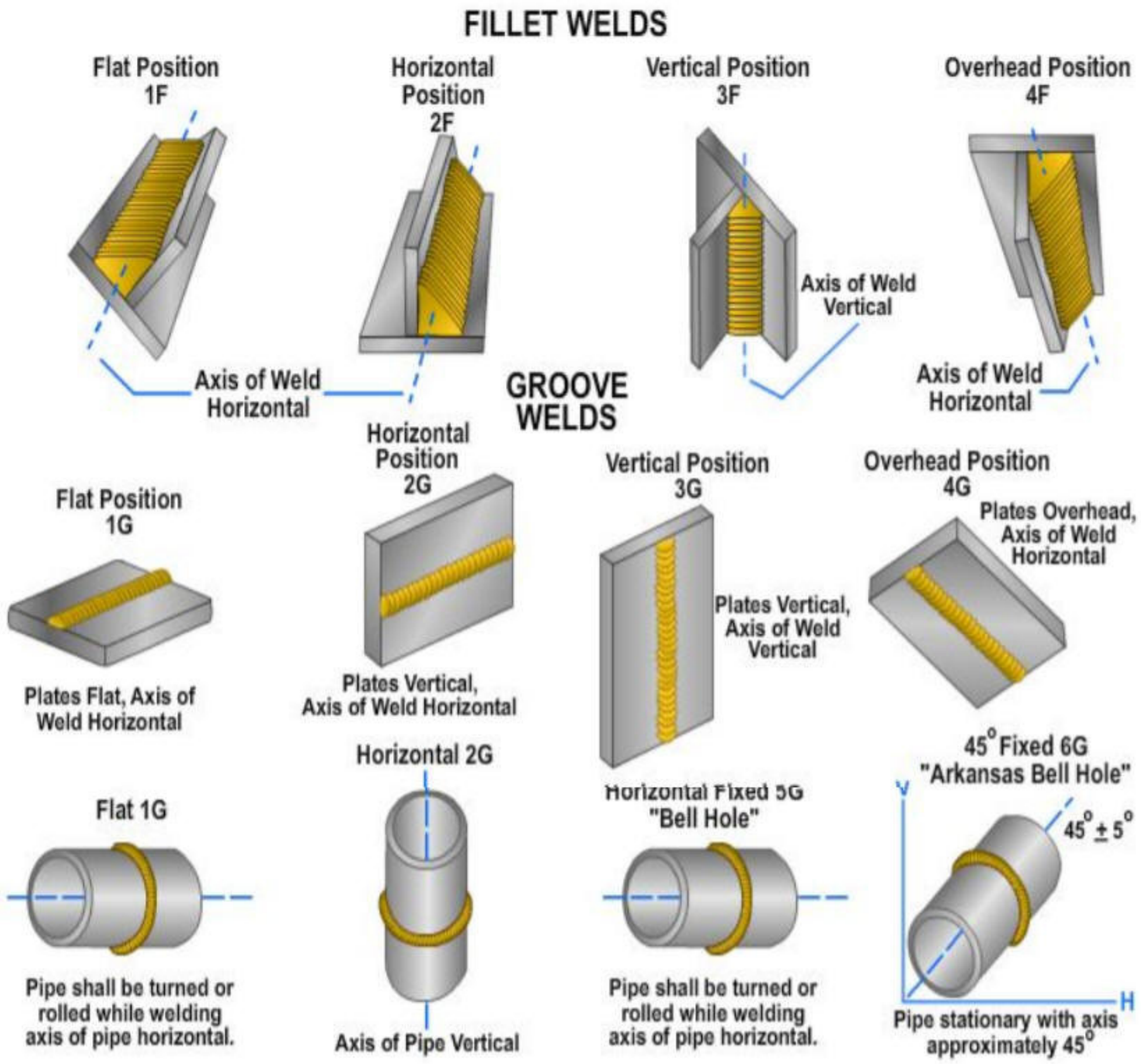


Figure 46 — Welding test positions.

The major effects that the position of a proposed weld will have are on the types of metal transfer used and the groove angles. The short-circuiting, spray, and pulsed arc modes may be used in all positions. Globular and spray transfer using high current levels are used for welding in the flat position.

Wider groove angles are often used when welding in the vertical position. Joints that are welded in the horizontal position often have an asymmetrical joint configuration. This usually consists of a groove angle that has horizontal lower groove face as shown in Figure 47. The upper groove face is raised accordingly to allow adequate access to the root of the joint. The horizontal lower groove face is used as a shelf to support the molten weld metal. This joint configuration is less expensive to prepare than symmetrical groove joints for welding in other positions because only one groove face has to be beveled. Other joint design differences will occur on many out of position joints when using the short-circuiting mode of metal transfer where larger root openings and smaller root faces are required.

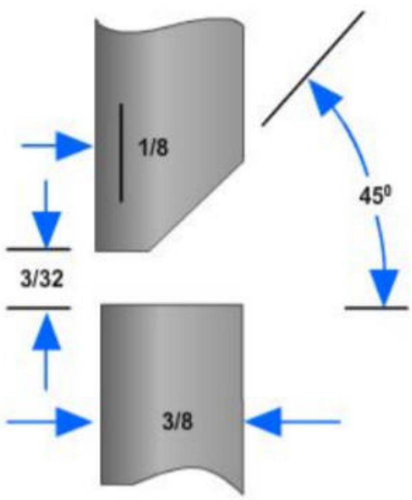


Figure 47 — Single bevel joint in horizontal position.

8.3.0 Thickness

The thickness of the base metal has a large influence on the joint preparation required to produce the best weld joint possible. Gas metal arc welding can be used to weld metal thicknesses down to .020 in. (.5 mm). This process is suitable for welding fairly thick metal so there are a wide variety of applicable joint preparations. The most common groove preparations used on butt joints are the square-, V-, J-, U-, bevel-, and combination grooves. The square-, J-, bevel-, and combination-groove preparations are also used on tee joints. The different preparations are employed on different thicknesses to make it possible to get complete or adequate penetration.

Square-groove welds are used on the thinnest metal thicknesses. The square-groove joint design is the easiest to prepare and requires the least filler metal. Thicknesses up to 3/8 in. (9.5 mm) can be welded with full penetration from both sides. This is thicker than the square-groove joints that can be welded with full penetration by shielded metal arc welding or gas tungsten arc welding because of the hotter arc produced by this process. Root openings are used to allow complete penetration through the joint. Many square-groove welds are made in one pass. A backing strip may be used so the root can be opened enough to provide better accessibility and ensure adequate penetration.

V-grooves for butt joints and bevel-grooves for tee joints are commonly used for thicker metal up to about ¾-in. (19.1 mm). These joints are more difficult to prepare and require more filler metal than square groove welds. The included angle for a V-groove is usually up to 75°. The wider groove angles are used to provide better accessibility to the root of the joint. Because of the deeper penetrating characteristics of this process, single-V-groove or single-bevel-groove welds are often welded with little or no root opening. Larger root faces and smaller groove angles are often used compared to those employed for shielded metal arc welding and gas tungsten arc welding. This helps to minimize the amount of distortion and reduce the amount of filler metal required. For complete penetration welds, root faces usually are close to 1/8-in. (3.2 mm).

U- and J-grooves are generally used on thicknesses greater than 5/8-in. (14.3 mm). These joint preparations are the most difficult and expensive to prepare, but the radius at the root of the joint allows better access to the root of the joint. Another advantage is that smaller groove angles may be used compared to those used in V-grooves. On thicker metal, this reduces the amount of filler metal required and on very thick metals, this savings becomes very substantial.

8.4.0 Accessibility

The accessibility of the weld joint is another important factor in determining the weld joint design. Welds can be made from either one side or both sides of the joint. SingleV-, J-, U-, bevel-, and combination grooves are used when accessibility is from one side only and on thinner metal. Double-V -, J-, U-, bevel-, and combination grooves are used on thicker metal where the joint can be welded from both sides. Double-groove welds have three major advantages over single-groove welds where accessibility is only from one side. The first is that distortion is more easily controlled through alternate weld bead sequencing. Weld beads are alternated from one side to the other to keep the distortion from building up in the one direction. The roots are nearer the center of the plate. A second advantage is that less filler metal is required to fill a double-groove joint than a single-groove joint. The third advantage is that complete penetration can be more easily ensured. The root of the first pass on the plate can be gouged or chipped out before the root pass on the second side is welded to make sure there is complete fusion at the root. The disadvantages of joints welded from both sides are that more joint preparation is required and gouging or chipping is usually required to remove the root of the first pass. Both of these add to the labor time required. Welding on both sides of a square-groove weld joint provides fuller penetration in thicker metal than metal welded from one side only. This would also save joint preparation time.

8.4.1 Backing Strips

When backing strips are used, joints are accessible from one side only. Backing strips allow better access to the root of the joint and support the molten weld metal. These strips are available in two forms, fusible or non-fusible. Fusible backing strips are made of the metal being welded and remain part of the weldment after welding. These may be cut or machined off. Non-fusible backing strips are made of copper, carbon, flux, or ceramic backing in tape or composite form. These forms of backing do not become part of the weld. Backing strips on square-groove joints make a full penetration weld from one side easier. For this application, using a backing is more expensive because of the cost of a backing strip and the larger amount of filler metal required. This is not always the case. On V-groove joints, the backing strip allows wider root openings and removes the need for a root face, which reduces the groove preparation costs. Another advantage is that because the root may be opened up, the groove angle may be reduced, which will reduce the amount of filler metal required in thicker metal. These effects are shown in Figure 48 where single V-groove joints are shown with and without a backing strip.

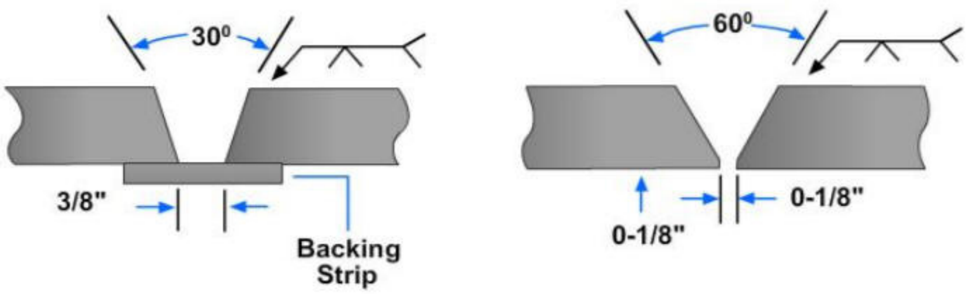


Figure 48 — Single V-groove joints with and without backing strips.

8.5.0 Types of Metal

The type of metal being welded is another factor that affects the joint design for gas metal arc welding. For example, aluminum has a high thermal conductivity and low melting point. Stainless steel has a lower thermal conductivity and a higher melting point. The maximum thickness that a square groove joint design may be used in aluminum is slightly less than that for stainless steel because the heat leaves the welding area quicker, which does not allow the weld puddle to melt as deeply. Another example is in nickel, where a larger root opening is used because the weld puddle is not very fluid. The larger root opening is required to allow proper manipulation of the electrode to get adequate fusion.

8.6.0 Weld Joint Designs

The weld joint designs in the rest of the course are those typically used for GMAW. The exact dimensions of the joint design used will vary depending on the mode of metal transfer being used. Some of the joint designs may not be acceptable when using the short circuiting mode of metal transfer. For many of the root opening dimensions and some of the root face dimensions, ranges are given to account for varying fitup or for different modes of metal transfer.

Several joint designs using backing strips are included. The thicknesses given are those typically used with the joint design. For different thickness of base metals, Table 19 shows the minimum effective throat thicknesses for partial penetration groove welds. Figure 49 through 10-59 shows the American Welding Society "Standard Welding Symbols," some of which have been used in the weld joint designs.

Table 19 — Effective Throat Thickness for Partial Joint Penetration Groove Welds.

Base Metal Thickness of Thicker Part Joined				Minimum Effective Throat	
	Inch	**(mm)**		**Inch**	**(mm)**
To	1/4	6.5	inclusive	1/8	3
Over	1/4 to 1/2	6.4 to 12.7	inclusive	3/16	5
Over	1/2 to 3/4	12.7 to 19.0	inclusive	1/4	6
Over	3/4 to 1 1/2	19.0 to 38.1	inclusive	5/16	8
Over	1 1/2 to 2 1/4	38.1 to 57.1	inclusive	3/8	10
Over	2 1/4 to 6	57.1 to 152	inclusive	1/2	13
Over	6	152		5/8	16

8.6.1 Welding Symbols

AWS welding symbols are the shorthand of welding. They enable the engineer and draftsman to convey complete welding instructions to the welder on blueprints and drawings.

Using welding symbols promotes standardization and a common understanding of design intent. It also eliminates unnecessary details on drawings and mistakes caused by lack of information or misunderstanding.

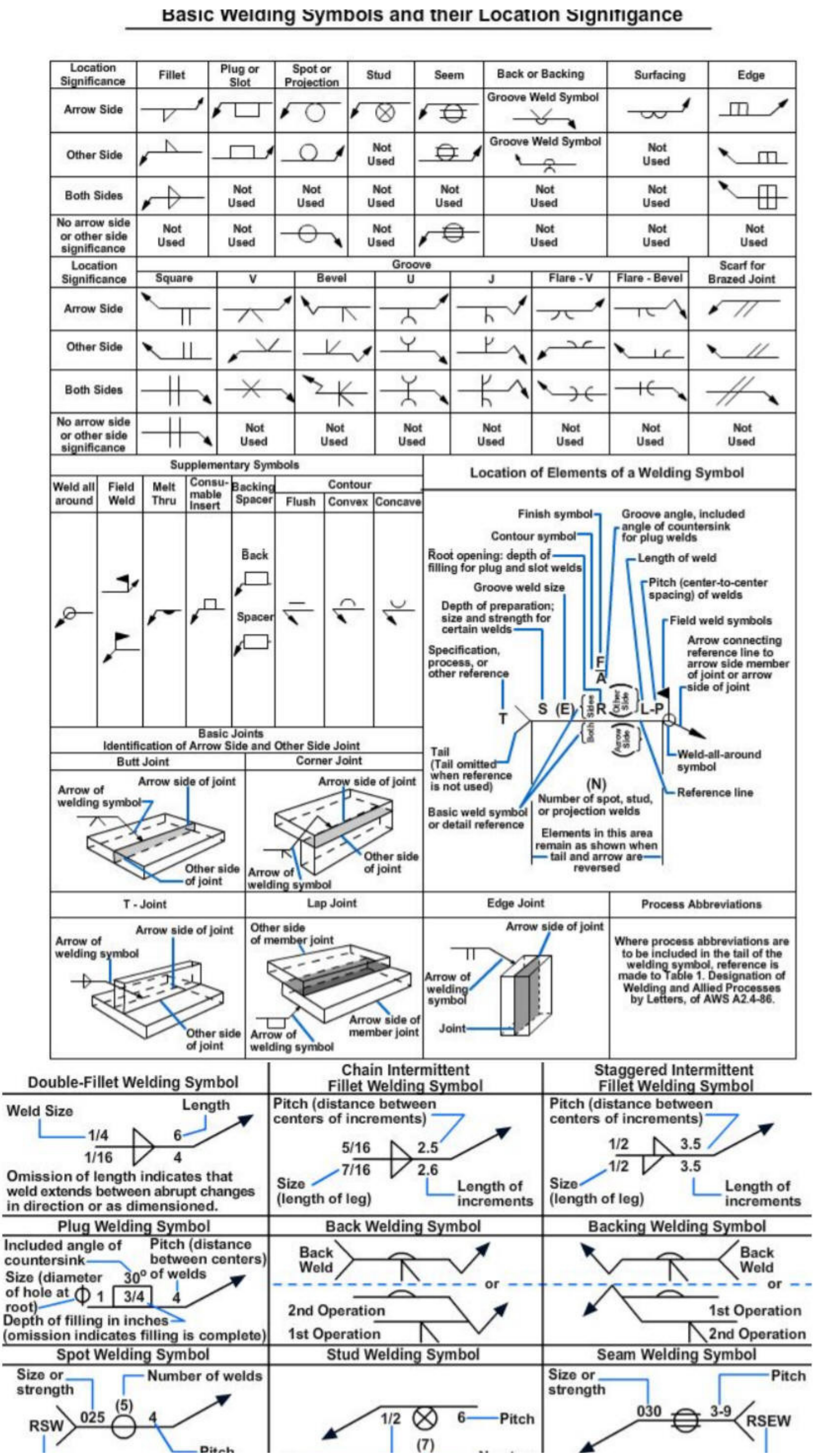

Basic Welding Symbols and their Location Signifigance
Location Significance
Fillet
Plug or Slot
Spot or Projection
Stud
Seem
Back or Backing
Surfacing
Edge
Arrow Side
Other Side
Both Sides
No arrow side or other side significance
Groove Weld Symbol
Not Used
Groove
Square
V
Bevel
U
J
Flare - V
Flare - Bevel
Scarf for Brazed Joint
Supplementary Symbols
Weld all around
Field Weld
Melt Thru
Consu-mable Insert
Backing Spacer
Contour
Flush
Convex
Concave
Back
Spacer
Location of Elements of a Welding Symbol
Finish symbol
Contour symbol
Root opening: depth of filling for plug and slot welds
Groove weld size
Depth of preparation; size and strength for certain welds
Specification, process, or other reference
Groove angle, included angle of countersink for plug welds
Length of weld
Pitch (center-to-center spacing) of welds
Field weld symbols
Arrow connecting reference line to arrow side member of joint or arrow side of joint
F
A
S (E)
R
L-P
T
Both Sides
Other Side
Arrow Side
Tail
(Tail omitted when reference is not used)
Basic weld symbol or detail reference
(N)
Number of spot, stud, or projection welds
Elements in this area remain as shown when tail and arrow are reversed
Weld-all-around symbol
Reference line
Basic Joints
Identification of Arrow Side and Other Side Joint
Butt Joint
Corner Joint
Arrow of welding symbol
Arrow side of joint
Other side of joint
T - Joint
Lap Joint
Other side of member joint
Arrow side of member joint
Edge Joint
Arrow side of joint
Joint
Process Abbreviations
Where process abbreviations are to be included in the tail of the welding symbol, reference is made to Table 1. Designation of Welding and Allied Processes by Letters, of AWS A2.4-86.
Double-Fillet Welding Symbol
Weld Size
Length
1/4
6
1/16
4
Omission of length indicates that weld extends between abrupt changes in direction or as dimensioned.
Chain Intermittent Fillet Welding Symbol
Pitch (distance between centers of increments)
5/16
2.5
7/16
2.6
Size (length of leg)
Length of increments
Staggered Intermittent Fillet Welding Symbol
Pitch (distance between centers of increments)
1/2
3.5
1/2
3.5
Size (length of leg)
Length of increments
Plug Welding Symbol
Included angle of countersink
Pitch (distance between centers) of welds
Size (diameter of hole at root)
30°
1
3/4
4
Depth of filling in inches (omission indicates filling is complete)
Back Welding Symbol
Back Weld
or
2nd Operation
1st Operation
Backing Welding Symbol
Back Weld
or
1st Operation
2nd Operation
Spot Welding Symbol
Size or strength
Number of welds
RSW
025
(5)
4
Stud Welding Symbol
1/2
6
Pitch
(7)
Seam Welding Symbol
Size or strength
Pitch
030
3-9
RSEW

Figure 49 — Welding symbols.

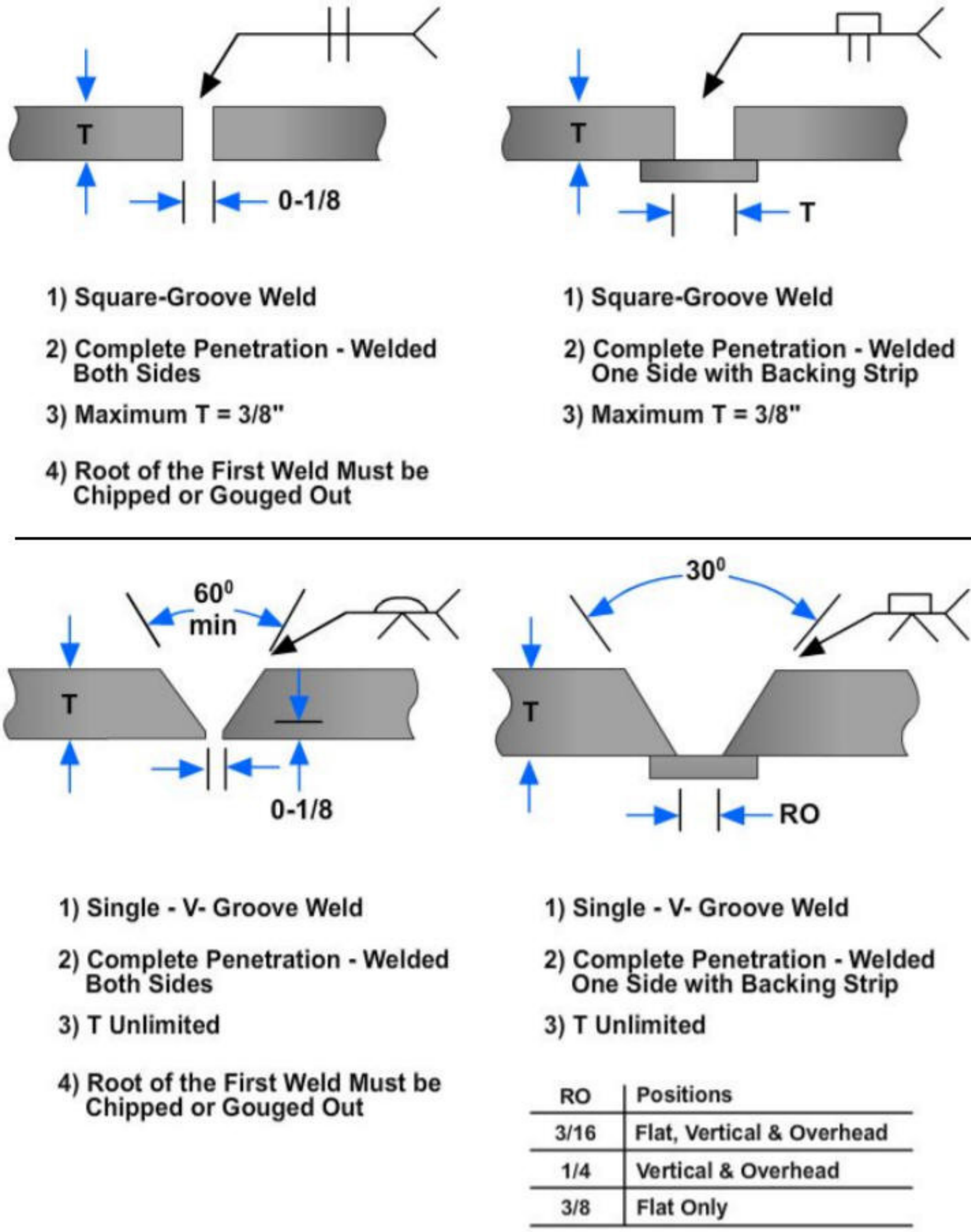


Figure 51 — Welding symbols (cont.).

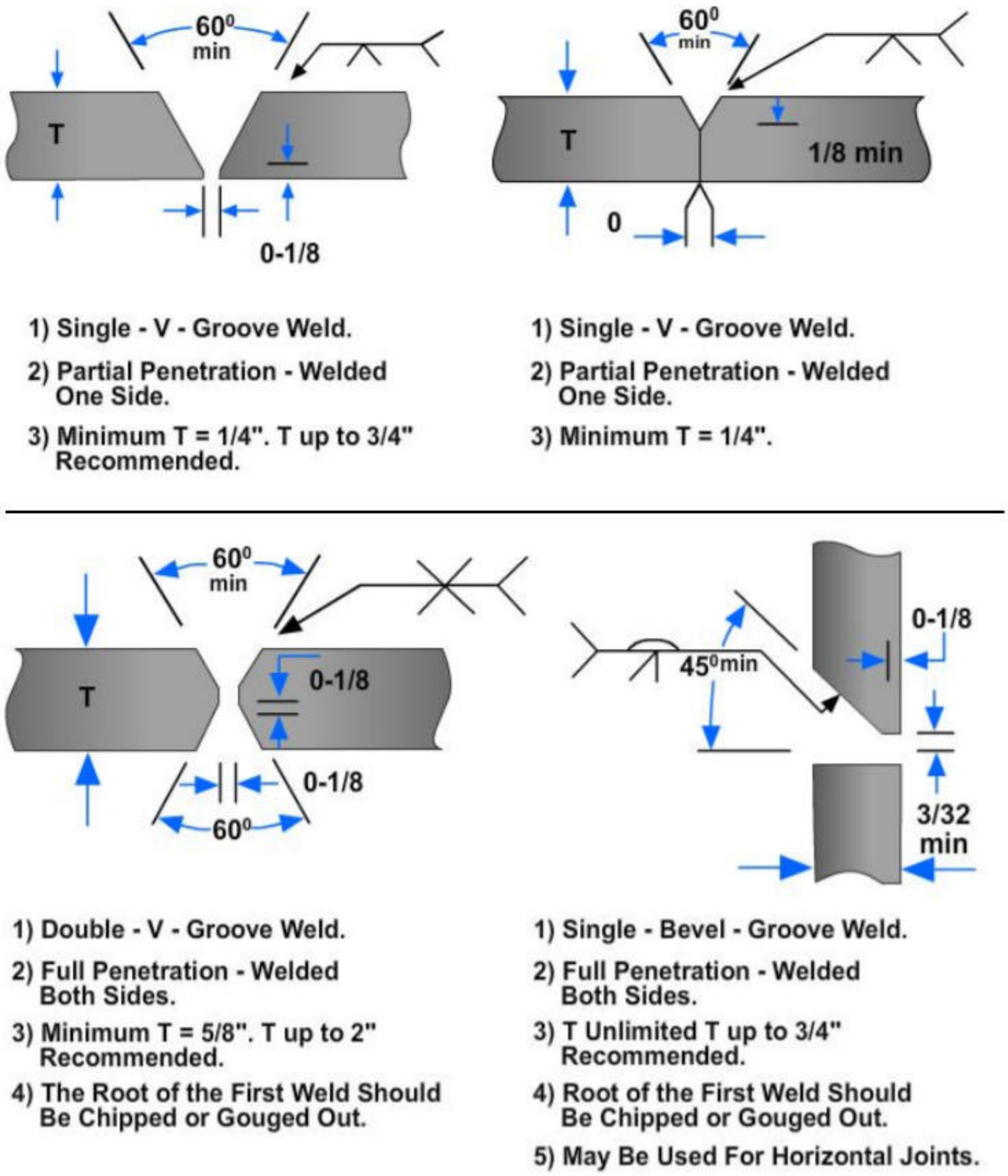
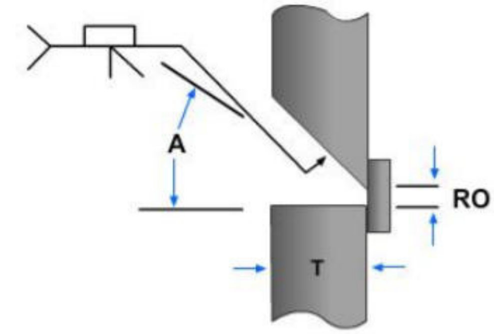
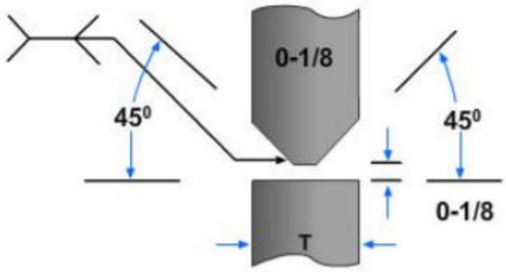


Figure 52 — Welding symbols (cont.).

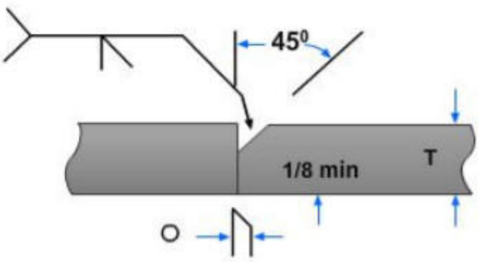


1) Single-Bevel-Groove Weld.
2) Complete Penetration - Welded One Side On Backing Strip.
3) T Unlimited.
4) May Be Used For Horizontal Joints.

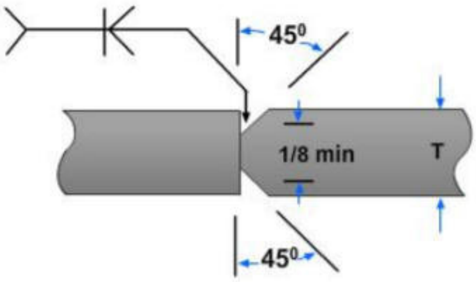
RO	A	Positions
3/16	30⁰	Flat, Vertical & Overhead
1/4	45⁰	Vertical & Overhead
3/8	30⁰	Flat Only



1) Double-Bevel-Groove Weld.
2) Complete Penetration - Welded Both Sides.
3) Minimum T = 5/8".
4) Root of First Weld Should Be Chipped or Gouged Out.
5) May Be Used For Horizontal Joints.



1) Single-Bevel-Groove Weld.
2) Partial Penetration - Welded One Side.
3) Minimum T = 1/4".



1) Double-Bevel-Groove Weld.
2) Partial Penetration - Welded Both Sides.
3) Minimum T = 3/8".

Figure 53 — Welding symbols (cont.).

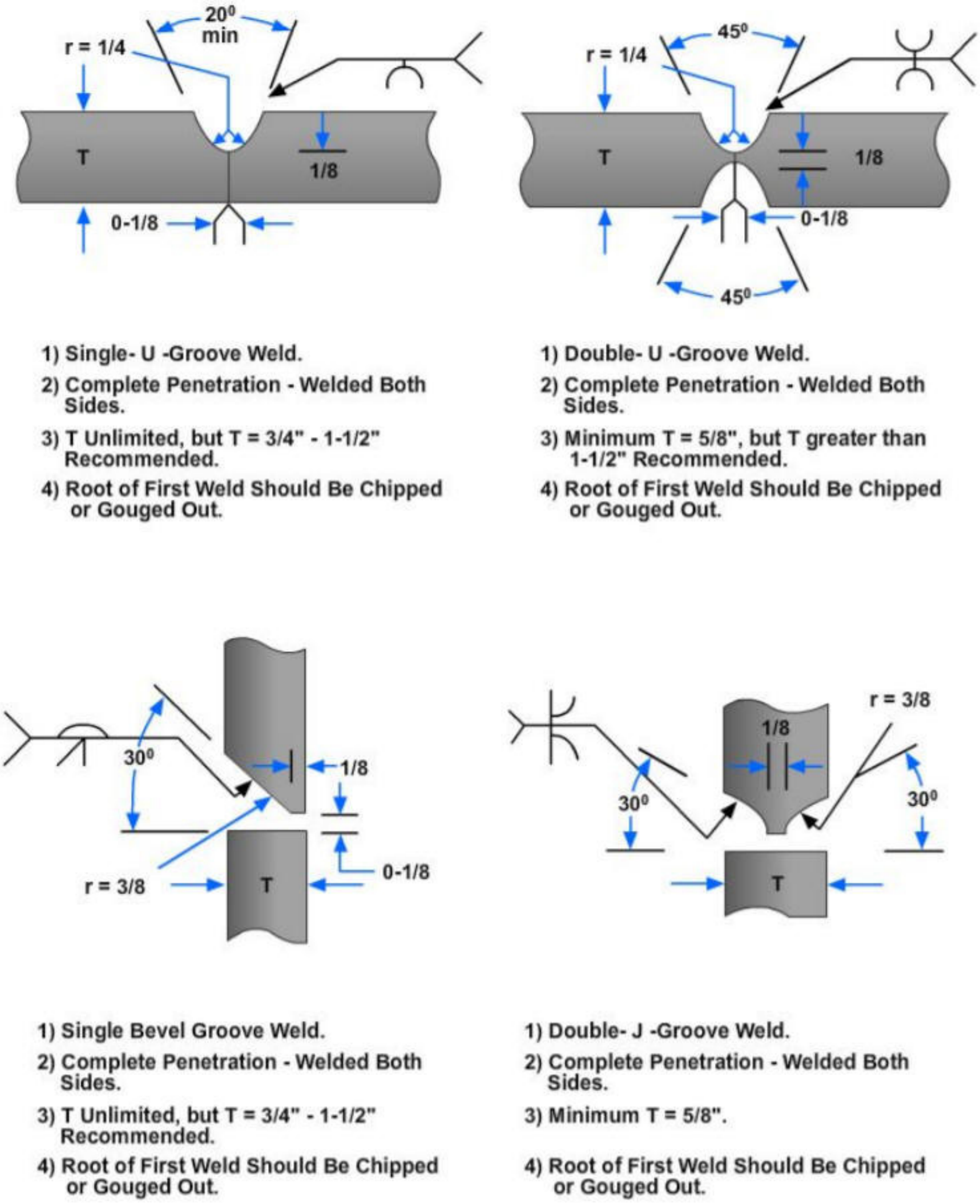
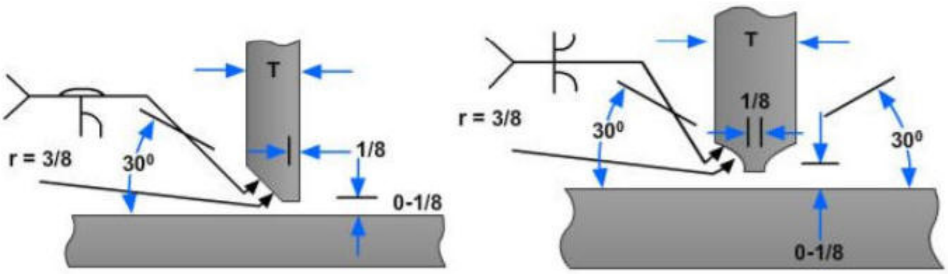
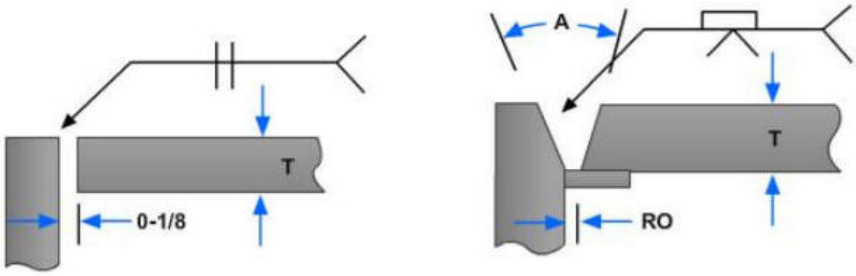


Figure 54 — Welding symbols (cont.).



1) Single-Bevel-Groove Weld.
2) Complete Penetration - Welded Both Sides.
3) T Unlimited. T = 3/4" Up to T = 1-1/2" Recommended.
4) Root of First Weld Should Be Chipped or Gouged Out.

1) Double- J -Groove Weld.
2) Complete Penetration - Welded Both Sides.
3) Minimum T = 5/8", but T Greater than 1-1/2" Recommended.
4) Root of First Weld Should Be Chipped or Gouged Out.

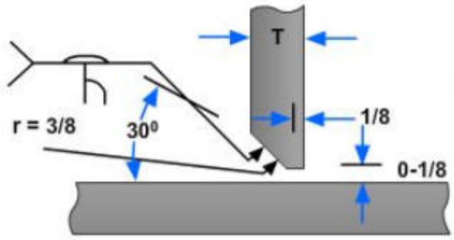


1) Square-Groove-Weld.
2) Complete Penetration - Welded Both Sides.
3) Maximum T = 3/8".
4) Root of First Weld Should Be Chipped or Gouged Out.

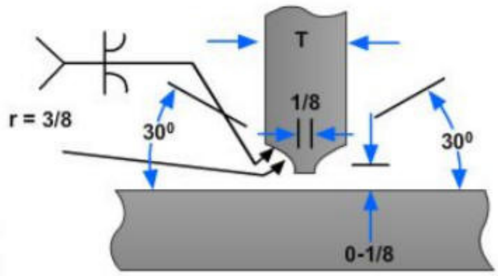
1) Single - V - Groove Weld.
2) Complete Penetration - Welded One Side On Backing Strip.
3) T Unlimited.

RO	A	Positions
3/16	30^0	Flat, Vertical, and Overhead

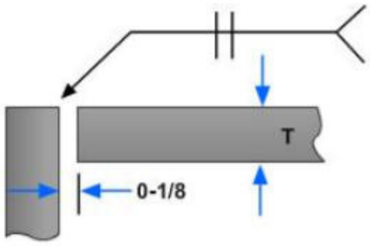
Figure 55 — Welding symbols (cont.).



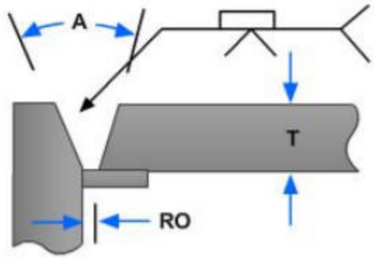
1) Single-Bevel-Groove Weld.
2) Complete Penetration - Welded Both Sides.
3) T Unlimited. T = 3/4" Up to T = 1-1/2" Recommended.
4) Root of First Weld Should Be Chipped or Gouged Out.



1) Double- J -Groove Weld.
2) Complete Penetration - Welded Both Sides.
3) Minimum T = 5/8", but T Greater than 1-1/2" Recommended.
4) Root of First Weld Should Be Chipped or Gouged Out.



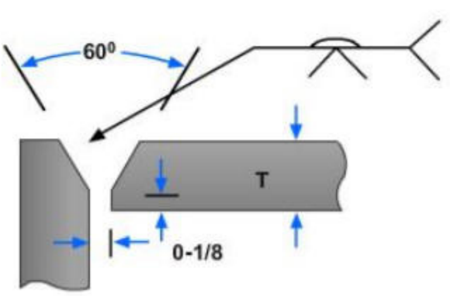
1) Square-Groove-Weld.
2) Complete Penetration - Welded Both Sides.
3) Maximum T = 3/8".
4) Root of First Weld Should Be Chipped or Gouged Out.



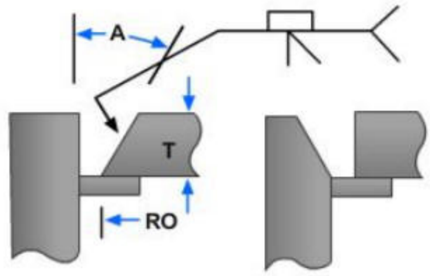
1) Single - V - Groove Weld.
2) Complete Penetration - Welded One Side On Backing Strip.
3) T Unlimited.

RO	A	Positions
3/16	30⁰	Flat, Vertical, and Overhead
1/4	30⁰	Vertical and Overhead
3/8	30⁰	Flat Only
1/2	30⁰	Flat and Overhead

Figure 56 — Welding symbols (cont.).

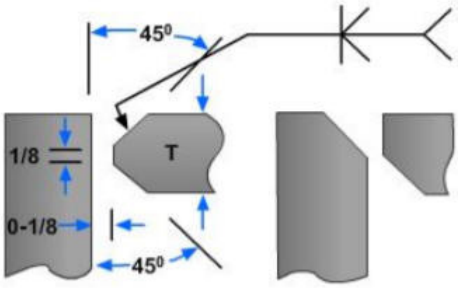


1) Single- V -Groove Weld.
2) Complete Penetration - Welded Both Sides.
3) T Unlimited, T Up to = 3/4" Recommended.
4) Root of First Weld Should Be Chipped or Gouged Out.

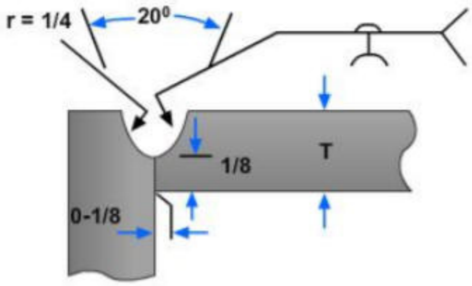


1) Single-Bevel-Groove-Weld.
2) Complete Penetration - Welded One Side on Backing Strip.
3) T Unlimited.

RO	A	Positions
3/16	30⁰	All
1/4	45⁰	All
3/8	30⁰	Flat Only



1) Double-Bevel-Groove Weld.
2) Complete Penetration - Welded Both Sides.
3) Minimum T = 5/8".
4) Root of First Weld Should Be Chipped or Gouged Out.



1) Single - U - Groove Weld.
2) Complete Penetration - Welded Both Sides.
3) Root of First Weld Should Be Chipped or Gouged Out.

Figure 57 — Welding symbols (cont.).

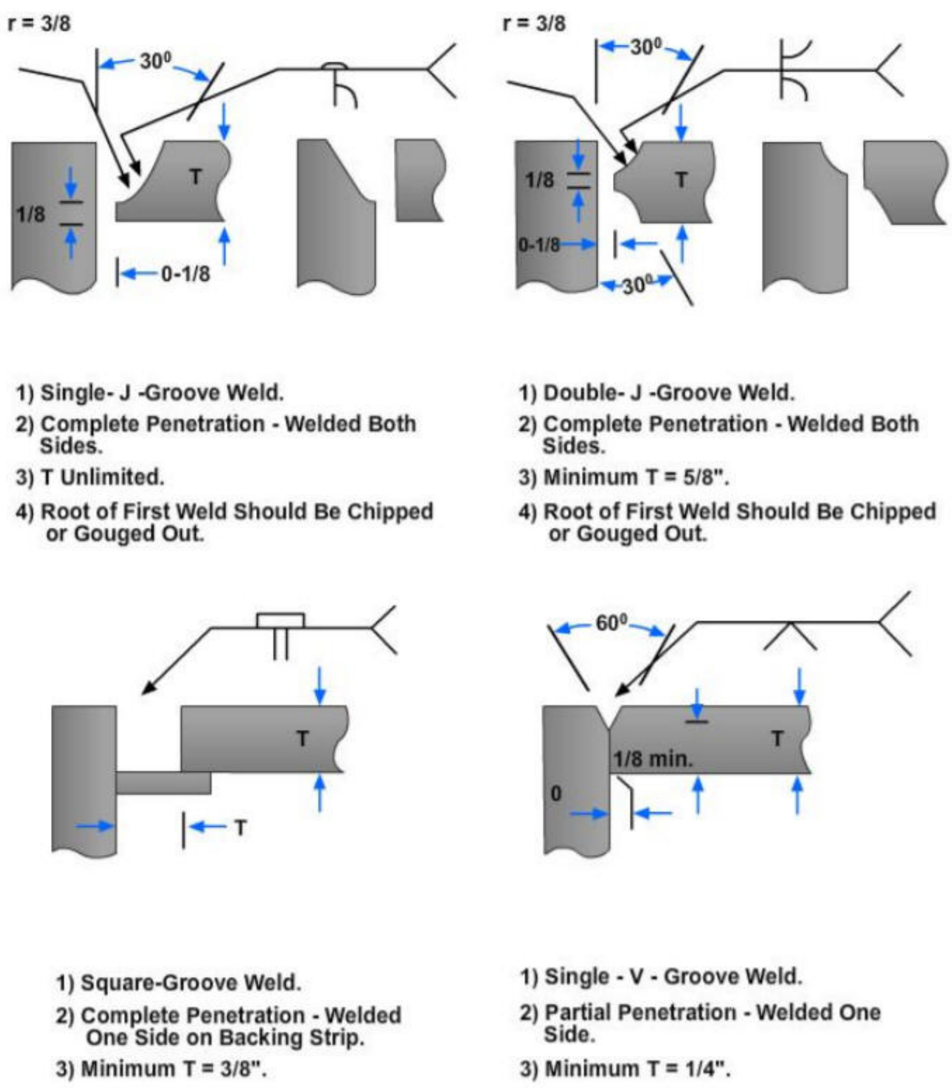


Figure 58 — Welding symbols (cont.).

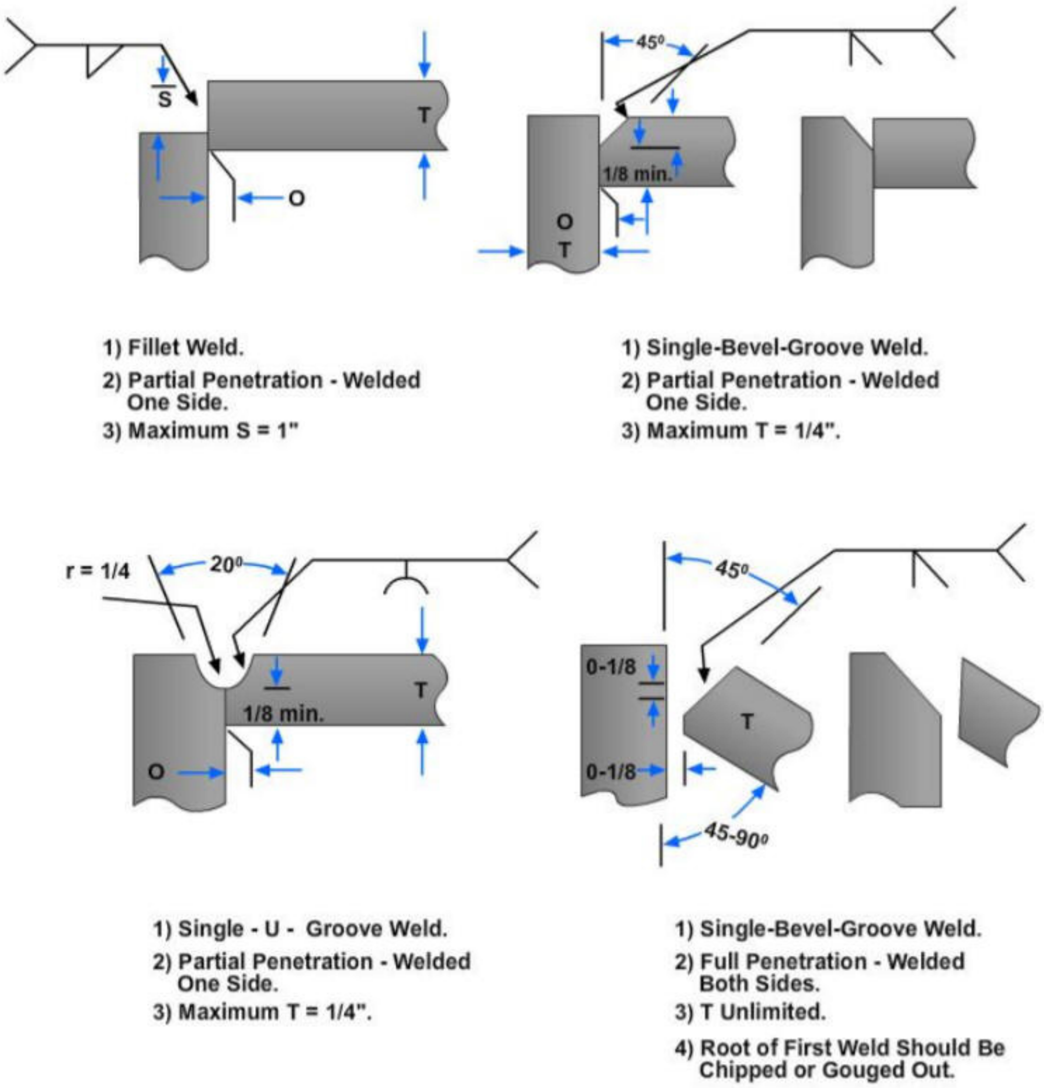


Figure 59 — Welding symbols (cont.).

8.7.0 Welding Positions

In GMAW, the proper position of the welding torch and weldment are important. The position of the torch in relation to the plate is called the work and travel angle. Work and travel angles are shown in Figure 60. If the parts are equal in thickness, the work angle should normally be on the center line of the joint; however, if the pieces are unequal in thickness, the torch should angle toward the thicker piece.

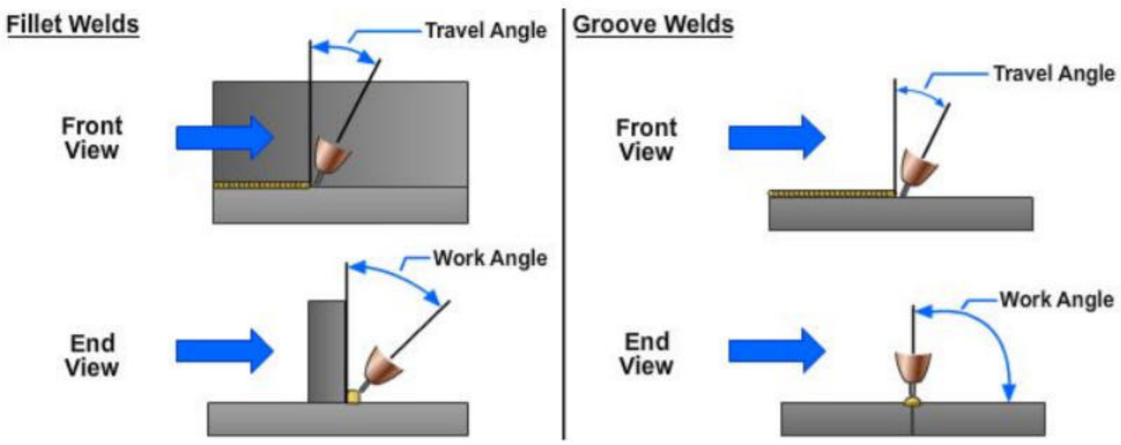


Figure 60 — Travel angle and work angle for GMAW.

The travel angle refers to the angle in which welding takes place. This angle should be between 5 and 25 degrees. The travel angle may be either a push angle or a drag angle, depending on the position of the torch.

When the torch is angled ahead of the weld, it is known as pulling (dragging) the weld or backhand welding. When the torch is angled behind (over) the weld, it is referred to as pushing the metal or forehand welding (Figure 61).

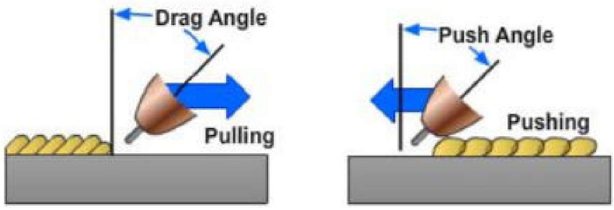


Figure 61 — Pulling and pushing travel angle techniques.

The pulling or drag technique is for heavy-gauge metals. Usually the drag technique produces greater penetration than the pushing technique. Also, since the welder can see the weld crater more easily, better quality welds can consistently be made. The pushing technique is normally used for light-gauge metals. Welds made with this technique are less penetrating and wider because the welding speed is faster.

For the best results, you should position the weldment in the flat position. This position improves the molten metal flow and bead contour, and gives better shielding gas protection.

After you have learned to weld in the flat position, you should be able to use your acquired skill and knowledge to weld out-of-position. These positions include horizontal, vertical-up, vertical-down, and overhead welds. The only difference in welding out-of-position from the flat position is a 10% reduction in amperage.

When welding heavier thicknesses of metal with GMAW, you should use the multi-pass technique (buildup sequence. This is accomplished by overlapping single, small beads or making larger beads, using the weaving technique. Various multi-pass welding sequences are shown in Figure 62. The numbers refer to the sequences in which you make the passes

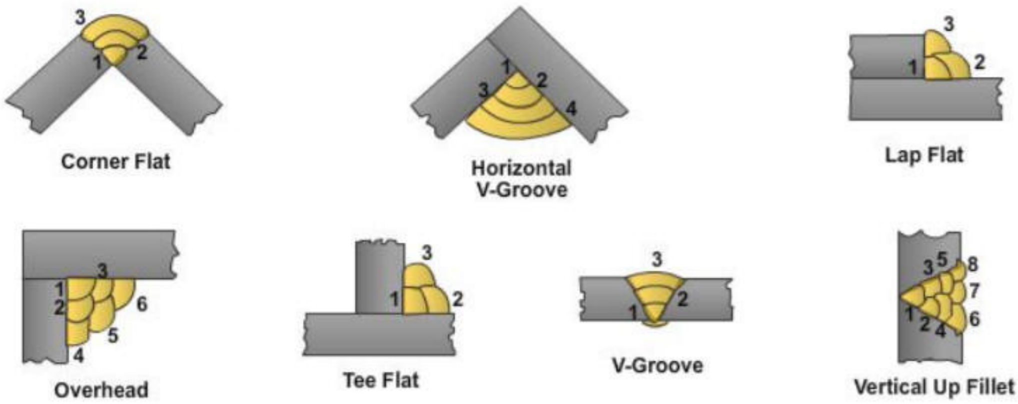


Figure 62 — Multi-pass welding.

8.7.1 Flat-Position Welding

Welding can be done in any position, but it is much simpler when done in the flat position. In this position, the work is less tiring, welding speed is faster, the molten puddle is not as likely to run, and better penetration can be achieved. Whenever possible, try to position the work so you can weld in the flat position. In the flat position, the face of the weld is approximately horizontal.

Butt joints are the primary type of joints used in the flat position of welding; however, flat-position welding can be made on just about any type of joint providing you can rotate the section you are welding to the appropriate position. Techniques that are useful in making butt joints in the flat position, with and without the use of backing strips, are described below.

Butt joints without backing strips — A butt joint is used to join two plates having surfaces in about the same plane. Several forms of butt joints are shown in Figure 63.

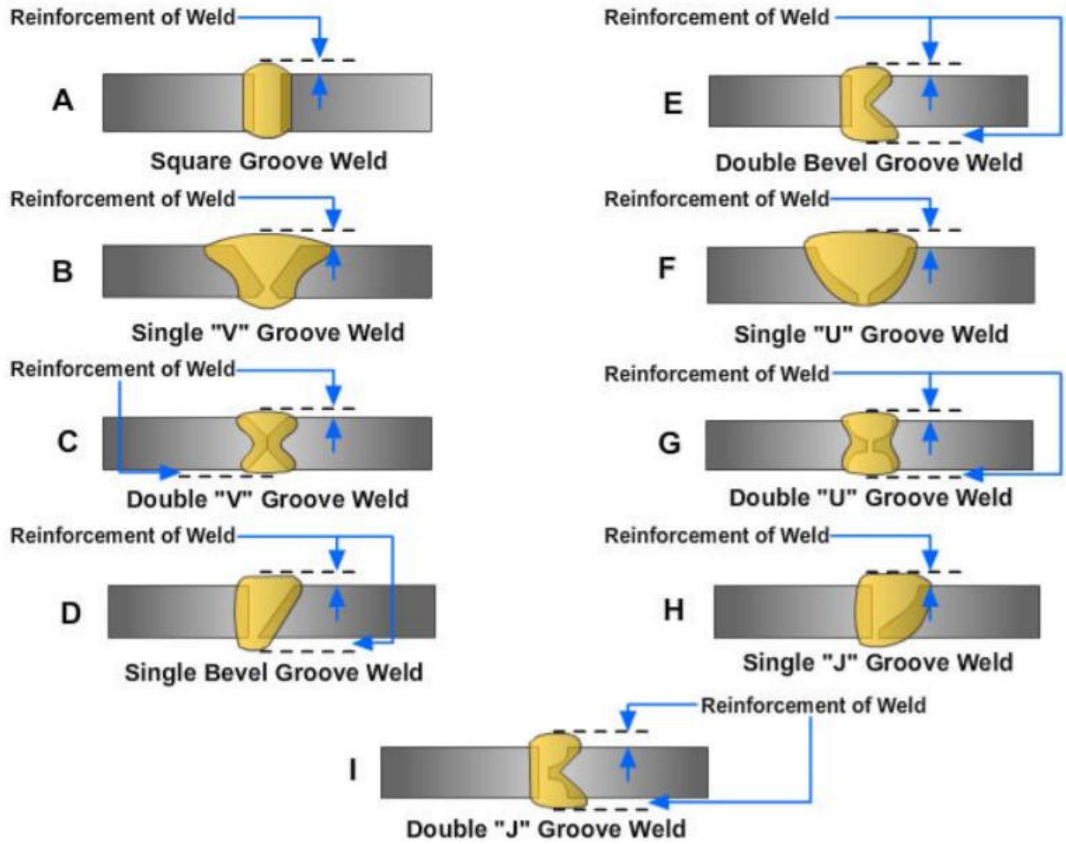


Figure 63 — Butt joints in the flat position.

Plates up to 1/8 in. thick can be welded in one pass with no special edge preparation. Plates from 1/8 to 3/16 in. thick also can be welded with no special edge preparation by welding on both sides of the joint. Tack welds should be used to keep the plates aligned for welding. The gun motion is the same as that used in making a bead weld.

In welding 1/4-in.plate or heavier, you should prepare the edges of the plates by beveling or by J-, U-, or V-grooving, whichever is the most applicable. You should use single or double bevels or grooves when the specifications and/or the plate thickness require it. The first bead is deposited to seal the space between the two plates and to weld the root of the joint. This bead or layer of weld metal must be thoroughly cleaned to remove all slag and dirt before the second layer of metal is deposited.

In making multi-pass welds, the second, third, and fourth layers of weld metal are made with a weaving motion of the gun, as shown in Figure 64.

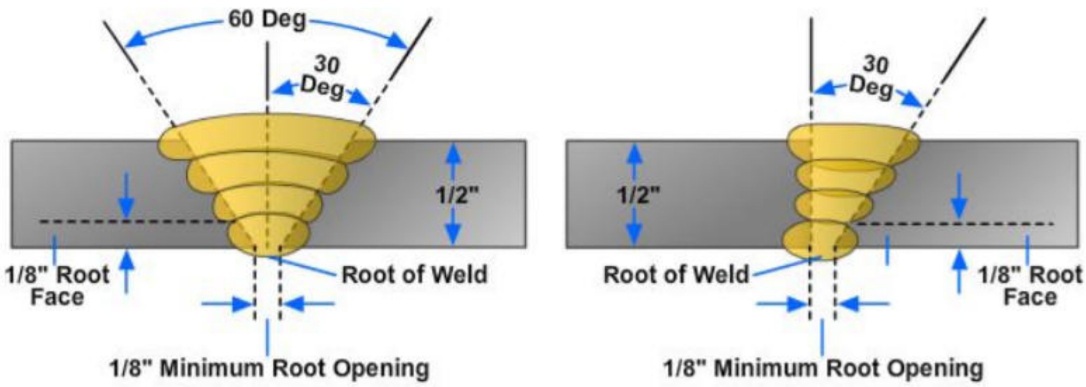


Figure 64 — Butt welds with multi-pass beads.

Clean each layer of metal before laying additional beads. You may use one of the weaving motions shown in Figure 65, depending upon the type of joint.

Figure 65 — Weave motions.

In the weaving motion, oscillate or move the gun uniformly from side to side, with a slight hesitation at the end of each oscillation. Incline the gun 5 to 15 degrees in the direction of welding as in bead welding. When the weaving motion is not done properly, undercutting can occur at the joint, as shown in Figure 66. Excessive welding speed also can cause undercutting and poor fusion at the edges of the weld bead.

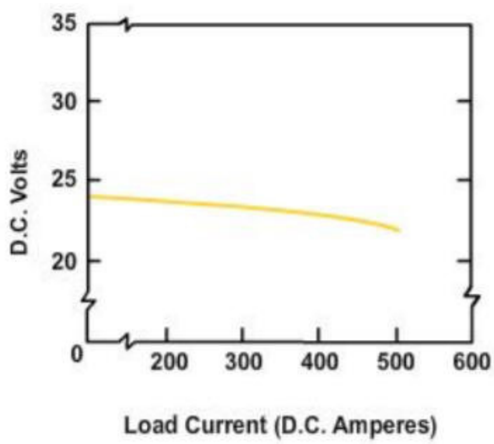


Figure 66 — Undercutting in butt joint welds.

Butt joints with backing strips — Welding 3/16-in. plate or thicker requires backing strips to ensure complete fusion in the weld root pass and to provide better control of the arc and the weld metal. Prepare the edges of the plates in the same manner as required for welding without backing strips.

For plates up to 3/8 in. thick, the backing strips should be approximately 1 in. wide and 3/16 in. thick. For plates more than ½ in. thick, the backing strips should be 1 1/2 in. wide and ¼ in. thick Tack weld the backing strip to the base of the joint, as shown in Figure 67. The backing strip acts as a cushion for the root pass. Complete the joint by welding additional layers of metal. After you complete the joint, the backing strip may be “washed” off or cut away with a cutting torch. When specified, place a seal bead along the root of the joint.

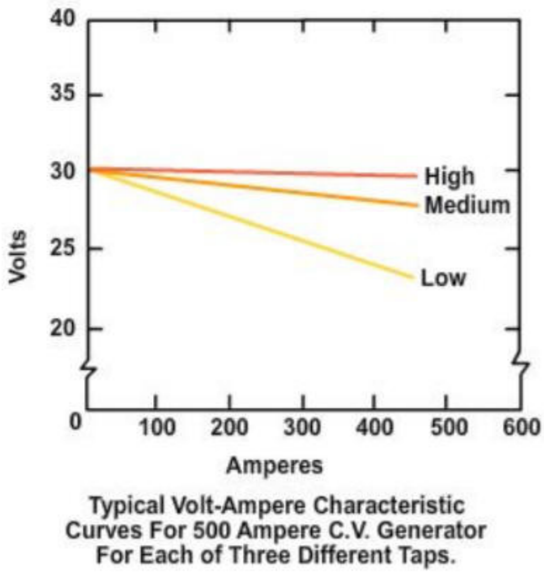
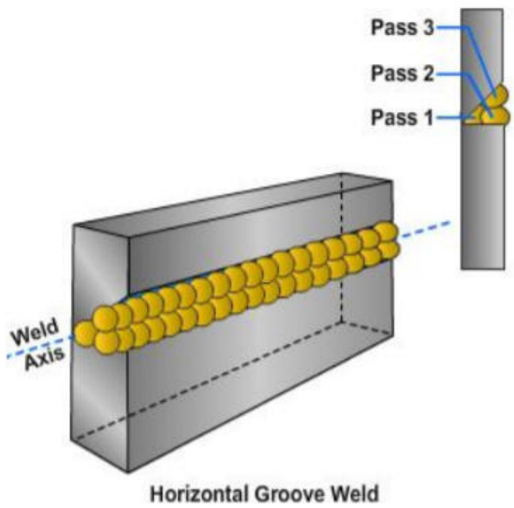


Figure 67 — Use of back strips in welding butt joints.

Bear in mind that many times it will not always be possible to use a backing strip; therefore, the welder must be able to run the root pass and get good penetration without the formation of icicles.

8.7.2 Horizontal-Position Welding

You will discover that it is impossible to weld all pieces in the flat position. Often the work must be done in the horizontal position. The horizontal position has two basic forms, depending upon whether it is used with a groove weld or a fillet weld. In a groove weld, the axis of the weld lies in a relative horizontal plane and the face of the weld is in a vertical plane (Figure 68). In a fillet weld, the welding is performed on the upper side of a relatively horizontal surface and against an approximately vertical plane (Figure 69).



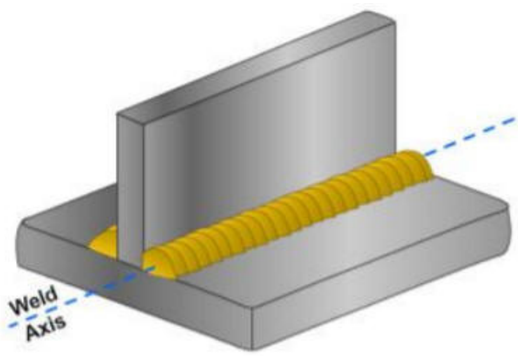
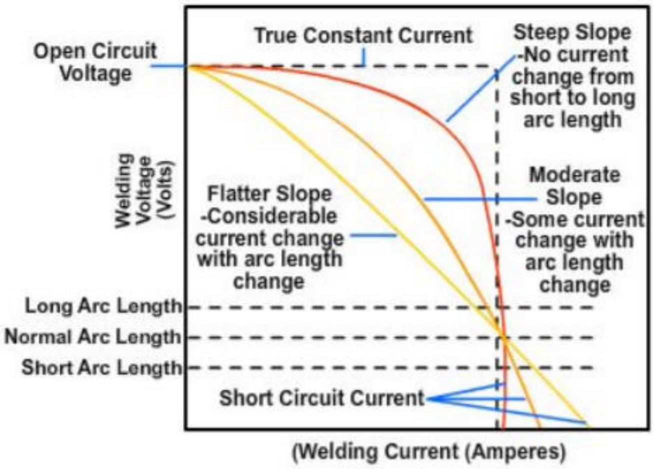


Figure 68 — Horizontal groove weld. ***Figure 69 — Horizontal fillet weld.***

Inexperienced welders usually find the horizontal position of arc welding difficult, at least until they develop a fair degree of skill in applying the proper technique. The primary difficulty is that in this position you have no “shoulder” of previously deposited weld metal to hold the molten metal.

Gun Movement
In horizontal welding, position the gun so points upward at a 5- to 10-degree angle in conjunction with a 20-degree travel angle (Figure 70). Use a narrow weaving motion in laying the bead. This weaving motion distributes the heat evenly, reducing the tendency of the molten puddle to sag. You should use the shortest arc length possible, and when the force of the arc undercuts the plate at the top of the bead, lower the gun a little to increase the upward angle.



10-70 — Horizontal welding angles.

As you move in and out of the crater, pause slightly each time you return. This keeps the crater small and the bead has fewer tendencies to sag.

Joint Type
Horizontal-position welding can be used on most types of joints; the most common are tee, lap j, and butt joints.

Tee joints — When you make tee joints in the horizontal position, the two plates are at right angles to each other in the form of an inverted T. The edge of the vertical plate may be tack welded to the surface of the horizontal plate, as shown in Figure 71.

A fillet weld is used in making the tee joint, and a short arc is necessary to provide good fusion at the root and along the legs of the weld (Figure 72, View A). Hold the gun at an angle of 45 degrees to the two plate surfaces (Figure 72, View B) with an incline of approximately 15 degrees in the direction of welding.

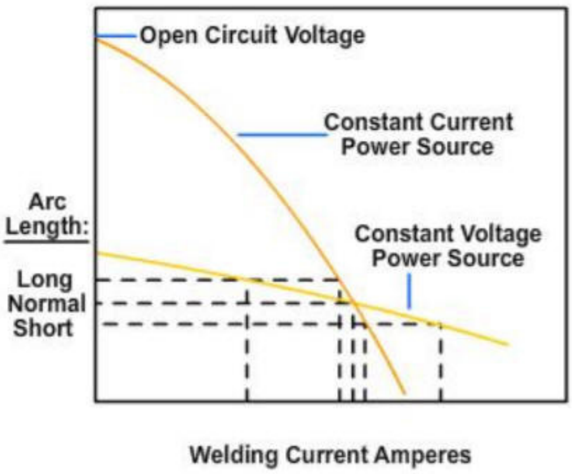


Figure 71 — Tack weld to hold the tee joint elements in place.

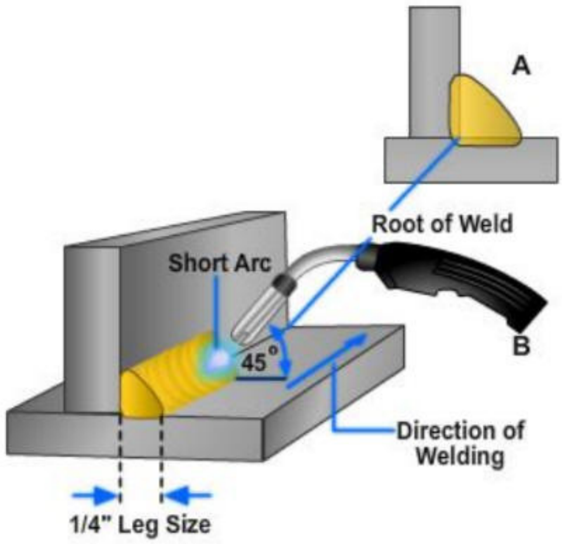


Figure 72 — Position of electrode on a fillet weld.

When practical, weld light plates with a fillet weld in one pass with little or no weaving of the gun. Welding of heavier plates may require two or more passes in which the second pass or layer is made with a semicircular weaving motion, as shown in Figure 73. To ensure good fusion and to prevent undercutting, you should make a slight pause at the end of each weave or oscillation. For fillet-welded tee joints on 1/2-in. plate or heavier, deposit stringer beads in the sequence shown in Figure 74.

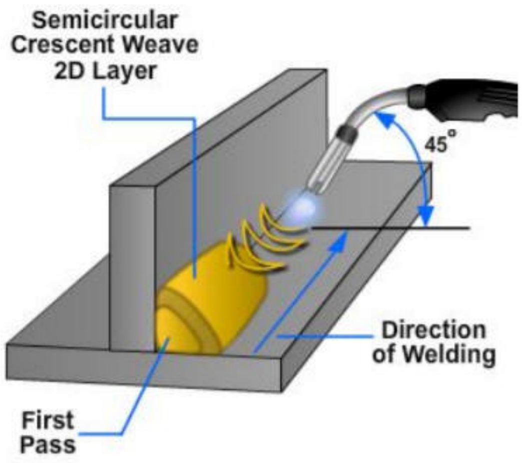


Figure 73 — Weave motion for multipass fillet weld.

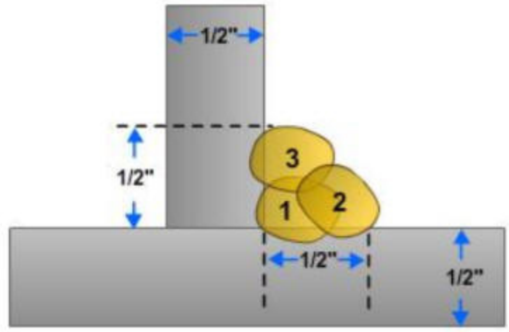
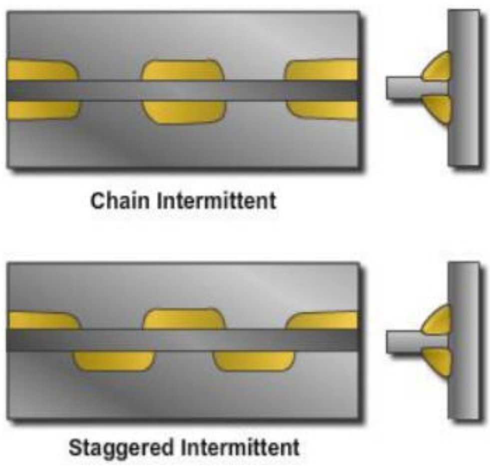


Figure 74 — Order of string beads for tee joint on heavy.

Chain-intermittent or staggered-intermittent fillet welds are used on long tee joints (Figure 75). Fillet welds of these types are for joints where high weld strength is not required; however, the short welds are arranged so the finished joint is equal in strength to that of a joint that has a fillet weld along the entire length of one side. Intermittent welds also have the advantage of reduced warpage and distortion.



10-75 — Intermittent fillet welds.

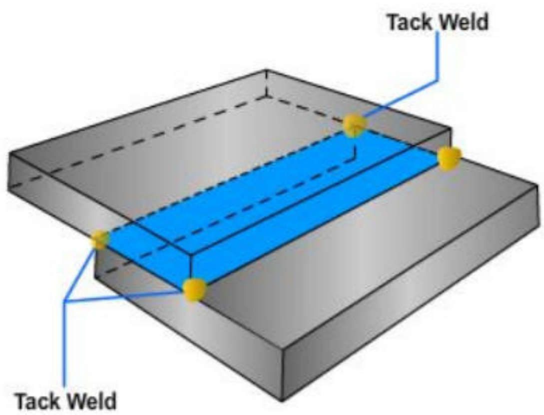


Figure 76 — Tack welding a lap joint.

Lap joints — When you make a lap joint, two overlapping plates are tack welded in place (Figure 76), and a fillet weld is deposited along the joint.

The procedure for making this fillet weld is similar to that used for making fillet welds in tee joints. You should hold the gun so it forms an angle of about 30 degrees from the vertical and is inclined 15 degrees in the direction of welding. The position of the gun in relation to the plates is shown in Figure 77. The weaving motion is the same as that used for tee joints, except that the pause at the edge of the top plate is long enough to ensure good fusion without undercutting. Lap joints on 1/2-in. plate or heavier are made by depositing a sequence of stringer beads, as shown in Figure 77

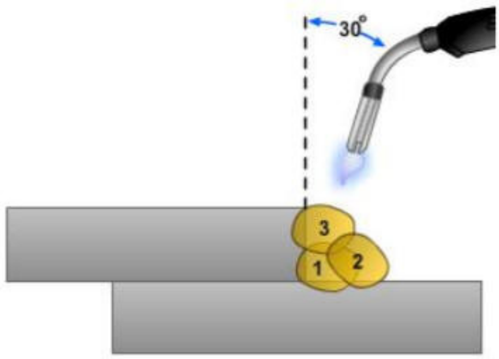


Figure 77 — Position of electrode on a lap joint. motion and ensure that each bead penetrates the base metal.

In making lap joints on plates of different thickness, you should hold the gun so that it forms an angle of between 20 and 30 degrees from the vertical (Figure 78). Be careful not to overheat or undercut the thinner plate edge.

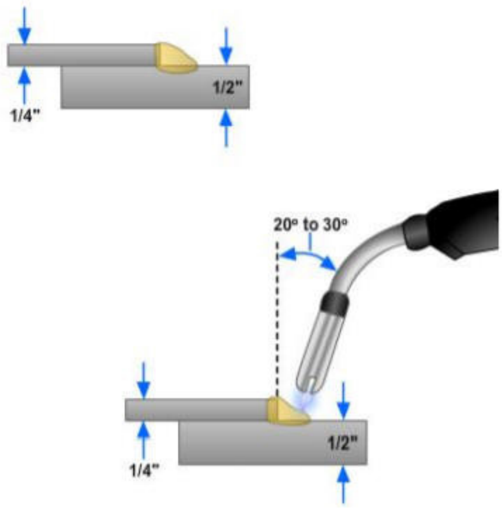


Figure 78 — Lap joints on plates of different thickness.

Butt joints— Most butt joints designed for horizontal welding have the beveled plate positioned on the top. The plate that is not beveled is on the bottom, and the flat edge of this plate provides a shelf for the molten metal so it does not run out of the joint (Figure 79). On other joint designs, both edges are beveled to form a 60-degree included angle. When this type of joint is used, more skill is required because you do not have the retaining shelf to hold the molten puddle.

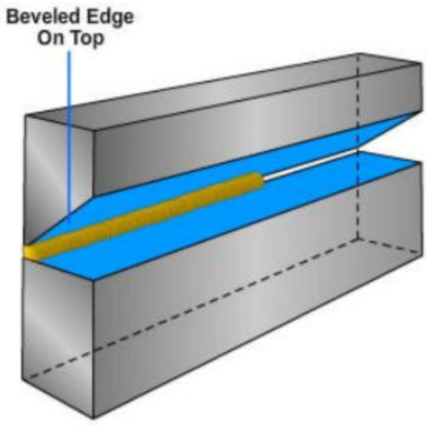


Figure 79 — Horizontal butt joint.

The number of passes required for a joint depends on the diameter of the gun and the thickness of the metal. When multiple passes are required (Figure 80), place the first bead deep in the root of the joint. The gun should be inclined about 5 degrees downward. Clean and remove all slag before applying each following bead. The second bead should be placed with the gun held about 10 degrees upward. For the third pass, hold the gun 10 to 15 degrees downward from the horizontal. Use a slight weaving

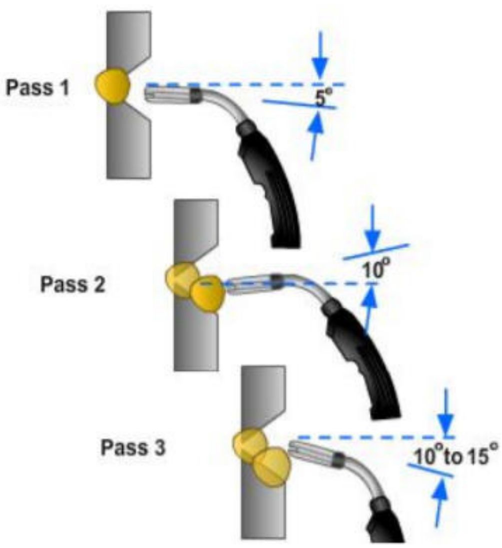


Figure 80 — Multiple passes.

8.7.3 Vertical-Position Welding

A vertical weld is a weld that is applied to a vertical surface or one that is inclined 45 degrees or less (Figure 81). Erecting structures, such as buildings, pontoons, tanks, and pipelines, require welding in this position. Welding on a vertical surface is much more difficult than welding in the flat or horizontal position due to the force of gravity; gravity pulls the molten metal down.

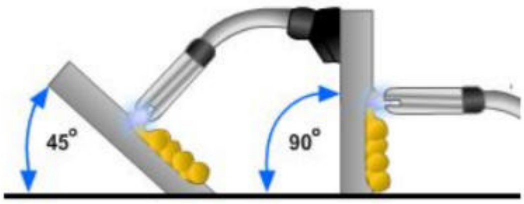


Figure 81 — Vertical weld plate positions.

Vertical welding is done in either an upward or downward position. The terms used for the direction of welding are vertical up or vertical down. Vertical down welding is suited for welding light gauge metal because the penetration is shallow and diminishes the possibility of burning through the metal. Furthermore, vertical down welding is faster, which is very important in production work.

Current Settings and Gun Movement
In vertical arc welding, the current settings should be less than those used for the same gun in the flat position. Another difference is that the current used for welding upward on a vertical plate is slightly higher than the current used for welding downward on the same plate.

To produce good welds, you must maintain the proper angle between the gun and the base metal. In welding upward, you should hold the gun at 90 degrees to the vertical (Figure 82, View A). When weaving is necessary, oscillate the gun as shown in Figure 82, View B.

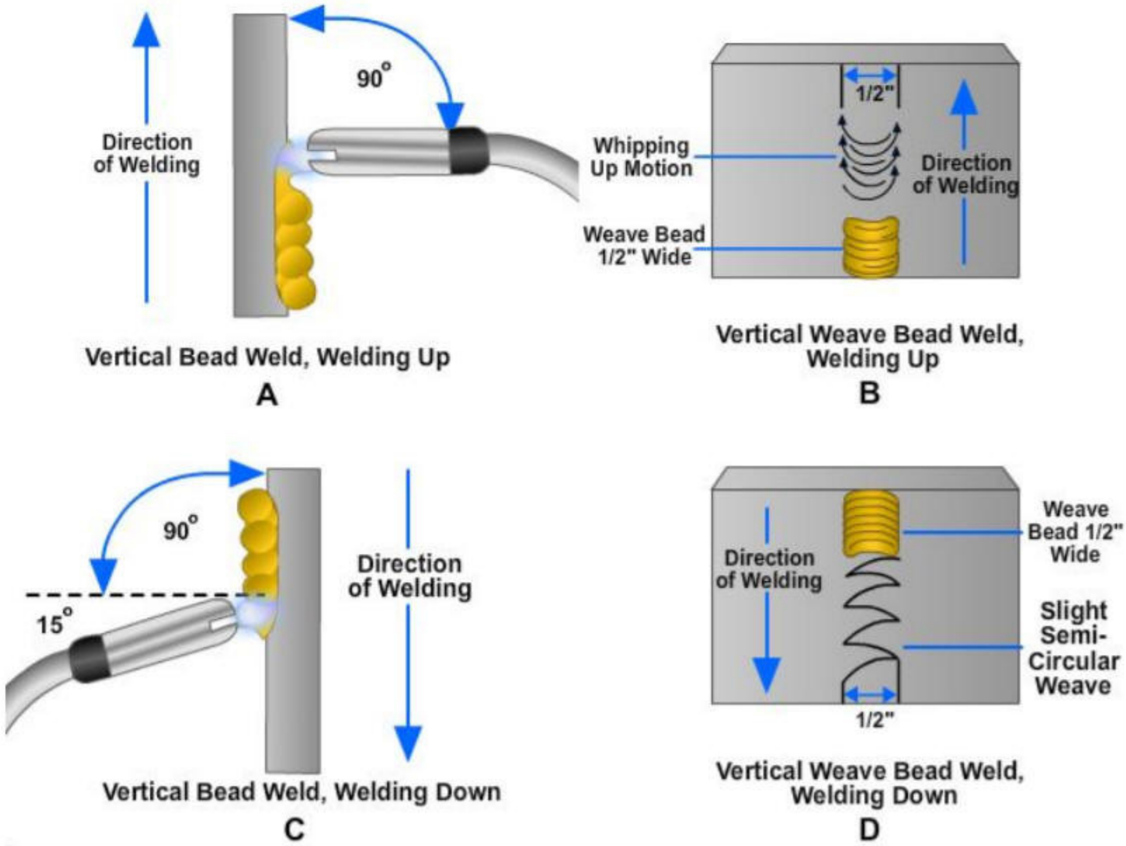


Figure 82 — Bead welds in the vertical position.

In vertical down welding, incline the outer end of the gun downward about 15 degrees from the horizontal while keeping the arc pointing upward toward the deposited molten metal (Figure 82, View C). When vertical down welding requires a weave bead, you should oscillate the gun as shown in Figure 82, View D.

Vertical welding is used on most types of joints. The types of joints you will most often use it on are tee joints, lap joints, and butt joints.

Hold the gun at 90 degrees to the plates or not more than 15 degrees off the horizontal for proper molten metal control when making fillet welds in either tee or lap joints in the vertical position. Keep the arc short to obtain good fusion and penetration.

Tee joints — To weld tee joints in the vertical position, start the joint at the bottom and weld upward. Move the gun in a triangular weaving motion as shown in Figure 83, View A. A slight pause in the weave at the points indicated improves the sidewall penetration and provides good fusion at the root of the joint.

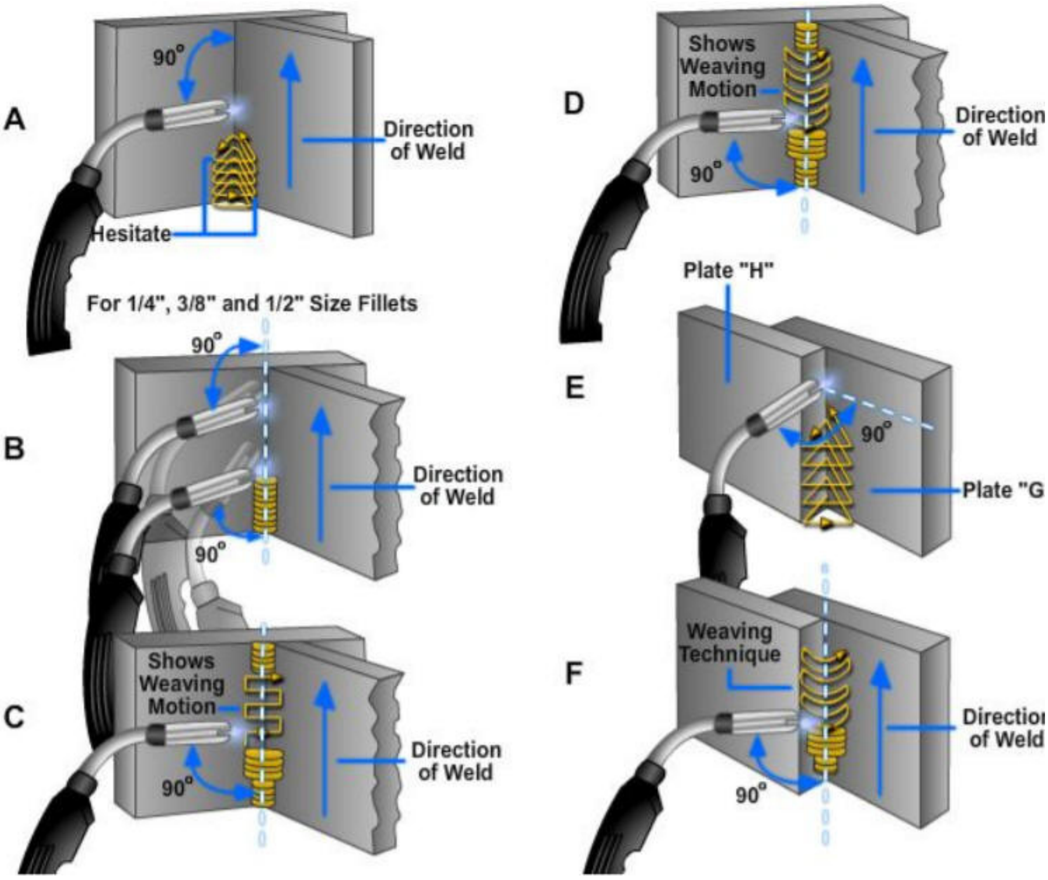


Figure 83 — Fillet welds in the vertical position.

When the weld metal overheats, you should quickly shift the gun away from the crater without breaking the arc, as shown in Figure 83, View B. This permits the molten metal to solidify without running downward. Return the gun immediately to the crater of the weld in order to maintain the desired size of the weld.

When more than one pass is necessary to make a tee weld, you may use either of the weaving motions shown in Figure 83, Views C and D. A slight pause at the end of the weave will ensure fusion without undercutting the edges of the plates.

Lap joints — To make welds on lap joints in the vertical position, you should move the gun in a triangular weaving motion, as shown in Figure 83, View E). Use the same procedure, as outlined above for the tee joint, except direct the gun more toward the vertical plate marked G. Hold the arc short, and pause slightly at the surface of plate G. Try not to undercut either of the plates or to allow the molten metal to overlap at the edges of the weave. Lap joints on heavier plate may require more than one bead. If it does, clean the initial bead thoroughly and place all subsequent beads as shown in Figure 83, View F.

The precautions to ensure good fusion and uniform weld deposits that were previously outlined for tee joints also apply to lap joints.

Butt joints — Prepare the plates used in vertical welding identically to those prepared for welding in the flat position. To obtain good fusion and penetration with no undercutting, you should hold a short arc and carefully control its motion.

Butt joints on beveled plates ¼ in. thick can be welded in one pass by using a triangular weave motion, as shown in Figure 84, View A. Welds made on 1/2-in. plate or heavier should be done in several passes, as shown in Figure 84, View B. Deposit the last pass with a semicircular weaving motion with a slight “whip-up” and pause of the gun at the edge of the bead. This produces a good cover pass with no undercutting. Welds made on plates with a backup strip should be done in the same manner.

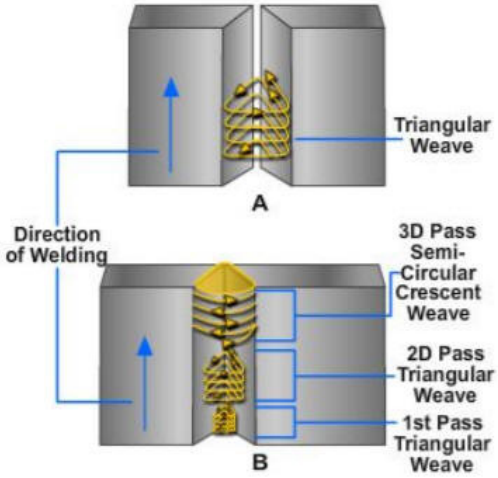


Figure 84 — Butt joint welding in the vertical position.

8.7.4 Overhead-Position Welding

Overhead welding is the most difficult position in welding. Not only do you have to contend with the force of gravity, but the majority of the time you also have to assume an awkward stance. Nevertheless, with practice it is possible to make welds equal to those made in the other positions.

Current Settings and Gun Movement
To retain complete control of the molten puddle, use a very short arc and reduce the amperage as recommended. As in the vertical position of welding, gravity causes the molten metal to drop or sag from the plate. When too long an arc is held, the transfer of metal from the gun to the base metal becomes increasingly difficult, increasing the chances of large globules of molten metal dropping from the gun. When you routinely shorten and lengthen the arc, dropping molten metal can be prevented; however, you will defeat your purpose should you carry too large a pool of molten metal in the weld.

One of the problems encountered in overhead welding is the weight of the cable. To reduce arm and wrist fatigue, drape the cable over your shoulder when welding in the standing position. When sitting, place the cable over your knee. With experience, cable placement will become second nature.

Warning

Because of the possibility of falling molten metal, use a protective garment that has a tight fitting collar that buttons or zips up to the neck. Roll down your sleeves and wear a cap and appropriate shoes.

Type of Welds
Techniques used in making bead welds, butt joints, and fillet welds in the overhead position are discussed in the following paragraphs.

Bead welds — For bead welds, the work angle of the gun is 90 degrees to the base metal (Figure 85, View A). The travel angle should be 10 to 15 degrees in the direction of welding (Figure 85, View B).

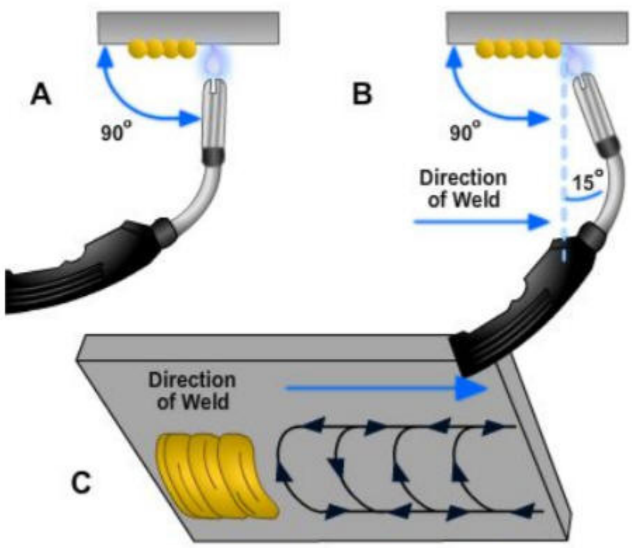


Figure 85 — Position of electrode and weave motion in the overhead position.

Weave beads can be made by using the motion shown in Figure 85, View C. A rather rapid motion is necessary at the end of each semicircular weave to control the molten metal deposit. Avoid excessive weaving because this can cause overheating of the weld deposit and the formation of a large, uncontrollable pool.

Butt Joint — Prepare the plates for overhead butt welding in the same manner as required for the flat position. The best results are obtained when backing strips are used; however, you must remember that you will not always be able to use a backing strip. When you bevel the plates with a featheredge and do not use a backing strip, the weld will repeatedly burn through unless you take extreme care.

For overhead butt welding, bead welds are preferred over weave welds. Clean each bead and chip out the rough areas before placing the next pass. The gun position and the order of deposition of the weld beads when welding on 1/4- or 1/2-in. plate are shown in Figure 86, Views B and C. Make the first pass with the gun held at 90 degrees to the plate, as shown in Figure 86, View A. When you use a gun that is too large, you cannot hold a short arc in the root area. This results in insufficient root penetration and inferior joints.

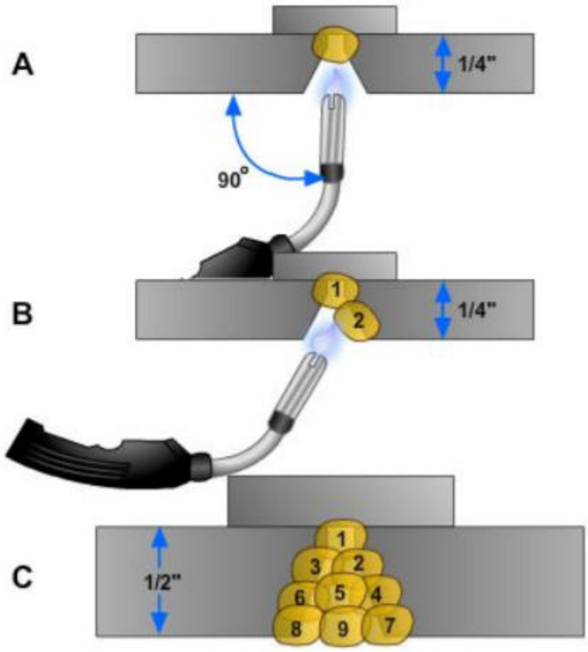


Figure 86 — Multi-pass butt joint in the overhead position.

Fillet welds — In making fillet welds in either tee or lap joints in the overhead position, maintain a short arc and refrain from weaving the gun. Hold the gun at approximately 30 degrees to the vertical plate and move it uniformly in the direction of welding, as shown in Figure 87, View B. Control the arc motion to secure good penetration in the root of the weld and good fusion with the sidewalls of the vertical and horizontal plates. When the molten metal becomes too fluid and tends to sag, whip the gun quickly away from the crater and ahead of the weld to lengthen the arc and allow the metal to solidify. Immediately return the gun to the crater and continue welding.

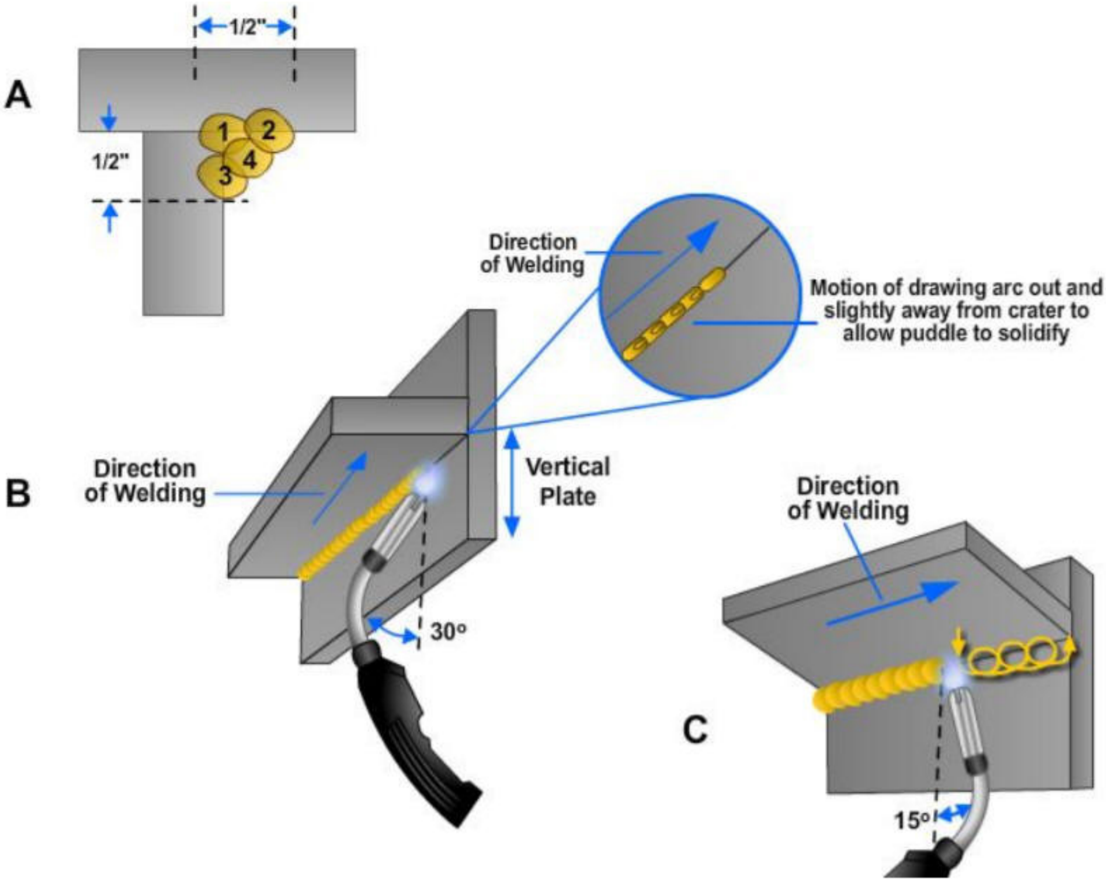


Figure 87 — Fillet welds in the overhead position.

Overhead fillet welds for either tee or lap joints on heavy plate require several passes or beads to complete the joint. One example of an order of bead deposition is shown in Figure 87, View A. The root pass is a string bead made with no weaving motion of the gun. Tilt the gun about 15 degrees in the direction of welding, as shown in Figure 87, View C, and with a slight circular motion make the second, third, and fourth pass.

This motion of the gun permits greater control and better distribution of the weld metal. Remove all slag and oxides from the surface of each pass by chipping or wire brushing before applying additional beads to the joint.

Welding is the simplest and easiest way to join sections of pipe. The need for complicated joint designs and special threading equipment is eliminated. Welded pipe has less flow restriction when compared to mechanical connections and the overall installation costs are less. The most popular method for welding pipe is the shielded metal arc process; however, gas shielded arc methods (GMAW, GTAW) have made big inroads as a result of new advances in welding technology.

Pipe welding has become recognized as a profession in itself. Even though many of the skills are comparable to other types of welding, pipe welders develop skills that are unique only to pipe welding. Because of the hazardous materials that most pipelines carry, pipe welders are required to pass specific tests before they can be certified

The following paragraphs discuss pipe welding positions, pipe welding procedures, definitions, and related information.

You may recall from Figure 46, there are four positions used in pipe welding. The American Welding Society's (AWS) welding positions for pipe are the horizontal rolled position (1G), the horizontal fixed position (5G), the pipe inclined fixed (6G), and the vertical position (2G). Remember, these terms refer to the position of the pipe and not to the weld.

Pipe Welding Procedures

Welds you cannot make in a single pass should be made in interlocked multiple layers, not less than one layer for each 1/8 inch of pipe thickness. Deposit each layer with a weaving or oscillating motion. To prevent entrapping slag in the weld metal, you should clean each layer thoroughly before depositing the next layer.

Butt joints are commonly used between pipes and between pipes and welded fittings. They are also used for butt welding flanges and welding stubs. In making a butt joint, place two pieces of pipe end to end, align them, and then weld them. (Figure 88)

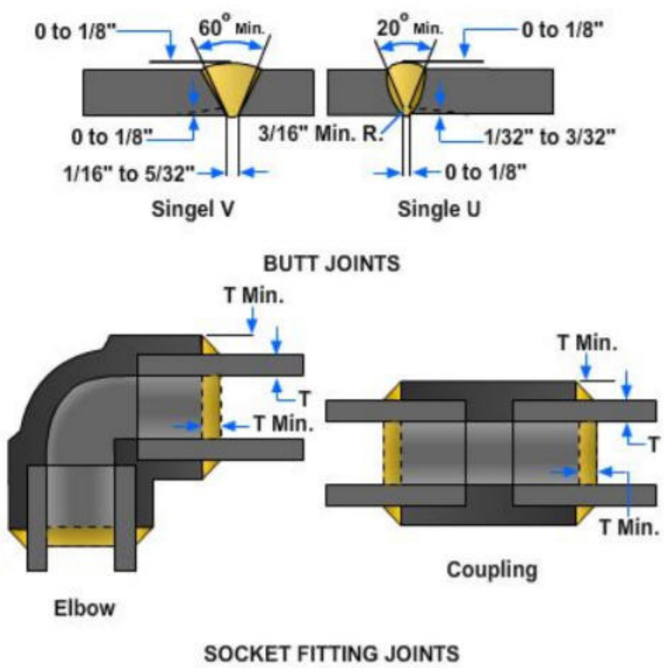


Figure 88 — Butt joints and socket fitting joints.

When the wall thickness of the pipe is ¾ in. or less, you can use either the single V or single U type of butt joint; however, when the wall thickness is more than ¾ in., only the single U type should be used.

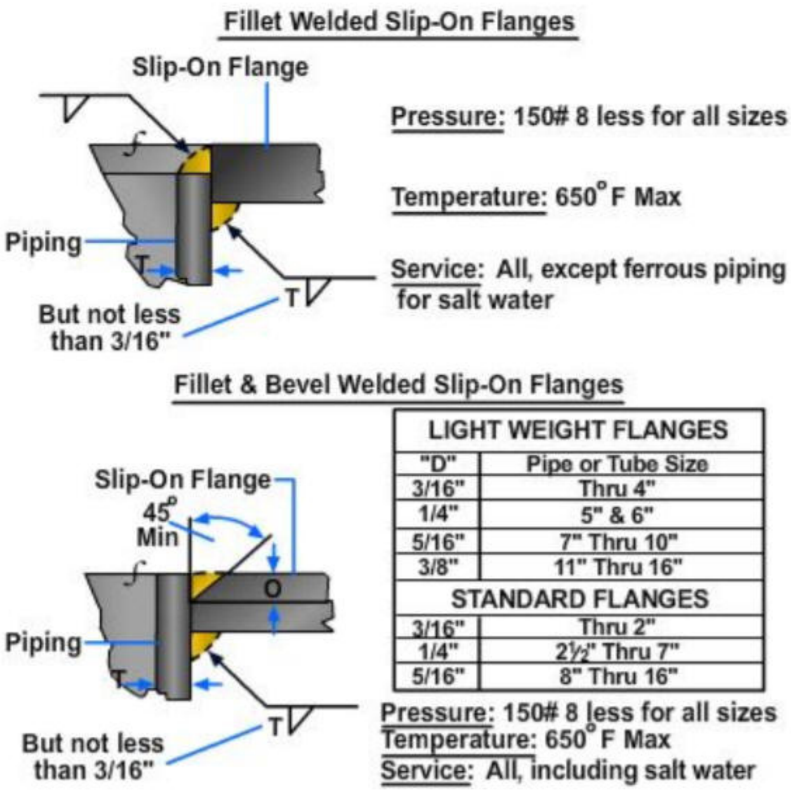


Figure 89 — Flange connections.

Fillet welds are used for welding slip-on and threaded flanges to pipe. Depending on the flange and type of service, fillet welds may be required on both sides of the flange or in combination with a bevel weld (Figure 89). Fillet welds are also used in welding screw or socket couplings to pipe, using a single fillet weld (Figure 87). Sometimes flanges require alignment. Figure 90 shows one type of flange square and its use in vertical and horizontal alignment.

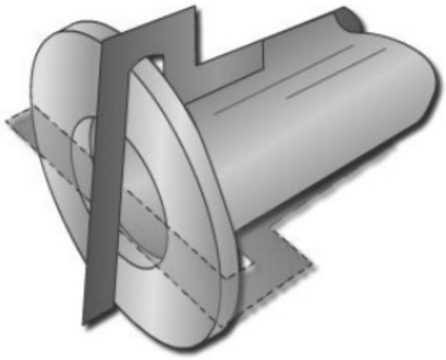


Figure 90 — Flange alignment.

Another form of fillet weld used in pipe fitting is a seal weld. A seal weld is used primarily to obtain tightness and prevent leakage. Seal welds should not be considered as adding strength to the joint.

Joint Preparation and Fitup

You must carefully prepare pipe joints for welding if you want good results. Clean the weld edges or surfaces of all loose scale, slag, rust, paint, oil, and other foreign matter. Ensure that the joint surfaces are smooth and uniform. Remove the slag from flamecut edges; however, it is not necessary to remove the temper color.

When you prepare joints for welding, remember that bevels must be cut accurately. Bevels can be made by machining, grinding, or using a gas cutting torch. In fieldwork, the welding operator usually must make the bevel cuts with a gas torch. When you are beveling, cut away as little metal as possible to allow for complete fusion and penetration. Proper beveling reduces the amount of filler metal required, which in turn reduces time and expense. In addition, it also means less strain in the weld and a better job of design and welding.

Align the piping before welding and maintain it in alignment during the welding operation. The maximum alignment tolerance is 20% of the pipe thickness. To ensure proper initial alignment, you should use clamps or jigs as holding devices. A piece of angle iron makes a good jig for a small-diameter pipe (Figure 91), while a section of channel or I-beam is more suitable for larger diameter pipe.

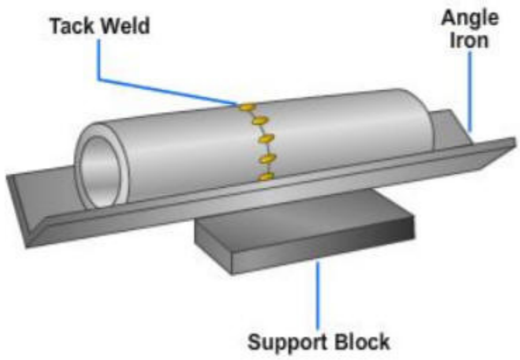


Figure 91 — Angle iron jig.

Tack Welding

When welding material solidly, you may use tack welds to hold it in place temporarily. Tack welding is one of the most important steps in pipe welding or any other type of welding. The number of tack welds required depends upon the diameter of the pipe. For 1/2-in. pipe, you need two tacks; place them directly opposite each other. As a rule, four tacks are adequate for standard size of pipe. The size of a tack weld is determined by the wall thickness of the pipe. Be sure that a tack weld is not more than twice the pipe thickness in length or two thirds of the pipe thickness in depth. Tack welds should be the same quality as the final weld. Ensure that the tack welds have good fusion and are thoroughly cleaned before proceeding with the weld.

Spacers

In addition to tack welds, spacers sometimes are required to maintain proper joint alignment. Spacers are accurately machined pieces of metal that conform to the dimensions of the joint design used. Spacers are sometimes referred to as chill rings or backing rings, and they serve a number of purposes. For example, they provide a means for maintaining the specified root opening, provide a convenient location for tack welds, and aid in the pipe alignment. In addition, spacers can prevent weld spatter and the formation of slag or icicles inside the pipe.

Weather Conditions

Do not assign a welder to a job under any of the following conditions listed below unless the welder and the work area are properly protected:

- When the atmospheric temperature is less than 0°F
- When the surfaces are wet

- When rain or snow is falling, or moisture is condensing on the weld surfaces
- During periods of high wind Before beginning to weld at temperatures between 0°F and 32°F, heat the weld area within 3 inches of the joint with a torch to a temperature warm to the hand.

Test Your Knowledge

11. How many basic types of weld joints are there?

A. 4
B. 5
C. 6
D. 8

12. Which type of weld is used for welding slip-on and threaded flanges to pipe?

A. Fillet
B. Bead
C. Butt
D. Tee

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9.0.0 WELDING PROCEDURE VARIABLES

Welding procedure variables control the welding process and the quality of the welds produced. The selection of the welding variables is done after the base metal, filler metal, and joint design are selected. A proper selection of welding variables will make the welding easier for the welder, increasing the chances of producing the weld properties required. The three major types of welding variables are fixed or preselected, primary adjustable, and secondary adjustable.

The fixed or preselected variables are those that are set before the welding takes place. These are items such as the electrode size, type of shielding gas, and shielding gas flow rate. Preselected variables are set according to the type of metal being welded, metal thickness, welding position, deposition rate required, and mechanical properties required. These are variables that cannot be easily changed once the welding starts.

The primary adjustable variables are the major variables used to control the welding process after the fixed variables have been selected. They control the formation of the weld bead by affecting items such as bead width, bead height, depth of penetration, arc stability, and weld soundness. The primary adjustable variables for gas metal arc welding are the welding current, welding voltage, and travel speed. These are the best controls over welding because they are easily measured and can be continually adjusted over a wide range.

The secondary adjustable variables are the minor variables that can be continually changed and used to control the welding process. These variables are often more difficult to measure or the effects of them may not be as obvious. In many cases, they do not directly affect the bead formation, but they may cause a change in a primary variable, which in turn causes a change in bead formation. The secondary variables are items such as the electrode extension and the travel angles.

The different variables affect the characteristics of the weld, such as the penetration of the weld, bead height and bead width, and the deposition rate. The definitions of bead height, bead width, and penetration are shown in Figure 92. The penetration of the weld is defined as the greatest depth below the surface of the base metal or previous weld bead that the weld metal reaches. The bead height is the height of the weld metal above the surface of the base metal. The bead width is the width of the weld bead. The deposition rate is the weight of metal that is deposited per unit of time.

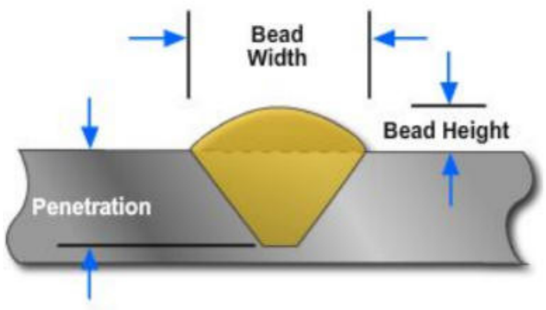

Figure 92 — Bead height, width, and penetration.

The welding variables are discussed with particular attention to the three major characteristics of penetration, deposition rate, and bead shape. Table 20 shows the effects of welding variables on the three major characteristics.

Table 20 — Recommended welding variable adjustments for GMAW.

Change Required	Welding Variable	Arc Voltage	Welding Current (See footnote)	Travel Speed	Nozzle Angle	Stick-out or Tip to Work Distance	Wire Size	Gas Type
Deeper Penetration			[1] Increase		[3] Trailing Max. 25°	[2] Decrease	[5] Smaller	[4] CO2
Shallower Penetration			[1] Decrease		[3] Leading	[2] Increase	[5] Larger	[4] Ar+CO2 [c]
Bead Height	Larger Bead		[1] Increase	[2] Decrease		[3] Increase		
	Smaller Bead		[1] Decrease	[2] Increase	[2] Trailing Max. 25°	[3] Decrease		
Bead Width	Higher Narrower Bead	[1] Decrease			[2] 90° or Leading	[3] Increase		
	Flatter Wider Bead	[1] Increase				[3] Decrease		
Faster Deposition Rate			[1] Increase			[2] Increase	[3] Smaller [b]	
Slower Disposition Rate			[1] Decrease			[2] Decrease	[3] Larger [b]	

FOOTNOTE SAME ADJUSTMENT IS REQUIRED FOR WIRE FEED SPEED. KEY 1 FIRST CHOICE, 2 SECOND CHOICE, 3 THIRD CHOICE. 4 FOURTH CHOICE, 5 FIFTH CHOICE.

a WHEN THESE VARIABLES ARE CHANGED, THE WIRE FEED SPEED MUST BE ADJUSTED SO THAT THE WELDING CURRENT REMAINS CONSTANT.
b SEE DEPOSITION RATE SECTION OF WELDING VARIABLES SECTION.
c THIS CHANGE IS ESPECIALLY HELPFUL ON MATERIALS 20 GAGE AND SMALLER IN THICKNESS.

9.1.0 Fixed Variables

The size of the electrode and the type of shielding gas used are fixed variables.

9.1.1 Electrode Size

Each electrode wire diameter of a given chemical composition has a usable welding current range. Larger diameter electrodes use higher current levels and produce higher deposition rates and deeper penetration. The rate at which the electrode melts is a function of the current density. If two electrode wires of different diameters are operated at the same current level, the smaller one will give a higher deposition rate because the heat is more concentrated. Figure 93 shows deposition rates produced by different diameters of electrode wires. The penetration is also a function of the current density. A smaller electrode wire will produce deeper penetration than a larger diameter wire at the same current setting. The weld bead will be wider when using the larger electrode wire. The choice of the size of the electrode wire to be used is dependent on the thickness of the metal being welded, the amount of penetration required, the deposition rate desired, the bead profile desired, the position of welding, and the cost of the different electrode wires. A smaller electrode wire is more costly on a weight basis, but for each application there is a wire size that will produce minimum welding costs.

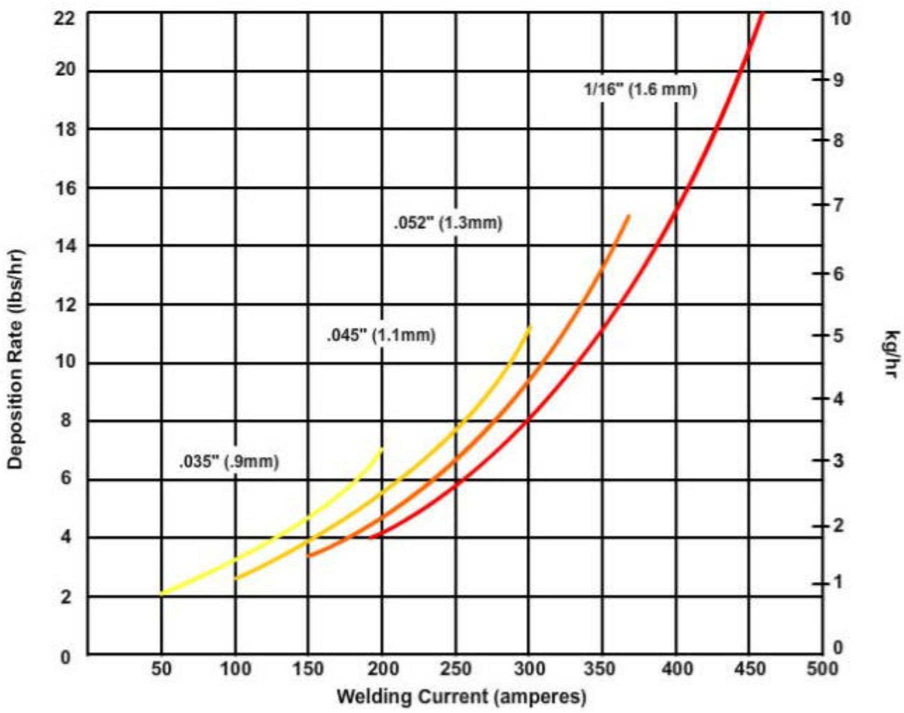

Figure 93 — Deposition rates of different sizes of electrode wires using CO_2.

9.1.2 Type of Shielding Gas

The different shielding gases used in gas metal arc welding each have their own penetration, bead shape, and deposition rate characteristics. The choice of shielding gas will also have an effect on the amount of smoke, gases, and spatter produced, the welding speed used, the mechanical properties obtained, and the type of metal transfer.

For welding ferrous metals, carbon dioxide, argon-carbon dioxide, and argon-oxygen mixtures are used most widely. Carbon dioxide shielding gas produces the highest electrode burn-off rates, greatest depth of penetration, widest weld bead, and most convex weld bead for a given current level. Carbon dioxide is the least expensive but produces the most spatter and smoke. Because of the high heat input, faster travel speeds may be used. Argon or argon-oxygen mixtures are the opposite of carbon dioxide. These gases will give the lowest electrode burn-off rates, the least penetration, and the narrowest, flattest weld bead for a given current level. Argon or argon-oxygen mixtures produce the least amount of smoke and spatter. Argon-carbon dioxide mixtures have characteristics in between carbon dioxide and argon-oxygen mixtures. Figure 94 shows the bead profile and penetration characteristics of carbon dioxide, argon-carbon dioxide mixtures, and argon-oxygen mixtures.

For welding the non-ferrous metals, the most commonly used shielding gases are argon, argon helium mixtures, and helium. Argon produces the least amount of penetration and lowest electrode burn-off rates. It also produces the narrowest and flattest weld bead. Argon is the least expensive of the three types and produces the least spatter. Helium produces the most penetration, higher electrode burn-off rates, and the widest and most convex weld bead. Helium causes higher voltages for a given arc length, is more expensive, and requires higher flow rates than argon. Argon-helium mixtures have characteristics between argon and helium. Figure 94 also shows the weld bead profile characteristics of argon, argon-helium mixtures, and helium.

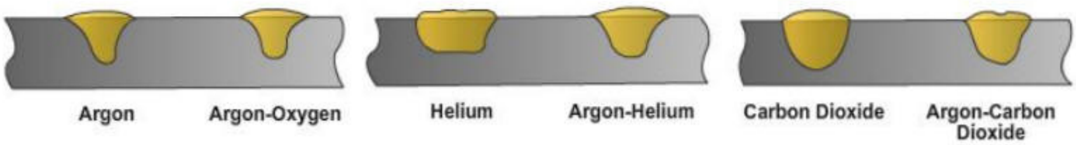

Figure 94 — Weld bead profile and penetration characteristics of different shielding gases.

9.2.0 Primary Variables

As with any other type of welding, the GMAW procedure consists of certain variables that you must understand and follow. Many of the variables have already been discussed. This section applies some of these variables to the actual welding procedure.

9.2.1 Starting the Arc

For a good arc start, the electrode must make good electrical contact with the work. For the best results, you should clean the metal of all impurities. The wire stick-out must be set correctly because as the wire stick-out increases, the arc initiation becomes increasingly difficult (Figure 95).

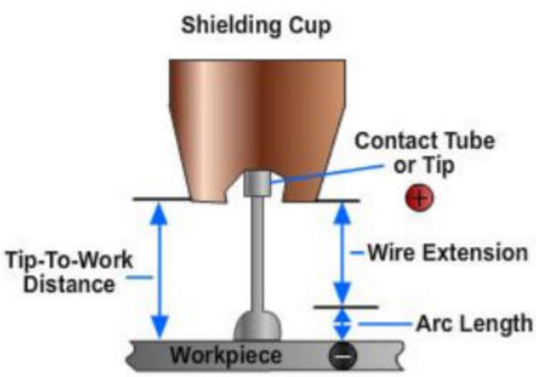

Figure 95 — Electrode stickout.

When preparing to start the arc, hold the torch at an angle between 5 and 20 degrees. Support the weight of the welding cable and gas hose across your shoulder to ensure free movement of the welding torch. Hold the torch close to, but not touching, the workpiece. Lower your helmet and squeeze the torch trigger. Squeezing the trigger starts the flow of shielding gas and energizes the welding circuit. The wire-feed motor does not energize until the wire electrode comes in contact with the work-piece. Move the torch toward the work, touching the wire electrode to the work with a sideways scratching motion (Figure 96). To prevent sticking, you should pull the torch back quickly, about 1/2 inch, the instant contact is made between the wire electrode and the workpiece. The arc strikes as soon as contact is made, and the wire-feed motor feeds the wire automatically as long as you hold the trigger.

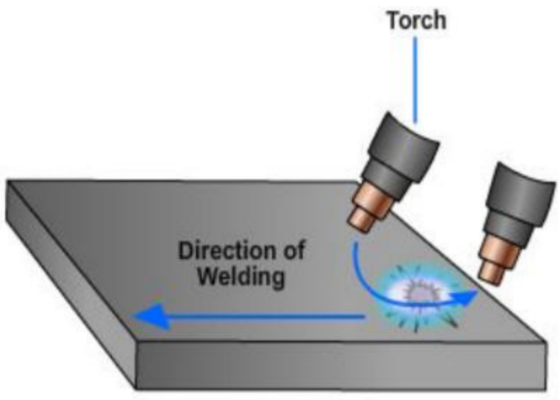

Figure 96 — Arc strike.

A properly established arc has a soft, sizzling sound. Adjustment of the wire-feed control dial or the welding machine itself is necessary when the arc does not sound right. For example, a loud crackling sound indicates that the arc is too short and that the wire-feed speed is too fast. You may correct this problem by moving the wire-feed dial slightly counterclockwise. This decreases the wire-feed speed and increases the arc length. A clockwise movement of the dial has the opposite effect. With experience, you can recognize the sound of the proper length of arc to use (Figure 97).

Figure 97 — Following the arc.

To break the arc, you simply release the trigger. This breaks the welding circuit and de-energizes the wire-feed motor. Should the wire electrode stick to the work when striking the arc or during welding, release the trigger and clip the wire with a pair of side cutters.

9.2.2 Welding Current

The amount of welding current used has the greatest effect on the deposition rate, the weld bead size and shape, and the penetration of the weld. In a constant voltage system, the welding current is controlled by the knob on the wire feeder control, which controls the wire feed speed. As the wire feed speed is increased, the welding current increases. In a constant current system, the welding current is set by a knob on the front of the welding machine. As shown earlier in Figure 93, the deposition rate of the process increases as the welding current increases. The lower part of the curve is flatter than the upper part because at higher current levels, the melting rate of the electrode increases at a faster rate as the current increases. This can be attributed to resistance heating of the electrode extension beyond the contact tube. When all of the other welding variables are held constant, increasing the welding current will increase the depth and width of the weld penetration and the size of the weld bead. Figure 98 shows the effects of varying the welding current. An excessive current level will create a large, deep penetrating weld bead, which wastes filler metal and can burn through the bottom of the joint. An excessively low welding current produces insufficient penetration and buildup of weld metal on the surface.

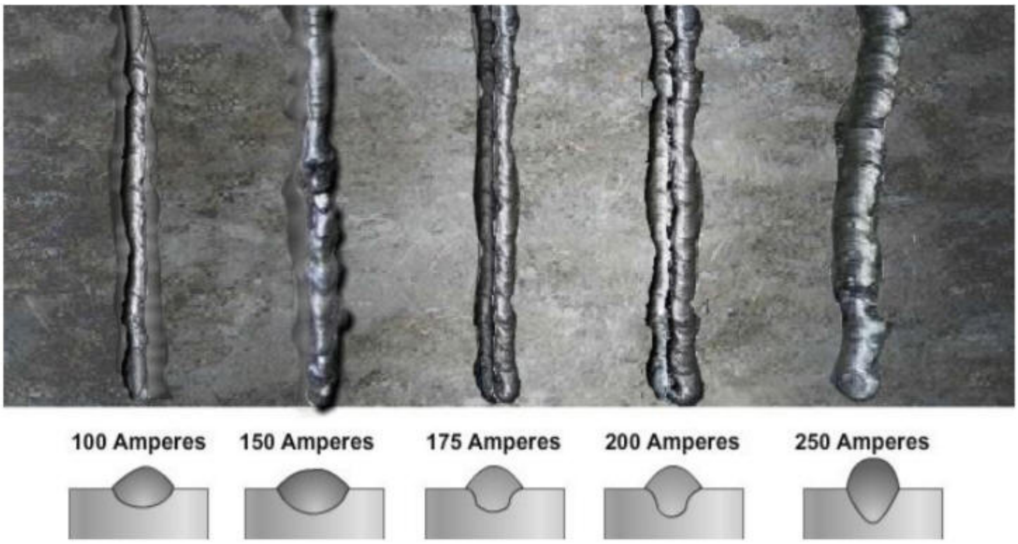

Figure 98 — Effect of welding current on bead.

9.2.3 Welding Voltage (Arc Length)

The welding voltage or arc voltage is determined by the distance between the tip of the electrode and the work. In a constant voltage system, the welding voltage is adjusted by a knob on the front of the power source because the machine maintains a given voltage, which maintains a certain arc length. In a constant current system, the welding voltage is controlled by the arc length held by the welder and the voltage sensing wire feeder. The arc voltage required for an application is dependent on the electrode size, type of shielding gas, position of welding, type of joint, and base metal thickness. There is no set arc length that will consistently give the same weld bead characteristics. For example, normal arc voltages in carbon dioxide and helium are much higher than those obtained in argon. When the other variables are held constant and the arc voltage is increased, the weld bead becomes flatter and wider. The penetration will increase up to an optimum voltage level and then begin to decrease, as shown in Figure 99.

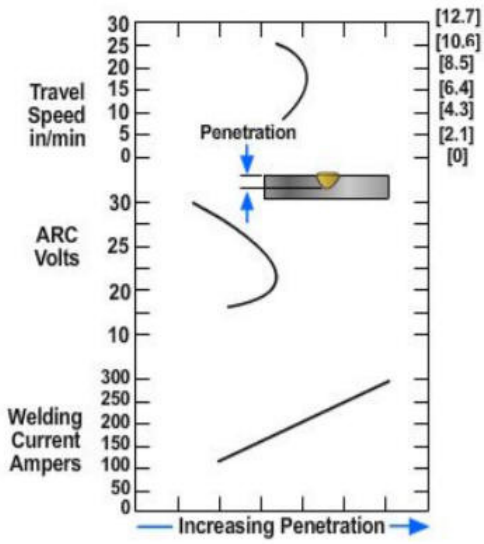

Figure 99 — Effect of travel speed, arc volts, and welding current on penetration.

A higher voltage is often used to bridge a gap because of the decreased penetration obtained. An excessively high arc voltage causes excessive spatter, porosity, and undercutting. A decrease in the arc length produces a narrower weld bead with a greater convexity and, down to the optimum voltage level, deeper penetration. An excessively low arc voltage may cause porosity and overlapping at the edges of the weld bead. Figures 10-100 and 10-101 show the effects of welding voltage on the bead height and bead width respectively. Figure 102 shows the effects of varying the arc length on the weld profile.

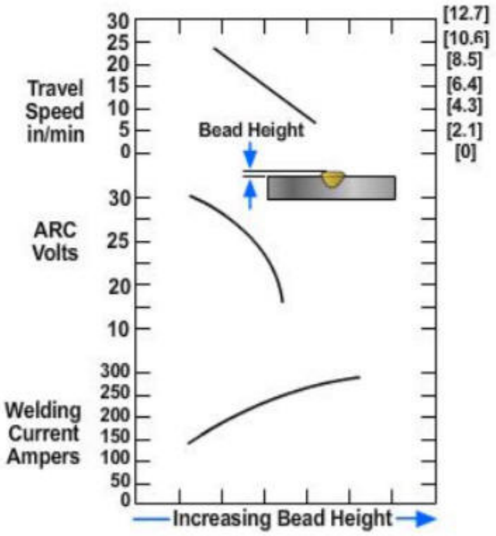

Figure 100 — Effect of travel speed, arc volts, and welding current on bead height.

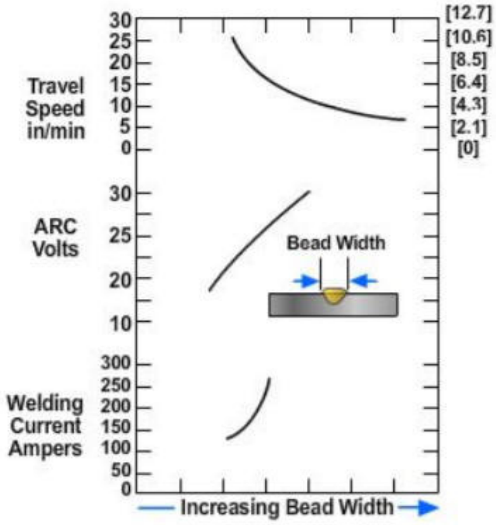

Figure 101 — Effect of travel speed, arc volts, and welding current on bead width.

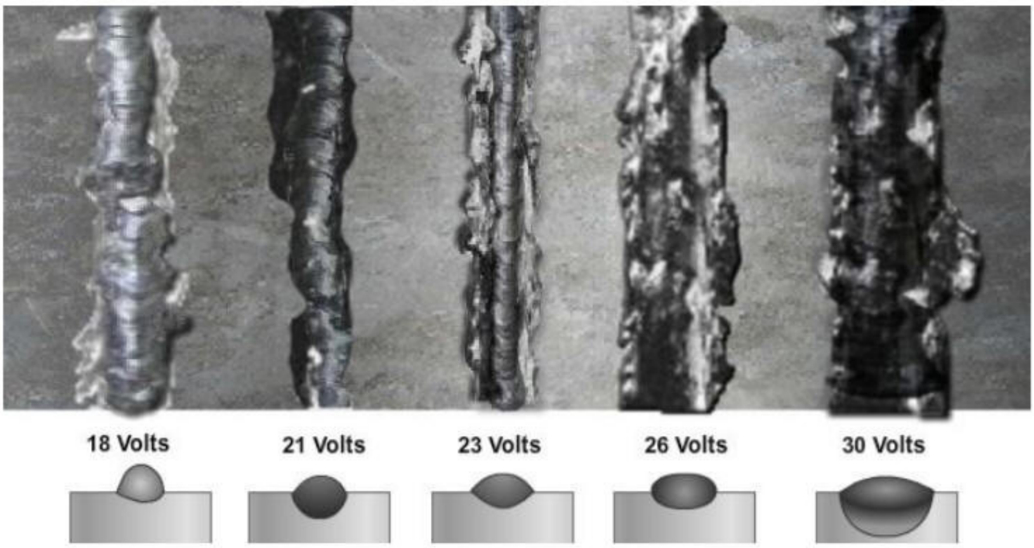

Figure 102 — Effect of arc voltage on bead and bead formation.

9.2.4 Travel Speed

The travel speed is the rate at which the arc travels along the workpiece. The travel speed is controlled by the welder in semiautomatic welding. In machine and automatic welding it is controlled by the machine. As shown in Figure 99, the penetration is maximum at a certain travel speed. Increasing or decreasing the travel speed from this point will reduce the amount of penetration. When the travel speed is decreased, the amount of filler metal deposited per unit length increases, which creates a large, shallow weld puddle. Weld metal tends to get slightly ahead of the arc, which reduces the amount of penetration and produces a wide weld bead. Reducing the travel speed will increase the bead height, as shown in Figure 100. An excessively slow travel speed can cause excessive piling up of the weld puddle overlapping at the edges, and excessive heat input to the plate, which creates a larger heat affected zone. As the travel speed is increased, the heat transmitted to the base metal is reduced, which reduces the melting of the base metal and limits the amount of penetration. The bead width and bead height are also decreased, as shown in Figures 10-100 and 10-101. An excessive travel speed will tend to cause undercutting along the edges of the weld bead because there is not enough filler metal to fill the groove melted by the arc. Figure 103 shows the effects on the size and shape of the weld bead of different travel speeds.

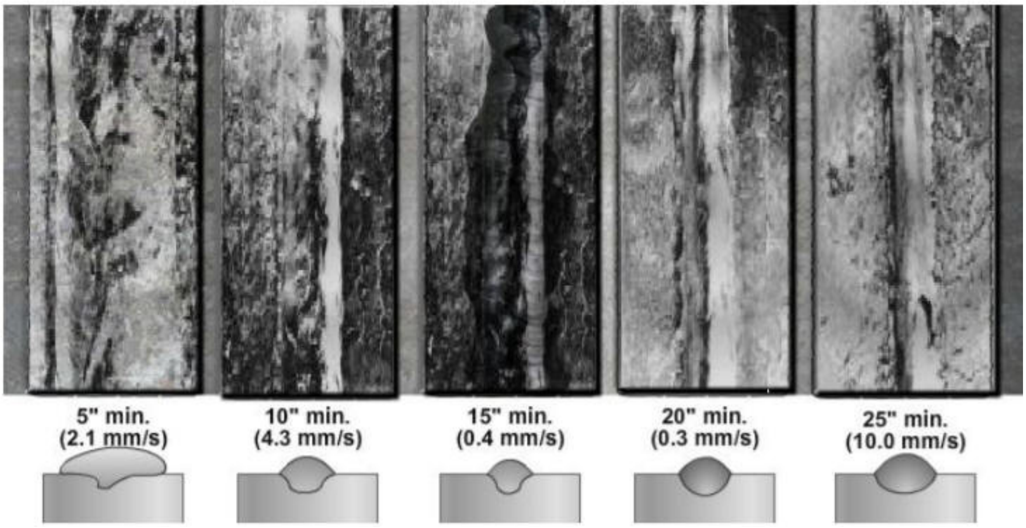

Figure 103 — Effect of travel speed on bead.

9.3.0 Secondary Variables

Secondary variables include electrode extension and angle.

9.3.1 Electrode Extension

The electrode extension, sometimes referred to as stick-out, is the distance between the tip of the contact tube and the tip of the electrode (Figure 104).

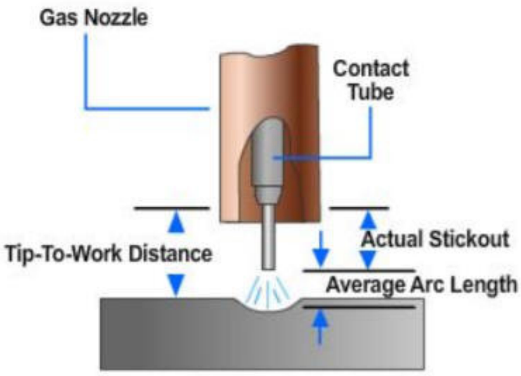

Figure 104 — Electrode. extension.

As this distance is increased, the electrical resistance of the electrode increases, which increases the preheating on the electrode. Because of this, less welding current is required to melt the electrode at a given wire feed rate. This is shown in Figure 105. The measurements are made from the tip of the contact tube to the surface of the work using a constant welding voltage or arc length. This distance is usually used because it is easier to measure than the actual electrode extension. Increasing the electrode extension will reduce the amount of penetration (Figure 106).

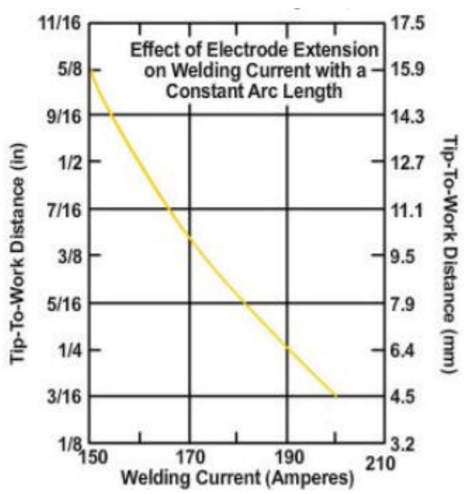

Figure 105 — Effect of electrode extension current.

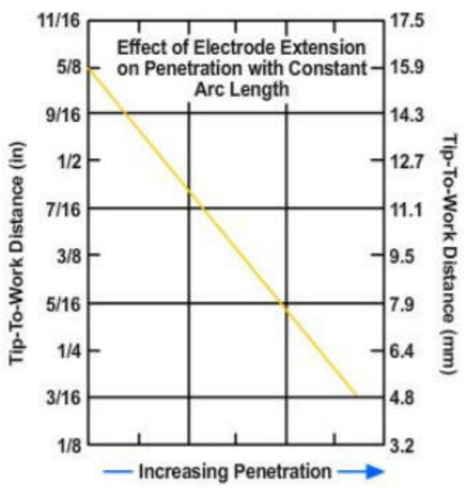

Figure 106 — Effect of electrode extension on penetration.

An excessively long electrode extension results in an excess of weld metal being deposited at low heat. This produces a poor weld bead shape and shallow penetration. As the contact tube-to-work distance increases, the arc has a tendency to become less stable. A longer electrode extension will also produce a higher deposition rate, as shown in Figure 107.

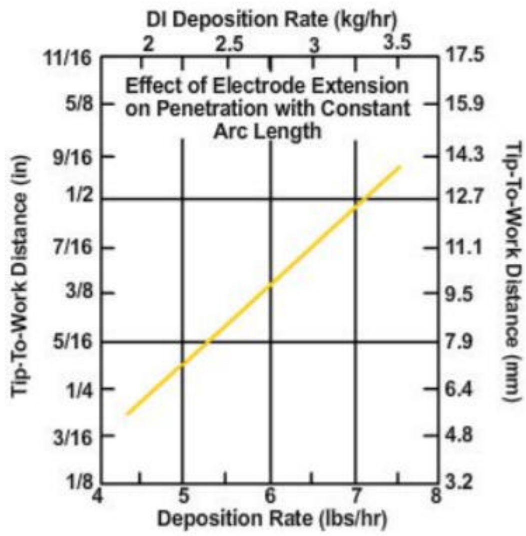

Figure 107 — Effect of electrode extension on deposition rate.

Typical electrode extensions range from 1/4-1/2 in. (12.7-25.4 mm) for the other types of metal transfer. The electrode extension is often used to make adjustments of the characteristics of the weld bead to compensate for changes over a short length of the weld, such as an area where the root opening of the joint is excessively large or small. If the penetration needed is to be reduced to compensate for a large root opening, the welder could increase the stickout, which reduces the welding current and penetration in this area.

9.3.2 Electrode Angles

The position of the welding electrode with respect to the weld joint affects the shape of the weld bead and the amount of penetration. The electrode angles are called the travel and work angles. The travel angle of the electrode is the angle between the joint and electrode in the longitudinal plane. A push angle exists when the electrode points in the direction of travel (forehand welding) and a drag angle exists when the electrode points in the direction opposite to travel (backhand welding). The work angle is the angle between the electrode and the plane perpendicular to the direction of travel. The travel and work angles are shown in Figure 108.

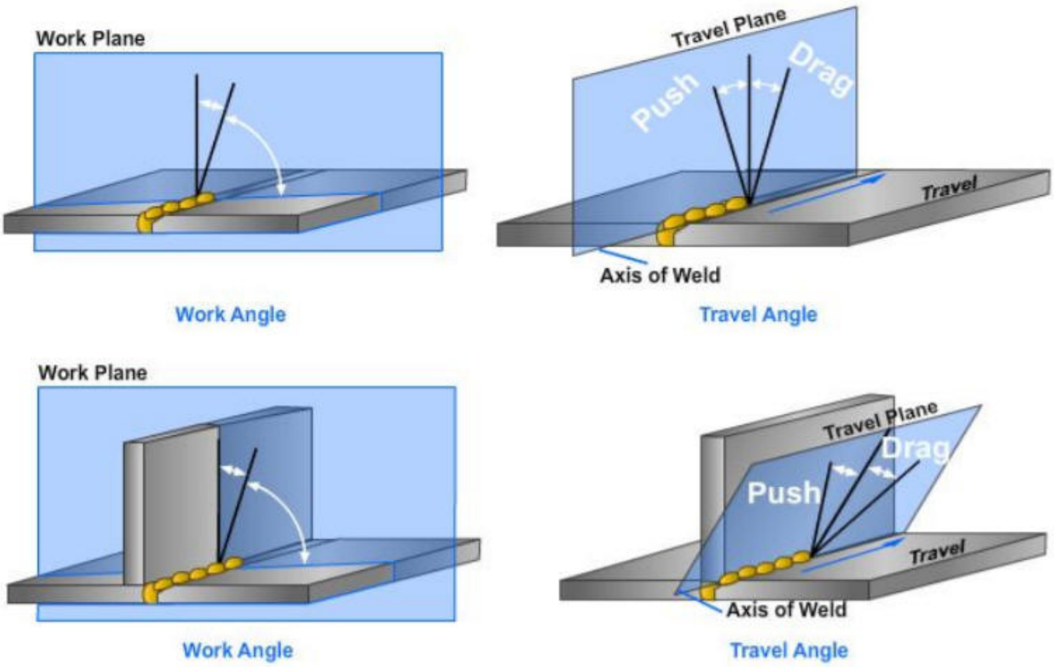

Figure 108 — Travel angle and work angle.

The effects on the weld bead with respect to travel angle are shown in Figure 109.

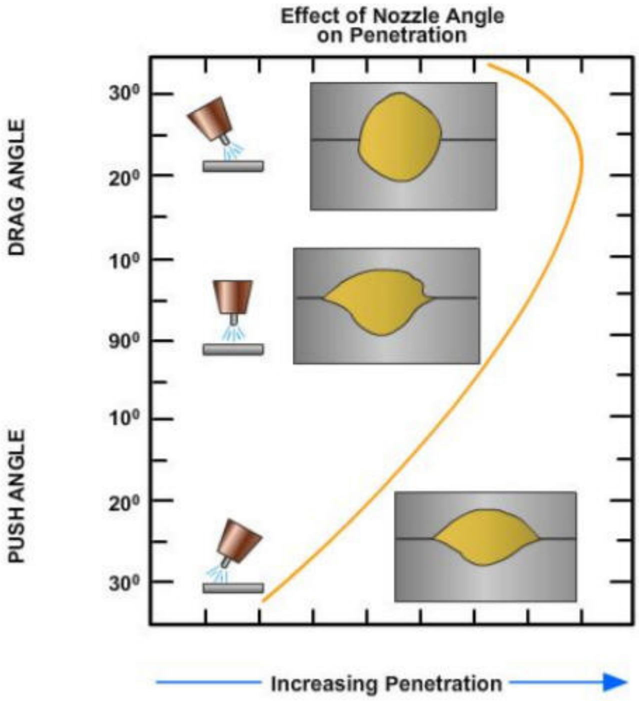

Figure 109 — Effects of travel angle on penetration and bead shape.

When the electrode angle is changed from 90° to a push angle, the amount of penetration is decreased and the weld bead becomes wider and flatter. When changing the electrode angle from 90° to a drag angle, the penetration will increase up to a travel angle of 25° from the vertical where the maximum penetration is obtained. A travel angle above this will start reducing the penetration and is not recommended because it greatly increases the chances of overlapping. The drag angle produces a narrower, more convex weld bead as well as a more stable arc with less spatter. A drag angle is commonly used on steel; a push angle is used on aluminum to avoid contamination and give good penetration but minimize the heat input to the base metal. Electrode travel angles of approximately 5-15° are normally used in all positions for good control of the molten weld puddle. When making fillet welds, the work angle should be approximately 45° from the plate.

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10.0.0 WELDING PROCEDURE SCHEDULES

The welding procedure schedules in this course give typical welding conditions which can be used to obtain high quality welds under normal welding conditions. Gas metal arc welding uses a wide variety of operating conditions for welding a wide variety of base metal types. The procedure schedules presented in this course are in no way a complete guide to the procedures that can be used for GMAW, and are not the only conditions that may be used to obtain a specific weld. These are not the only conditions that could be used because factors such as weld appearances, welder skill, method of application, and the specific application often require variations from the schedules. For example, automatic GMAW usually employs higher welding currents and faster travel speeds than semiautomatic welding.

The mode of metal transfer in GMAW has a large effect on the welding conditions. This is because the different modes of metal transfer are dependent on the welding current and voltage levels used, as well as the type of shielding gas. For example, the spray transfer mode requires a higher welding current and often a different shielding gas than the globular transfer mode. As the particular requirements of the application become known, the settings may be adjusted to obtain the optimum welding conditions. Qualifying tests or trials should be made under the actual conditions before using this process for production welding.

When changing or adjusting the variables for welding, you must consider the effect of the variables on each other. One variable cannot usually be drastically changed without adjusting or changing the other variables to obtain a stable arc and good overall welding conditions.

The following schedules are based on welding specific metals and using a specific mode of metal transfer and method of application. The welding schedules for steel include the semiautomatic and automatic methods of application and short-circuiting, globular, and spray transfer modes of welding. Other base metals such as stainless steel, aluminum, copper, magnesium, and nickel are also included. The tables use the base metal thickness or fillet size, number of weld passes, electrode diameter, welding current (wire feed speed), gas flow rate, and welding travel speed as variables. Each table contains the type of shielding gas, type of joint, and the position of welding being used. All of the schedules are based on using direct current electrode positive. Both the welding current and wire feed speed values are given because even though the welding current is set by the wire feed speed, it is sometimes more convenient to directly establish the welding current without exactly knowing the wire feed speed. Figure 110 shows wire feed speeds and their corresponding welding currents for several sizes of steel electrode wire. Figure 111 shows wire feed speeds and their corresponding welding currents for several sizes of non-ferrous metal electrode wire.

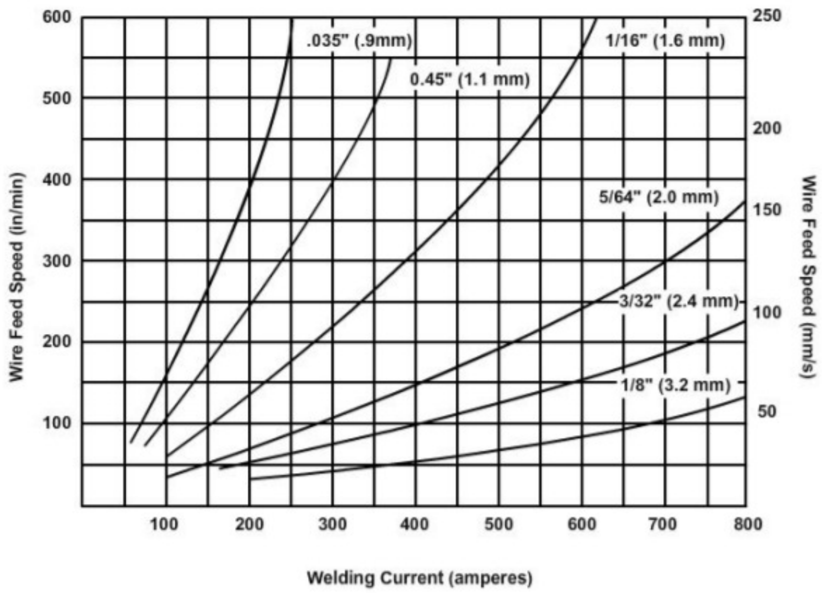


Figure 110 — Wire-feed speed vs. welding current for steel electrodes.

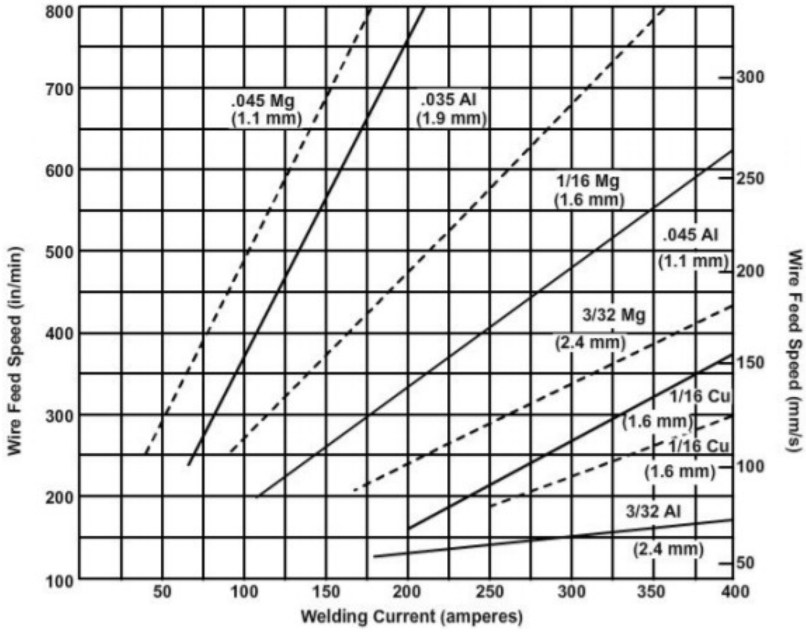
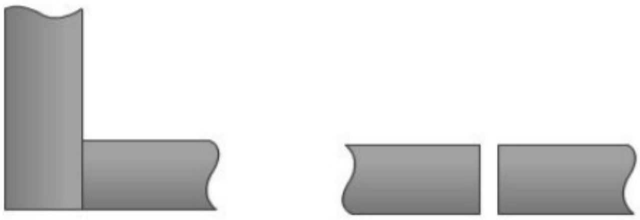


Figure 111 — Wire feed speed vs. welding current for several non-ferrous electrodes. *

Welding procedure schedules for gas metal arc spot welding are given at the end of this section. Many of the tables include welding conditions for both groove and fillet welds given on the same chart. In general, fillet welds will use the higher current levels for the ranges given and groove welds will generally use the lower end of the current range. See Tables 10-21 through 10-33 for specific welding schedules.



1) For Fillet and Square-Groove Welds.
2) Shielding Gas is Carbon Dioxide or a 75% Argon - 25% Carbon Dioxide Mixture.
3) Flat and Horizontal Positions Only. Reduce Current 10-15% For Vertical and Overhead Welding.
4) For Semi-automatic or Automatic Welding.

Table 21 — Welding procedure schedules for GMAW of plain carbon and low alloy steels using short circuiting metal transfer.

Thickness of Base Metal or Fillet Size in. (mm)	No. of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min (mm/s)	Gas Flow Rate ft/hr (l/min)	Travel Speed in./min (mm/s)
20 ga (.9)	1	.035 (.9)	15-17	65-85	90-130 (38-55)	20 (9)	35-40 (15-17)
18 ga (1.2)	1	.035 (.9)	17-19	80-100	120-170 (51-72)	20 (9)	35-40 (15-17)
1/16" (1.6)	1	.035 (.9)	17-19	90-110	150-190 (63-80)	25 (12)	30-35 (13-15)
3/32" (2.4)	1	.035 (.9)	18-20	110-130	190-240 (80-102)	25 (12)	25-30 (11-13)
1/8" (3.2)	1	.035 (.9)	19-21	140-160	250-320 (118-135)	25 (12)	20-25 (6-8)
1/8" (3.2)	1	045 (1.1)	20-23	180-200	210-240 (89-102)	25 (12)	27-32 (11-14)
3/16" (4.8)	1	.035 (.9)	19-21	140-160	280-320 (118-135)	25 (12)	14-19 (6-8)
3/16" (4.8)	1	.045 (1.1)	20-23	180-200	210-240 (89-102)	25 (12)	18-23 (7.5-10)
1/4" (6.4)	1	.035 (.9)	19-21	140-160	280-320 (118-135)	25 (12)	10-15 (4-6.5)
1/4" (6.4)	1	.045 (1.1)	20-23	180-200	210-240 (118-135)	25(12)	12-17 (5-7)

1) For Fillet Welds Only.
2) Shielding Gas is Carbon Dioxide.
3) Vertical-Up Position Only.
4) Semi-automatic Welding.

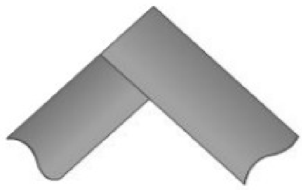


Table 22 — Welding procedure schedules for GMAW of plain carbon and low alloy steels using short circuiting metal transfer.

Fillet size in. (mm)	No. of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min. (mm/s)	Gas Flow Rate Ft^3/hr. (l/min)	Travel Speed in./min (mm/s)
3/8 (9.5)	1-2	.035 (.9)	19-21	150-160	290-320 (123-135)	25 (12)	6-7 (2.5-3)
1/2 (12.7)	2-3	.035 (.9)	20-22	160-170	320-350 (135-148)	25 (12)	5-6 (2-2.5
3/4 (19.1)	3-4	.035 (.9)	20-22	170-180	350-380 (148-161)	25 (12)	4-5 (1.5-2)

1) For Fillet Welds Only.
2) Shielding Gas is Carbon Dioxide.
3) Overhead Position Only.
4) Semi-automatic Welding.

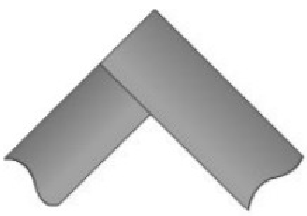


Table 23 — Welding procedure schedules for GMAW of plain carbon and low alloy steels using short circuiting metal transfer.

Fillet size in. (mm)	No. of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min. (mm/s)	Gas Flow Rate FT3/hr. (l/min)	Travel Speed in./min (mm/s)
3/8 (9.5)	3	.035 (.9)	19-21	150-160	290-320 (123-135)	25 (12)	11-12 (5-5.5)
1/2 (12.7)	3	.035 (.9)	20-22	160-170	320-350 (135-148)	25 (12)	7-8 (3-3.5)
3/4 (19.1)	6	.035 (.9)	20-22	170-180	350-380 (148-161)	25 (12)	6-7 (2.5-3)

1) For Fillet and Square-Groove Welds with Backing Strip.

2) Carbon Dioxide Shielding Gas.

3) Flat and Horizontal Fillet Positions Only.

4) Automatic or Machine Welding.

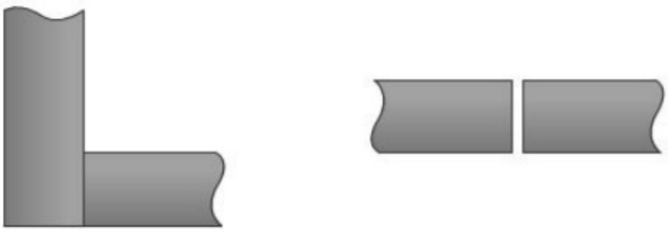
Table 24 — Welding procedure schedules for GMAW of plain carbon and low alloy steels using globular metal transfer.

Thickness of Base Metal or Fillet Size in. (mm)	No. of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min (mm/s)	Gas Flow Rate ft/hr (l/min)	Travel Speed in./min (mm/s)
18 ga (1.2)	1	.045 (1.1)	24-26	260-290	325-375 (137-159)	25 (12)	180-190 (76-80)
16 ga (1.5)	1	.045 (1.1)	26-28	300-340	400-480 (169-203)	35 (17)	140-150 (59-63)
14 ga (1.9)	1	.045 (1.1)	27-29	310-350	410-500 (173-212)	35 (17)	100-130 (42-55)
1/8" (3.2)	1	1/16 (1.6)	27-29	360-400	270-310 (114-131)	35 (17)	75-95 (32-40)
1/8" (3.2)	1	045 (1.1)	28-30	330-370	450-550 (190-233)	35 (17)	90-110 (38-47)
3/16" (4.8)	1	1/16 (1.6)	30-32	375-425	280-320 (118-135)	35 (17)	70-80 (30-34)
1/4" (6.4)	1	1/16 (1.6)	31-33	450-500	360-420 (152-178)	35 (17)	45-55 (19-23)
3/8 (9.5)	1	3/32 (2.4)	33-35	550-600	125-150 (53-63)	35 (17)	30-40 (13-17)
1/2 (12.7)	1	3/32 (2.4)	35-37	600-650	150-175 (63-74)	35 (17)	25-35 (11-15)

1) For V-Groove Welds with Backing Strip.
2) Carbon Dioxide Shielding Gas.
3) Flat Position Only.
4) Automatic or Machine Welding.

Table 25 — Welding procedure schedules for GMAW of plain carbon and low alloy steels using globular metal transfer.

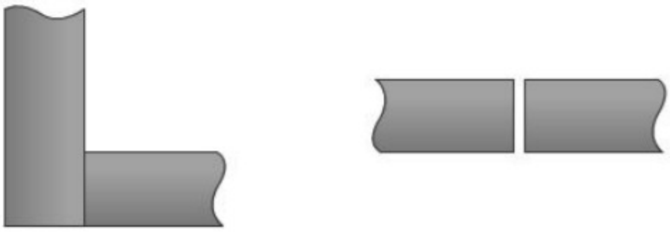
Thickness of Base Metal in. (mm)	No. of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min (mm/s)	Gas Flow Rate ft/hr (l/min)	Travel Speed in./min (mm/s)
1/2 (12.7)	1	3/32 (2.4)	35-37	525-575	130-145 (55-61)	35 (17)	200-30 (8.5-13)
5/8 (15.9)	1	3/32 (2.4)	36-38	600-650	150-175 (63-74)	35 (17)	17-25 (7-11)
3/4 (19.1)	1	1/8 (3.2)	36-38	650-700	90-100 (38-42)	35 (17)	15-23 (6.5-10)
1 (25.4)	2	1/8 (3.2)	36-38	650-700	90-100 (38-42)	35 (17)	12-20 (5-8.5)



1) For Square-Groove and Fillet Welds.
2) Argon-Oxygen (1 to 2% Oxygen) Mixture Used.
3) Values Are For Flat Position. Reduce Current 10-20% For Other Positions.
4) Semi-Automatic or Automatic Welding.

Table 26 — Welding procedure schedules for GMAW of plain carbon and low alloy steels using spray transfer.

Thickness of Base Metal in. (mm)	No. of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min (mm/s)	Gas Flow Rate ft/hr (l/min)	Travel Speed in./min (mm/s)
1/8 (3.2)	1	1/16 (1.6)	23-25	275-325	155-175 (66-74)	45 (21)	34-36 (14-15)
3/16 (4.8)	1	1/16 (1.6)	24-26	325-375	210-260 (89-110)	45 (21)	31-33 (13-14)
1/4 (6.4)	1-2	1/16 (1.6)	24-26	325-375	210-260 (89-110)	45 (21)	30-32 (13-14)
1/4 (6.4)	1-2	3/32 (2.4)	26-29	400-450	100-120 (42-51)	45 (21)	32-35 (14-15)
3/8 (9.5)	2	1/16 (1.6)	24-26	325-375	100-120 (42-51)	45 (21)	20-24 (8-10)
3/8 (9.5)	1-2	3/32 (2.4)	26-29	400-450	100-120 (42-51)	45 (21)	20-28 (8-12)
1/2 (12.7)	3	1/16 (1.6)	24-26	325-375	210-260 (89-110)	45 (21)	22-26 (9-11)
1/2 (12.7)	3	3/32 (2.4)	26-29	400-450	100-120 (42-51)	45 (21)	26-30 (11-13)
3/4 (19.1)	4-5	1/16 (1.6)	24-26	325-375	210-260 (89-110)	45 (21)	22-26 (9-11)
3/4 (19.1)	4	3/32 (2.4)	26-29	400-450	100-120 (42-51)	45 (21)	24-28 (10-12)
1 (25.4)	7	1/16 (1.6)	24-26	325-375	210-260 (89-110)	45 (21)	22-26 (9-11)



1) For Square-Groove and Fillet Welds.

2) Argon-Oxygen (1 to 2% Oxygen) Mixture Used.

3) Values Are For Flat Position. Reduce Current 10-20% For Other Positions.

4) Semi-Automatic or Automatic Welding.

Thickness of Base Metal in. (mm)	No. of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min (mm/s)	Gas Flow Rate ft/hr (l/min)	Travel Speed in./min (mm/s)
1/16 (1.6)	1	.035 (.9)	15-18	60-100	125-200 (53-85)	15 (7)	25-30 (11-13)
3/32 (2.4)	1	.035 (.9)	18-21	125-150	250-320 (106-135)	15 (7)	25-30 (11-13)
3/32 (2.4)	1	.045 (1.1)	18-21	125-150	130-160 (55-68)	15 (7)	25-30 (11-13)
1/8 (3.2)	1	.035 (.9)	19-24	130-160	260-330 (110-140)	15 (7)	20-25 (8-11)
1/8 (3.2)	1	.045 (1.1)	19-24	150-225	160-250 (68-106)	15 (7)	20-30 (8-13)
5/32 (4.0)	1	.045 (1.1)	22-26	190-250	200-290 (85-123)	20 (9)	25-30 (11-13)
1/4 (6.4)	2	.045 (1.1)	24-30	225-300	250-370 (106-157)	25 (12)	25-30 (11-13)

Table 27 — Welding procedure schedules for GMAW of stainless steel.

1) For Groove and Fillet Welds. Square Groove Welds Are Used For Thickness Less Than 3/16" (4.8 mm). V-Groove Welds Are Used For 1/4" (6.4 mm) and Higher.
2) Argon Shielding Gas is Used. Increase the Gas Flow Rate 10% For the Overhead Position.
3) These Are All Position Values Except Those Designated by *, Which Are Flat Position Only.

Table 28 — Welding procedure schedules for GMAW of aluminum and alloys.

Fillet size in. (mm)	No. of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Speed in./min. (mm/s)	Rate ft3/hr. (l/min)	Speed in./min (mm/s)
1/16 (1.6)	1	.035 (.9)	13-14	55-60	250-300 (106-127)	15 (7)	12-24 (6-10)
3/32 (2.4)	1	.035 (.9)	16-18	90-100	300-350 (127-148)	30 (14)	24-36 (10-15)
1/8 (3.2)	1	3/64 (1.2)	19-21	110-130	160-200 (68-85)	35 (17)	22-26 (9-11)
3/16 (4.8)	1	3/64 (1.2)	19-21	150-190	225-275 (95-116)	35 (17)	20-25 (8-11)
1/4 (6.4)	1	1/16 (1.6)	20-22	175-225	150-190 (63-80)	35 (17)	20-25 (8-11)
3/8 (7.9)	2	1/16 (1.6)	21-26	200-250	170-210 (72-89)	40 (19)	24-30 (10-13)
112 (12.7)	3-5	1/16 (1.6)	24-29	200-250	170-210 (72-89)	50 (24)	12-18 (5-7.5)
1/2 (12.7)*	2-3	3/32 (2.4)	26-28	240-280	140-150 (59-63)	45 (21)	15-20 (6.5-8.5)
3/4 (19.1)	4-8	1/16 (1.6)	22-27	250-300	230-260 (97-110)	50 (24)	10-16 (4-7)
3/4 (19.1)*	3-4	3/32 (2.4)	27-29	280-320	150-160 (63-68)	50 (24)	16-22 (7-9.5)
1 (25.4)	6-10	1/16 (1.6)	22-27	250-300	230-260 (97-110)	50 (24)	8-14 (3.5-6)
1 (25.4)*	5-6	3/32 (2.4)	27-29	280-320	150-160 (63-68)	50 (24)	14-26 (6-8.5)

1) For Groove and Fillet Welds. Square-Groove Welds Are Used For Thickness Less Than 1/4" (6.4 mm). V-Groove Welds Are Used For 1/4" (6.4 mm) and Higher.
2) Argon Shielding Gas is Used. Argon-Helium Mixtures or Helium Are Often Used on Thicker Metal Sections of Deoxidized Copper to Increase Heat Input and Reduce Porosity.
3) Values Are For Flat Position Only. Decrease Welding Current 10-20% For Vertical and Overhead Welding.

Table 29 — Welding procedure schedules for GMAW of copper and copper alloys.

Thickness of Base Metal in. (mm)	No. of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min (mm/s)	Gas Flow Rate ft/hr (l/min)	Travel Speed in./min (mm/s)
1/16 (1.6)	1	3/64 (1.2)	22-24	150-170	210-220 (89-93)	35 (17)	20-23 (8-10)
5/64 (2.0)	1	3/64 (1.2)	22-25	180-200	240-270 (102-114)	40(19)	20-25 (8.5-11)
7/64 (2.8)	1	3/64 (1.2)	23-27	200-230	270-290 (114-123)	40 (19)	20-25 (8.5-11)
1/8 (3.2)	1	3/64 (1.2)	23-27	210-240	280-300 (118-127)	40 (19)	20-25 (8.5-11)
1/4 (6.4)	1	1/16 (1.6)	23-27	340-360	190-210 (80-89)	40 (19)	12-15 (5-6.5)
3/8 (7.9)	2	1/16 (1.6)	24-28	380-410	220-240 (93-102)	40 (19)	12-15 (5-6.5)
1/2 (12.7)	2	1/16 (1.6)	24-28	400-440	270-290 (114-123)	50 (19)	8-10 (3.5-4)
3/4 (19.1)	2-3	1/16 (1.6)	24-30	420-460	280-300 (118-127)	50 (24)	7-9 (3.5-4)
1 (25.4)	4	1/16 (1.6)	24-30	420-460	280-300 (118-127)	50 (24)	7-9 (3.5-4)

Silicon Bronze

Thickness of Base Metal in. (mm)	No. of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min (mm/s)	Gas Flow Rate ft/hr (l/min)	Travel Speed in./min (mm/s)
1/8 (3.2)	1	3/64 (1.2)	25-28	220-230	220-230 (93-97)	35 (17)	25-32 (11-14)
1/4 (6.4)	1-3	1/16 (1.6)	27-30	170-190	170-190 (72-80)	40 (19)	25-32 (11-14)
1/4 (6.4)	1	1/16 (1.6)	25-28	220-250	220-250 (93-106)	50 (24)	30-34 (13-14)
1/2 (12.7)	3-5	1/16 (1.6)	27-30	180-200	180-200 (76-85)	50(24)	15-20 (6.5-8.5)

Aluminum Bronze

Thickness of Base Metal in. (mm)	No. of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min (mm/s)	Gas Flow Rate ft/hr (l/min)	Travel Speed in./min (mm/s)
1/8 (3.2)	1	3/64 (1.2)	22-25	190-225	280-300 (118-127)	40 (19)	18-24 (7.5-10)
1/4(6.4)	2	1/16 (1.6)	23-29	275-300	170-190 (72-80)	50 (24)	16-22 (7-9.5)
3/8(7.9)	3-6	1/16 (1.6)	23-29	300-340	190-210 (80-89)	50 (24)	16-22 (7-9.5)
1/2 (12.7)	6-8	1/16 (1.6)	23-29	320-350	200-220 (85-93)	50 (24)	11-15 (4.5-6.5)
5/8 (15.9)	6-8	1/16(1.6)	23-29	320-350	200-220 (85-93)	50 (24)	9-13 (4-5.5)
3/4 (19.1)	6-8	1/16 (1.6)	23-29	340-370	210-230 (89-97)	50 (24)	8-12 (3.5-5)

1) For Groove and Fillet Welds. Square-Groove Welds Are For Thicknesses Less Than 1/4" (6.4 mm) and Greater.

2) Argon Shielding Gas.

3) For Flat Position, Decrease Welding Current 10-20% For Welding in OtherPositions.

Table 30 — Welding procedure schedules for GMAW of nickel and

nickel alloys.

Thickness of Base Metal in. (mm)	No. of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min (mm/s)	Gas Flow Rate ft/hr (l/min)	Travel Speed in./min (mm/s)
1/16 (1.6)	1	3/64 (1.2)	21-23	200-230	290-310 (123-131)	50 (24)	55-65 (23-27)
1/8 (3.2	) 1	1/16 (1.6)	25-27	310-350	190-215 (80-91)	50 (24)	30-35 (13-15)
1/4 (6.4)	2	1/16 (1.6)	26-28	300-350	180-215 (76-91)	50 (24)	20-25 (8.5-11)

1) For Groove and Fillet Welds. Square-Groove Welds Made For Thicknesses Less Than 3/16" (4.8 mm) V-Groove Welds Are Used For 3/16" (4.8 mm) and Thicker.

2) Argon Shielding is Used. Argon-Helium Mixtures Are Often Preferred For Welding Thicker Sections.

3) These Are All Position Values.

Table 31 — Welding procedure schedules for GMAW of magnesium alloys.

Thickness of Base Metal in. (mm)	No. of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min (mm/s)	Gas Flow Rate ft/hr (l/min)	Travel Speed in./min (mm/s)
.044 (1.0)	1	.040 (1.0)	14-17	40-70	225-325 (95-137)	50 (24)	30-36 (13-15)
1/16 (16)	1	.040 (1.0)	14-17	50-90	275-425 (116-180)	50 (24)	30-36 (13-15)
3/32 (2.4)	1	1/16 (1.6)	15-19	100-140	275-350 (116-148)	50 (24)	30-36 (13-15)
1/8 (3.2)	1	1/16 (1.6)	15-19	120-160	310-380 (131-161)	50 (24)	24-32 (10-14)
3/16 (4.8)	1	1/16 (1.6)	24-29	220-270	515-615 (218-260)	65 (31)	24-32 (10-14)
1/4 (6.4)	1	1/16 (1.6)	24-29	250-300	575-675 (243-286)	65 (31)	24-32 (10-14)
3/8 (9.5)	2	1/16 (1.6)	24-29	275-375	625-725 (264-307)	65 (31)	24-32 (10-14)
3/8 (9.5)	1	3/32 (2.4)	24-29	300-350	330-380 (140-161)	65 (31)	24-32 (10-14)
1/2 (12.7)	3	1/16 (1.6)	23-26	320-370	725-825 (307-349)	65 (31)	24-32 (10-14)
1/2 (12.7)	2-3	3/32 (2.4)	24-29	330-380	365-410 (154-173)	65 (31)	24-32 (10-14)
5/8 (15.9)	3	3/32 (2.4)	25-30	350-400	380-430 (161-182)	65 (31)	20-30 (8.5-13)
1 (25.4)	5	3/32 (2.4)	25-30	350-400	380-430 (161-182)	65 (31)	20-30 (9.5-13)

1) Carbon Dioxide Shielding Gas.
2) Flat Position.
3) Contact Tip to Work Distance 1/4-3/8" (6.4-9.5 mm) For .035" (.9 mm) and .045" (1.1 mm) Electrode Diameters. Contact to Work Distance 7/8" (22 mm) For 1/16" (1.6 mm) Electrode Wire.
4) Produces Approximately a 1/4" (6.4 mm) Diameter Weld Nugget.

Table 32 — Welding procedure schedules for GMAW of plain carbon steel.

Metal Thickness in. (mm)	Electrode Diameter in. (mm)	Arc Spot Time sec.	Welding Voltage	Welding Current	Wire Consumed Per Spot in./min	Gas Flow Rate ft/hr (l/min)	Shear Strength Per Spot lbs. (kN)
24 ga. (.6)	.030 (.8)	1.0	24	90	4.6(117)	25 (12)	625 (2.78)
22 ga. (.8)	.030 (.8)	1.2	27	120	5.0 (127)	25 (12)	730 (3.25)
22 ga (.8)	.035 (.9)	1.0	26	140	6.0 (152)	25 (12)	800(3.561
20 ga. (.9)	.030 (.8)	1.2	27	120	10.1 (257)	25 (12)	1337 (5.95)
20 ga. (.9)	.035 (.9)	1.0	26	140	6.0 (152)	25 (12)	1147 (5.10)
18 ga. (1.2)	.035 (.9)	1.0	27	190	8.5 (216)	25 (12)	1507 (6.70)
18 ga. (1.2)	.045 (1.1)	0.7	27	200	4.0 (102)	25 (12)	1414 (6.29)
16 ga.(1.5)	.035 (.9)	2.0	28	190	17.3 (438)	25 (12)	1434 (6.38)
16 ga. (1.5)	.045 (1.1)	1.0	29	260	6.0 (152)	25 (12)	2070 (9.21)
16 ga (1.5)	1/16 (1.6)	1.0	29	250	2.8 (70)	35 (17)	1654 (7.36)
14 ga. (1.9)	.035 (.9)	5.0	28	190	40.5 (1029)	25 (12)	2600 (11.57)
14 ga. (1.9)	.045 (1.1)	1.5	30	300	12.8 (324)	25 (12)	3224 (14.34)
14 ga (1.9)	1/16 (1.6)	1.0	31	360	5.5 (140)	35 (17)	3340 (14.86)
12 ga. (2.7)	.045 (1.1)	3.5	30	300	28.5 (724)	25 (12)	4300 (19.13)
12 ga. (2.7)	1/16~1.6)	1.0	32	440	7.3 (184)	35 (17)	5000 (22.24)
11 ga (3.0)	.045(1.1)	4.2	30	300	4 (864)	25 (12)	4114 (18.30)
11 ga. (3.0)	1/16 (1.6)	1.0	32	490	8.5 (216)	35 (17)	634 (25.06)
5/32 (4.0)	1/16 (1.61	1.5	32	490	9 (229)	35 (17)	5447 (24.25)
3/16 (4.8)	1/16 (1.6)	2.0	32	490	16.8 (425)	35(17)	6834 (30.40)
1/4 (6.4)	1/16 (1.6)	3.5	32	490	28.1 (714)	35 (17)	8667 (38.55)

1) Argon Shielding Gas.
2) Flat Position.
3) Contact Tip to Work Distance 3/8-1/2" (9.5-12.7mm).

Table 33 — Welding procedure schedules for GMAW of aluminum and aluminum alloys.

Metal Thickness in. (mm)	Electrode Diameter in. (mm)	Arc Spot Time sec.	Welding Voltage	Welding Current	Wire Consumed Per Spot in./min	Gas Flow Rate ft/hr (l/min)
.020 (.5)	3/64 (1.2)	0.3	23	105	0.8 (21)	35 (17)
.030 (.8)	3/64 (1.2)	0.3	23	135	1.0 (25)	35 (17)
.040 (1.0)	3/64 (1.2)	0.3	24	175	1.3 (33)	35 (17)
.040 (1.0)	1/16 (1.6)	0.8	24	320	4.4 (113)	50 (24)
.050 (1.3)	3/64 (1.2)	0.4	25	225	2.2 (56)	35 (17)
.050 (1.3)	1/16(1.6)	1.0	24	335	6.0 (152)	50 (24)
.064 (1.6)	3/64 (1.2)	0.5	26	270	3.1 (79)	35 (17)
.064 (1.6)	1/16 (1.6)	1.2	24	340	7.5 (191)	50 (24)
.080 (2.0)	1/16 (1.6)	1.4	24	375	9.5 (241)	50 (24)
.092 (2.3)	1/16 (1.6)	2.0	23	300	10.9 (277)	50 (24)
.125 (3.2)	1/16 (1.6)	2.2	23	300	12 (305)	50 (24)

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11.0.0 PREWELD PREPARATIONS

Preparation is the key to producing quality weldments with the gas metal arc welding process. Several operations may be required before making a weld. These include preparing the weld joint, cleaning the nozzle of the weld gun, setting up or fixturing the weldment, setting the variables, and in some cases preheating. The amount of preweld preparation depends upon the size of the weld, the material to be welded, the ease of fitup, the quality requirements, the governing code or specification, and the welder.

11.1.0 Preparing the Weld Joint

For the most part, the same joint designs recommended for other arc welding processes can be used for GMAW (refer to Course 3). However, some minor modifications should be considered due to the welding characteristics of the GMAW process. Since the arc in GMAW is more penetrating and narrower than the arc for shielded metal arc welding, groove joints can have smaller root faces and root openings. Also, since the nozzle does not have to be placed within the groove, less beveling of the plates is required. GMAW welding can actually lower material costs since you use less weld metal in the joint.

There are different ways of preparing the edges of the joint for welding. The methods most often used for edge preparation are oxygen fuel cutting, plasma arc cutting, shearing, machining, air carbon arc gouging, grinding, and chipping. When they can be used, the thermal cutting methods, oxy fuel, plasma arc cutting, and air carbon arc cutting are generally faster than the mechanical cutting methods, with the exception of shearing. Oxygen fuel cutting is used on carbon and low alloy steels; plasma arc cutting is used on ferrous and non-ferrous metals, and is best for applications where high production rates are required. Air carbon arc cutting is used for preparing joints in most steels including stainless steels, but this process should not be used on stainless steels for critical corrosion applications because of the carbon deposited, unless the cut surfaces are cleaned by grinding and brushing. The surfaces cut by these thermal methods often have to be ground lightly to remove scale or contamination. Common types of prepared joints are the V-, U-, J-, bevel-, and combination grooves, The more complex types of bevels require longer joint preparation times, which makes the joint preparation more expensive.

Since GMAW is used on all metal thicknesses, all of the different joint preparations are widely employed. Joints for fillet or square-groove welds are prepared simply by squaring the edges of the members to be welded if the as-received edge is not suitable.

Next to the square-edge preparation, the V-groove and single-bevel grooves are the types most easily prepared by oxygen fuel cutting, plasma arc cutting, chipping, or machining. These methods leave a smooth surface if properly done. The edges of U- and J-grooves can be done by using special tips and techniques with oxy fuel cutting or machining, which will produce a uniform groove. Carbon arc cutting is used extensively for preparing U-grooves in steels, and for removing part of root passes, so the joint can be welded from both sides. Chipping is done on the backside of the weld when full penetration is required on non-ferrous metals.

Weld backings are commonly used in GMAW to provide support for the weld metal and to control the heat input. Copper, steel, stainless steel, and backing tape, which are used as weld backing, are the three most common methods. Copper is a widely used method of weld backing because it does not fuse to thin metals. It also provides a fast cooling rate because of the high heat conductivity of copper, which makes this the best method of controlling the heat input. Steel backing is used when welding steels. These are fusible and remain part of the weldment unless they are cut off, usually by oxy fuel, air carbon arc cutting, or grinding. Stainless steels are good backing materials for GMAW of aluminum, magnesium, and the other non-ferrous metals. Backing tape is popular because it can be molded to any joint configuration, such as the inside of a pipe.

11.2.0 Cleaning the Work Metal

Welds made by gas metal arc welding are very susceptible to contamination during the welding process. The surface of the base metal must be free of grease, oil, paint, plating, dirt, oxides, or any other foreign material. This is especially critical when welding aluminum and the non-ferrous metals. Except for titanium, very dirty workpieces are usually cleaned by using solvent cleaners, followed by vapor degreasing. Simple degreasing is often used for cleaning metals that have oxide-free surfaces. Acid pickling is generally used for cleaning metals that have a light oxide coating; heavier oxide coatings are generally removed mechanically by grinding and abrasive blasting.

The type of cleaning operation will vary, depending on the type of metal. Aluminum forms a thick, refractory oxide coating, which has a high electrical resistance. This oxide coating is removed by de-oxidation with a hot alkaline cleaning solution, followed by rinsing in distilled water. Carbon and low alloy steels may be cleaned chemically in a hydrochloric acid solution. Nickel alloys and stainless steels may be cleaned by pickling, which removes iron, sand blast residue, and other contaminants. Titanium and titanium alloys may be cleaned in molten salt baths or by abrasive blasting. Chlorinated solvents, which are used for degreasing operations, should not be used on titanium because they will cause corrosion cracking. Welding should never be done near chlorinated solvents because the arc can create phosgene gas, which is toxic. Chemical cleaning can be done by pickling.

Just before welding, you should perform several other tasks. One is to file the edges of the joint smooth so there are no burrs. Burrs can cause physical pain as well as create a place to trap contaminants in a weld joint. You can use grinding on plain carbon and low alloy steels to remove burrs and rust or mill scale from the area in and around the joint. You should wire brush the surfaces of the joint and surrounding area. Use mild steel brushes for cleaning plain carbon and low alloy steel, and stainless steel wire brushes for cleaning stainless steel, aluminum, and the other non-ferrous metals.

You should also brush off the joint surfaces and surface of the previous weld bead between passes of a multiple pass weld. Use stainless steel brushes on these metals to avoid contamination due to rust or carbon from the mild steel wire brushes. Begin welding soon after cleaning, especially on metals that form moderate or thick surface oxides, such as stainless steel, aluminum, and magnesium. Wire brushing does not completely remove the oxide, but it reduces their thickness and makes the metals easier to weld. Wear gloves while cleaning stainless steels and non-ferrous metals to prevent oil or dirt from your fingers from getting on the joint surfaces, which can also cause contamination.

11.3.0 Fixturing and Positioning

Fixturing can affect the shape, size, and uniformity of a weld bead. Fixtures are devices that are used to hold the parts to be welded in proper relation to each other. When fixturing is not used, it usually indicates that the resulting weld distortion can be tolerated or be corrected by straightening operations. The three major functions of fixtures are the following:

- Locate and maintain parts in their positions relative to the assembly.
- Increase the welding efficiency of the welder.
- Control distortion in the weldment.

When a welding fixture is used, the components of a weldment can be assembled and securely held in place while the weldment is positioned and welded. Using these devices is dependent on the specific application. They are used more often when large numbers of the same parts are produced. When fixtures can be used, the production time for the weldments can be greatly reduced. They are also good for applications where close tolerances must be held.

Positioners are used to move the workpiece into a position so welding can be done more conveniently, which affects the appearance and quality of the weld bead. Positioning is sometimes needed simply to make the weld joint more accessible. The main objective of positioning is to put the joint in the flat or other more favorable position, which increases the efficiency of the welder because higher welding speeds can be used. This also allows the use of larger diameter wires with globular and high current spray transfer. These modes of metal transfer will produce the highest deposition rates, and flat position welding usually increases the quality of the weld because it makes the welding easier.

11.4.0 Preheating

Preheating is sometimes required, but this depends on the type of metal being welded, the base metal thickness, and the amount of joint restraint. The specific amount of preheat needed for a given application is often obtained from the welding procedure.

The preheat temperature of the metal is often carefully controlled. There are several good methods of performing this such as furnace heating, electric induction coils, and electric resistance heating blankets. On thin materials, hot air blasts or radiant lamps may be used. With these methods, temperature indicators are attached to the parts being preheated. Oxy fuel torches are another method of preheating. This method gives a more localized heating than the previously mentioned methods. When using oxy fuel torches, it is important to avoid localized overheating and deposits of incomplete combustion products from collecting on the surface of the parts to be welded. There are several methods of measuring the temperature of preheat, such as temperature color crayons, pellets, and hand-held temperature indicators. The crayons and pellets melt at a specific predetermined temperature. The hand-held temperature indicators can give meter readings, digital readings, or recorder readings, depending on the type of temperature indicators.

Test Your Knowledge

13. Which is NOT a major type of welding variable?

A. Fixed
B. Primary adjustable
C. Secondary adjustable
D. Secondary fixed

14. What is the main objective of a positioning fixture?

A. Stop warping
B. Proper alignment
C. Increase access
D. Portability

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12.0.0 WELDING DISCONTINUITIES AND PROBLEMS

Once you get the feel of welding with GMAW equipment, you will probably find the techniques are less difficult to master than many of the other welding processes; however, as with any other welding process, GMAW does have some pitfalls. To produce good quality welds, you must learn to recognize and correct possible welding defects. The following are a few of the more common defects you may encounter, along with corrective actions that you can take.

12.1.0 Discontinuities Caused by Welding Technique

Like all welding processes, GMAW can develop discontinuities or defects that include one or a combination of multiple defects, including inclusions, porosity, wormhole porosity, undercutting, incomplete fusion, overlapping, melt-through, whiskers, excessive spatter, arc strikes, and craters.

These problems with the welding technique or procedure weaken the weld and can cause cracking. A poor welding technique and improper choice of welding parameters are major causes of weld defects. Some defects are caused by the use of improper base metal, filler metal, or shielding gas.

The base metal and filler metal should also be clean to avoid creating a discontinuity. These defects will appear in many of your early attempts, but will usually disappear as you put forth more practice effort and gain experience.

12.1.1 Inclusions

There are two basic types of inclusions that can occur in gas metal arc welding: slag inclusions and oxide inclusions (Figure 112). Inclusions cause a weakening of the weld and often serve as crack initiation points. GMAW does not have as many problems with slag inclusions as shielded metal arc welding because the weld puddle is protected by a shielding gas instead of by a slag layer. Some electrodes, particularly those used for welding steel, will sometimes leave small, glassy slag islands on the surface of the weld. Slag inclusions can be caused by welding over these in multiple pass welds. The best method of preventing this problem is to clean the surface of the weld bead, especially the toes of the weld where any slag can be easily trapped.

Figure 112 — Inclusions.

An oxide inclusion is a film type inclusion. These inclusions often occur when excessively high travel speeds are used when welding metals such as aluminum, magnesium, or stainless steel, which have heavy oxide coatings; the oxide coatings on the surface of these metals become mixed in the weld puddle. Methods of preventing or correcting this problem are to reduce the travel speed, increase the welding voltage, and use a more highly deoxidized type of electrode.

Another major cause of oxide inclusions is by welding the metal without cleaning. Because of the thick oxide coatings on the surface of aluminum, magnesium, and stainless steel, you should reduce the thickness of the oxide layer by chemical cleaning, grinding, or wire brushing before welding. This will decrease the chance of an oxide inclusion being formed.

12.1.2 Porosity

Porosity is the presence of gas pockets in the weld metal that may be scattered in small clusters or along the entire length of the weld (Figure 113). These voids left in the weld cause it to be weakened. Porosity may be internal, on the surface of the weld bead, or both.

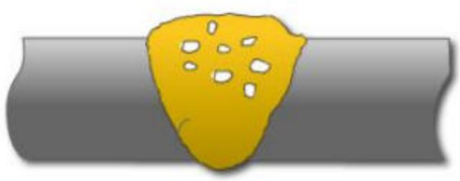

Figure 113 — Porosity.

This discontinuity is caused by one or more of the following:

- Inadequate shielding gas flow rate
- Wind drafts that deflect the shielding gas coverage
- Blockage of the shielding gas flow when spatter builds up on the nozzle
- Contaminated or wet shielding gas
- Excessive welding current.
- Excessive welding voltage
- Excessive electrode extension
- Excessive travel speed which causes freezing of the weld puddle before gases can escape
- Rust, grease, oil, moisture, or dirt on the surface of the base metal or filler wire including moisture trapped in aluminum oxide
- Impurities in the base metal, such as sulfur and phosphorous in steel

Porosity can be prevented or corrected by the following:

- Increasing the shielding gas flow rate.
- Setting up wind shields.
- Cleaning the nozzle of the welding gun.
- Replacing the cylinder of shielding gas.
- Lowering the welding current (reducing the wire feed speed).
- Decreasing the voltage.
- Decreasing the electrode extension.
- Reducing the travel speed.
- Cleaning the surface of the base metal or filler metal.
- Changing to a different base metal with a different composition.

12.1.3 Wormhole Porosity (Piping Porosity)

Wormhole porosity is the name given to elongated gas pockets, and is usually caused by sulfur in the steel or moisture on the surface of the base metal which becomes trapped in the weld joint (Figure 114). Wormhole porosity can seriously reduce the strength of the weld. The best methods of preventing this are to clean the surfaces of the joint and preheat to remove moisture. If sulfur in the steel is the problem, a more weldable grade of steel should be selected.

Figure 114 — Wormhole.

12.1.4 Undercutting

Undercutting is a groove melted in the base metal next to the toe or root of a weld that is not filled by the weld metal (Figure 115). This is particularly a problem with fillet welds. Undercutting causes a weaker joint at the toe of the weld, which may result in cracking.

Figure 115 — Undercutting.

Undercutting can be caused by one or more of the following:

- Excessive welding current
- Arc voltage too high
- Excessive travel speed which does not allow enough filler metal to be added
- Erratic feeding of the electrode wire.
- Excessive weaving speed

Incorrect electrode angles, especially on vertical and horizontal welds It can be prevented by the following:

- Reducing the welding current.
- Reducing the welding voltage.
- Using a travel speed slow enough so the weld metal can completely fill all of the melted-out areas of the base metal.
- Cleaning the nozzle inside of the contact tube, or removing the jammed electrode wire.
- Pausing at each side of the weld bead when a weaving technique is used.
- Correcting the electrode angles being used.

12.1.5 Incomplete

Fusion Incomplete fusion occurs when the weld metal is not completely fused to the base metal (Figure 116). This can occur between the weld metal and the base metal, or between passes in a multiple pass weld. Incomplete fusion between the weld metal and the base metal is usually due to inadequate penetration. This is often a major problem with the short-circuiting mode of metal transfer. When short-circuiting welding is done, wider root openings are often used to allow better penetration. You should take more care when using a weaving technique to prevent creating an area of incomplete penetration because short-circuiting welding has the poorest penetration characteristics of the different modes of gas metal arc welding.

Figure 116 — Incomplete fusion.

Incomplete fusion between passes in a multiple pass weld is often caused by welding over a previous weld bead that has an excessive convexity. If an excessively convex weld bead is created, grind the surface off enough so complete fusion can be made by the next pass.

Causes of incomplete fusion can be the following:

- Excessive travel speed which causes an excessively convex weld bead or does not allow adequate penetration
- Welding current too low
- Poor joint preparation
- Letting the weld metal get ahead of the arc or letting the weld layer get too thick, which keeps the arc away from the base metal

Incomplete fusion can be prevented by the following:

- Reducing the travel speed.
- Increasing the welding current.
- Preparing the joint better.
- Using proper electrode angles or increasing the travel speed.

A special type of incomplete fusion is wagon tracks, shown in Figure 117. Wagon tracks are linear voids along both sides of a weld deposit and are usually caused by a highly convex weld bead. The area where the bead fuses to the side of the joint is depressed, and the following weld bead may not completely fill the void. The excessive convexity of the bead can be reduced by using a slightly higher arc voltage, or increasing the travel speed. If you must weld over a bead with an excessively convex profile, grinding is often required to make the voids more accessible.

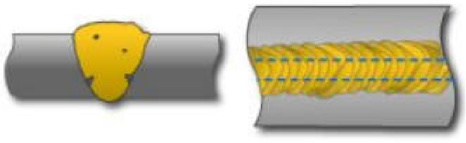

Figure 117 — Wagon tracks.

12.1.6 Overlapping

Overlapping is the protrusion of the weld metal over the edge or toe of the weld bead (Figure 118). This defect can cause an area of incomplete fusion which creates a notch and can lead to crack initiation. If this is allowed to occur, you can grind off the excess weld metal after welding.

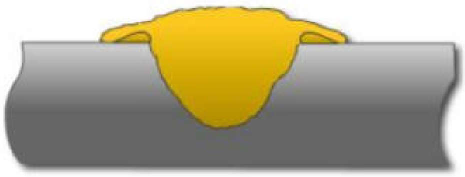

Figure 118 — Overlapping.

Overlapping is produced by one or more of the following:

- Too slow a travel speed, which permits the weld puddle to get ahead of the electrode
- Arc welding current that is too low.
- Incorrect electrode angle that allows the force of the arc to push the molten weld metal over unfused sections of the base metal

Overlapping can be prevented or corrected by the following:

- Using a higher travel speed.
- Using a higher welding current.
- Using the correct electrode angles.

12.1.7 Melt-through

Melt-through occurs when the arc melts through the bottom of the weld and creates holes (Figure 119).

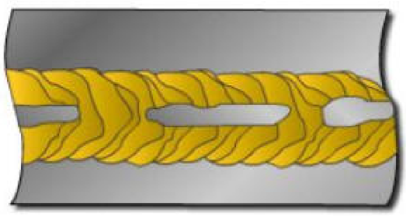

Figure 119 — Melt through.

This can be caused by one or more of the following:

- Excessive welding current
- Travel speed that is too slow
- Root opening that is too wide or a root face that is too small.

This can be prevented by the following:

- Reducing the welding current.
- Increasing the travel speed.
- Reducing the width of the root opening, using a slight weaving motion, or increasing the electrode extension.

12.1.8 Whiskers

Whiskers are short lengths of weld electrode wire, visible on the top or bottom surface of the weld or contained within the weld (Figure 120). They are caused by pushing the electrode wire past the leading edge of the weld puddle. The small sections of wire will protrude inside the joint and are welded to the deposited metal.

Figure 120 — Whiskers.

Whiskers can be prevented by:

- Reducing the travel speed.
- Using a weaving motion.
- Increasing electrode extension.
- Reducing electrode current.

12.1.9 Excessive Weld Spatter

Spatter consists of the metal particles expelled during welding. Excessive weld spatter creates a poor weld appearance, wastes electrodes, causes difficult slag removal, and can lead to incomplete fusion in multi-pass welds. In addition, excessive spatter can block the flow of shielding gas from the nozzle, which causes porosity. The amount of welding spatter produced in GMAW varies depending on the type of metal transfer and the type of shielding gas. For example, globular transfer with carbon dioxide shielding creates high levels of spatter compared to spray transfer with argon shielding.

Excessive spatter is caused by an excessive welding current, arc voltage, or electrode extension. Methods of reducing the amount of spatter would then be to reduce the welding current, the arc voltage, or the amount of stick-out. Another method of reducing weld spatter when using carbon dioxide shielding gas would be to change to an argon-carbon dioxide mixture, which in many cases produces spray transfer and less spattering. You can also remove spatter by grinding or chipping.

12.1.10 Arc Strikes

Many codes prohibit striking the arc on the surface of the workpiece. Striking the arc on the base metal outside of the weld joint can produce a hard spot on the base metal surface. Failures can then occur due to the notch effect. The arc strikes might create a small notch on the surface of the metal which can act as an initiating point for cracks.

12.1.11 Craters

Weld craters are depressions on the weld surface at the point where the arc was broken (Figure 121). These are caused by the solidification of the metal after the arc has been broken. The weld crater often cracks and can serve as an origin for linear cracking back into the weld metal or into the base metal. These craters can usually be removed by chipping or grinding and the depression filled in with a small deposit of filler metal.

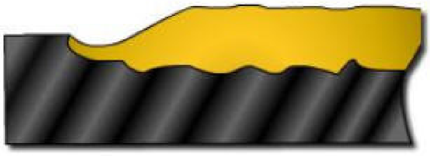

Figure 121 — Craters.

There are three common methods of preventing craters. The first is to reverse the travel of the electrode a little way back into the weld bead from the end before breaking the arc. For automatic welding, a downslope control is sometimes used. This is done by gradually reducing the welding current at the end of the weld, which gradually reduces the size of the molten weld puddle. The third method is by stopping the travel long enough to fill the crater before breaking the arc.

12.2.0 Cracking

Weldment cracking can be caused by an improper welding procedure, welder technique, or materials. All types of cracking can be classified as either hot or cold cracking. These cracks are transverse or longitudinal to the weld. Transverse cracks are perpendicular to the axis of the weld where longitudinal shrinkage strains are acting on excessively hard and brittle weld metal. Longitudinal cracks are often caused by high joint restraint and high cooling rates. Preheating will often help to reduce these problems.

Hot cracking occurs at elevated temperatures and generally happens just after the weld metal starts to solidify. This type of cracking is often caused by excessive sulfur, phosphorous, and lead contents in the steel base metal. In non-ferrous metals, it is often caused by sulfur or zinc. It can also be caused by an improper method of breaking the arc, or in a root pass when the cross-sectional area of the weld bead is small compared to the mass of the base metal.

Hot cracking often occurs in deep penetrating welds and can continue through successive layers if not repaired. Hot cracking may be prevented or minimized by the following:

- Preheating to reduce shrinkage stresses in the weld.
- Using clean or uncontaminated shielding gas.
- Increasing the cross-sectional area of the weld bead.
- Changing the contour of the weld bead.
- Using base metal with very low contents of those elements that tend to cause hot cracking.
- In steel, using filler metals that are high in manganese.

Crater cracks are shallow hot cracks caused by improperly breaking the arc; Figure 122 shows two types.

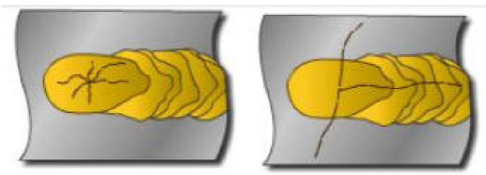

Figure 122 — Cracking.

Crater cracks may be prevented the same way craters are, by reversing the travel of the electrode back into the weld bead a little way, gradually reducing the welding current at the end of the weld, or by stopping the travel before breaking the arc.

Cold cracking occurs after the weld metal solidification is complete. Cold cracking may occur several days after welding and is generally caused by hydrogen embrittlement, excessive joint restraint, and rapid cooling. Preheating and using a dry high purity shielding gas help reduce this problem.

Centerline cracks are cold cracks that often occur in single pass concave fillet welds. A centerline crack is a longitudinal crack that runs down the center of the weld (Figure 123).

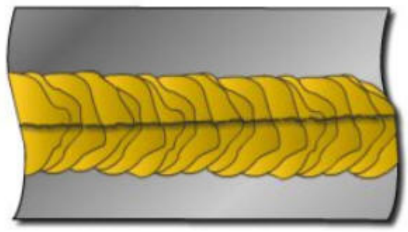

Figure 123 — Crater cracks.

This problem may be caused by one or more of the following:

- Weld bead too small for the thickness of the base metal
- Poor fitup
- High joint restraint
- Extension of a crater crack

The best methods of preventing centerline cracks are the following:

- Increasing the bead size.
- Decreasing the gap width.
- Preheating.
- Preventing weld craters.

Base metal and underbead cracks are cold cracks that form in the heat affected zone of the base metal. Underbead cracks occur underneath the weld bead, as shown in Figure 124. Base metal cracks are those cracks that originate in the heat affected zone of the weld. These types of cracking are caused by excessive joint restraint, entrapped hydrogen, and a brittle microstructure. A brittle microstructure is caused by rapid cooling or excessive heat input. Underbead and base metal cracking can be reduced or eliminated by using preheat.

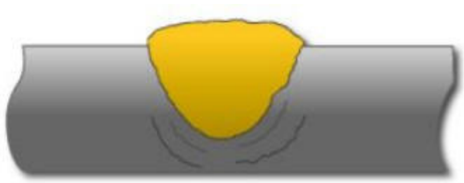

Figure 124 — Underbead cracks.

12.3.0 Other Problems

Other problems that can occur and reduce the quality of the weld are arc blow, loss of shielding gas coverage, defective electrical contact between the contact tube and the electrode, and wire feed stoppages.

12.3.1 Arc Blow

The electric current that flows through the electrode, workpiece, and work cable sets up magnetic fields in a circular path perpendicular to the direction of the current. When the magnetic fields around the arc are unbalanced, it tends to bend away from the greatest concentration of the magnetic field. This deflection of the arc is called arc blow. Deflection is usually in the direction of travel or opposite to it, but it sometimes occurs to the side. Arc blow can result in an irregular weld bead and incomplete fusion.

Direct current is highly susceptible to arc blow, especially when welding is being done in corners and near the end of joints. Arc blow occurs with direct current because the induced magnetic field is in one direction. Arc blow is shown in Figure 125.

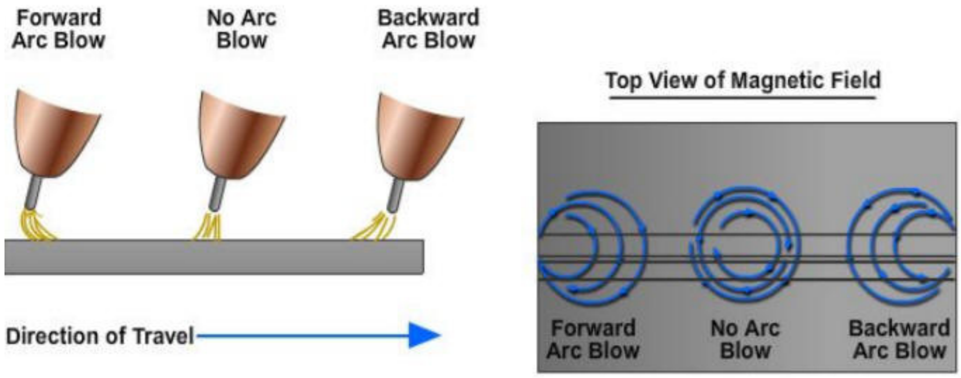

Figure 125 — Arc blow.

It is often encountered when welding magnetized metal or near a magnetized fixture. This problem also occurs when welding complex structures and on massive structures with high currents and poor fitup. Forward arc blow is encountered when welding away from the ground connection or at the beginning of a weld joint. Backward arc blow occurs toward the grounding connection, into a corner, or toward the end of a weld joint. You can use several corrective methods to correct the arc blow problem:

- Weld toward an existing weld or tack weld.
- Reduce the welding current and reduce the arc voltage.
- Place the work connection as far as possible from the weld, at the end of the weld, or at the start of the weld, and weld toward the heavy tack weld.
- Change the position of the fixture or demagnetize the base metal or fixture.

12.3.2 Inadequate Shielding

Many defects that occur in gas metal arc welding are caused by an inadequate flow or blockage of shielding gas to the welding area.

An inadequate gas supply can cause oxidation of the weld puddle, which causes porosity in the weld bead, usually appearing as surface porosity. This can be easily detected because the arc will change color, the weld bead will be discolored, and the arc will become unstable and difficult to control. The most common causes of this problem are the following:

- Blockage of gas flow in the torch or hoses, or freezing of the regulator with carbon dioxide
- Leak in the gas system
- Weld spatter blocking the nozzle of the welding gun
- Very high travel speed
- Improper flow rate
- Wind or drafts
- Distance between the nozzle and the work too long

There are several ways you can correct or prevent this problem. Check the torch and hoses before welding to make sure the shielding gas can flow freely and is not leaking. Clean spatter from the nozzle and contact tube regularly. A very high travel speed may leave the weld puddle or part of it exposed to the atmosphere. This may be corrected in some cases by inclining the gun in the direction of travel, using a nozzle that directs shielding gas back over the heated area, or by increasing the gas flow rate. The best method is to slow the travel speed.

Increasing the gas flow rate will increase the expense of the welding. An improper flow rate may occasionally be a problem. For example, when using argon and welding in the overhead position, you may have to use higher gas flow rates to provide adequate shielding. This is because argon is heavier than air and it will fall away from the weld area. Too high of a flow rate can cause excessive turbulence in the weld puddle.

When winds or air drafts are present, you may take several corrective steps. Setting up screens around the operation is the best method of solving this problem. Increasing the gas flow rate is another method, but again, this will increase the cost of welding. An excessive distance between the end of the nozzle and the molten weld puddle will also create a problem in providing adequate shielding, which can be corrected by shortening this distance.

12.3.3 Clogged or Dirty Contact Tube

The power delivered to the arc in GMAW depends on a transfer of current from the tip of the contact tube to the electrode by means of a sliding contact tube. A clogged, dirty, or worn contact tube can cause changes in the amount of power transferred to the electrode, which can have an effect on the arc characteristics. It can also cause an irregular weld bead and possibly incomplete fusion because of the power fluctuations. A clogged contact tube can stop the feed of the electrode wire, which stops the welding arc. A contact tube can become dirty or clogged by spatter from the arc, by rust, scale, copper wire coating, drawing compounds left from the manufacture of the wire on the surface of the electrode, or by metal chips created by tight wire feed rolls. These problems can best be prevented by making sure that the electrode wire is clean and the wire feed rolls are tight enough to feed the wire without creating chips. A wire wipe made of cloth is often attached to the wire feeder to clean the electrode wire as it is fed.

12.3.4 Wire Feed Stoppages

GMAW has the greatest problem with wire feed stoppages compared to the other continuous wire feed welding processes because of the relatively small diameter of the electrode wires used. Wire feed stoppages cause the arc to be extinguished and can create an irregular weld bead because of the stops and starts. Wire stoppages can also cause a loss of welding time because many of the problems take a long time to correct when wire becomes wrapped around the wire feed rolls, wadded up in bird nests in the wire feeder, or broken.

Wire feed stoppages can be caused by the following:

- Clogged contact tube
- Clogged conduit in the welding gun assembly
- Sharp bends or kinks in the wire feed conduit
- Excessive pressure on the wire feed rolls which can cause breakage of the wire
- Inadequate pressure on the wire feed rolls
- Attempting to feed the wire over excessively long distances
- Spool of wire clamped too tightly to the wire reel support

Problems such as sharp bends or kinks in the wire feed conduit, excessive pressure on the wire feed rolls, or attempting to feed the wire over excessively long distance are particularly troublesome when using soft electrode wires such as aluminum, magnesium, and copper. In many cases, wire feed stoppages must be corrected by taking the gun assembly apart and cutting and removing the wire or by cutting and removing the wire from the wire feeder. These both result in time lost to locate the problem and feed the new length of wire through the assembly to the gun.

Wire stoppages can be prevented by the following:

- Cleaning the contact tube.
- Cleaning the conduit, which is usually done with compressed air.
- Straightening or replacing the wire feed conduit.
- Reducing the pressure on the wire feed rolls to prevent breakage.
- Increasing the pressure on the wire feed rolls to provide adequate driving force.
- Using a shorter distance from the wire feeder to the gun or from the wire feeder to the electrode wire source.
- Reducing clamping pressure on the spool of wire.

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13.0.0 POSTWELD PROCEDURE

Several operations may be required after welding, such as cleaning, inspecting the welds, and postheating. These are items which may or may not be part of the procedure. The operations performed will depend on the governing code or specification, type of metal, and the quality of the weld deposit.

13.1.0 Cleaning

Gas metal arc welding generally produces a very smooth weld bead with very little slag, so in some cases cleaning the weld bead may be omitted. When welding steel, you can remove the slag islands left by the process with a chipping hammer, an air chisel, or a grinder. Removal of these slag islands is particularly important between passes of a multiple pass weld because if they are not removed from the weld surface and then welded over, slag inclusions can be formed. A certain amount of spatter is normally produced, which you can remove by wire brushing, chipping, or grinding. Wire brushing or buffing may be required to remove the discoloration around the weld bead. Mild steel brushes can be used on most steels. Stainless steel brushes should be used on stainless steels and non-ferrous metals to prevent contamination by rust from a mild steel brush.

13.2.0 Inspection and Testing

Inspection and testing the weld to determine the quality of the weld joint are done after cleaning. The many different methods of inspection and testing were covered in previous courses. The uses of these methods will often depend on the code or specification that covered the welding. Testing of a weldment may be done nondestructively or destructively.

Nondestructive testing is used to locate defects in the weld and base metal. Of the many different nondestructive testing methods, some of the most widely used methods are visual, magnetic particle, liquid penetrant, ultrasonic, and radiographic. Visual, magnetic particle and liquid penetrant inspection are used to locate surface defects where ultrasonic and radiographic inspections are used to locate internal defects.

Destructive testing is used to determine the mechanical properties of the weld such as the strength, ductility, and toughness. Destructive testing is also done by several methods, depending on the mechanical properties being tested for. Some of the most common types of destructive testing are tensile bar tests, impact tests, and bend tests.

13.3.0 Repairing of Welds

Repairing the weld is sometimes necessary when defects are found during inspection. When a defect is found, it can be gouged, ground, chipped, or machined out depending on the type of material being welded. For steels, grinding and air carbon arc gouging are commonly used. Air carbon arc gouging is used on stainless steels when maximum corrosion resistance is required, after grinding or wire brushing the groove face to remove carbon deposits is done. It is not used on the non-ferrous metals because it causes contamination in the form of carbon deposits.

For the stainless steels and the non-ferrous metals, chipping is a common method of removing defects. Air carbon arc gouging is preferred for many applications because it is usually the quickest method. Grinding is popular for removing surface defects and shallow lying defects. Once the defects have been removed, the low areas created by the grinding and gouging can be rewelded using GMAW or some other welding process. The welds are then reinspected to make sure the defects have been properly repaired.

13.4.0 Postheating

Postheating is the heat treatment applied to the weld or weldment after welding. Postheating is often required after the weld has been completed, but this depends upon the type of metal being welded, the specific application, and the governing code or specifications. Many of the low carbon steels and non-ferrous metals are rarely postheated.

Various types of postheating are used to obtain specific properties. Some of the most commonly used postheats are annealing stress relieving, normalizing, and quenching and tempering. Stress relieving is the most widely used heat treatment after welding. Postheating is accomplished by most of the same methods used for preheating such as furnaces, induction coils, and electric resistance heating blankets. One method used for stress relieving that does not involve the reheating of the weldments is called vibratory stress relief. This method vibrates the weldment during or after welding to relieve the residual stresses during or after solidification.

Annealing is a process involving heating and cooling that is usually applied to induce softening. This process is widely used on metals that become very hard and brittle because of welding. There are several different kinds, and when used on ferrous metals it is called full annealing. Annealing is the heating up of a material to cause re-crystallization of the grain structure, which causes softening. Full annealing is a softening process in which a ferrous alloy is heated to a temperature above the transformation range and is slowly cooled to a temperature below this range. This process is usually done in a furnace to provide a controlled cooling rate.

Normalizing is a heat treatment that is applied only to ferrous metals. Normalizing occurs when the metal is heated to a temperature above the transformation range and is cooled in still air to a temperature below this range. The main difference between normalizing and annealing is that a normalized weldment is cooled in still air which produces a quicker cooling rate than an annealed weldment which is slowly cooled in a furnace. A normalizing heat treatment will refine the metal grain size and yield a tougher weld, where an annealing heat treatment will result in a softer weld

Stress relieving is the uniform heating of a weldment to a high enough temperature below the critical range to relieve most of the residual stresses due to welding. This is followed by uniform cooling. This operation is performed on the ferrous metals and some of the non-ferrous metals. This process also reduces warpage during machining that may occur with a high residual stress buildup. Stress relieving is performed on nonferrous metal when stress buildup is a problem, but, for example in the case of aluminum alloys, this heat treatment also will reduce the mechanical properties of the base metal. In the case of magnesium alloyed with aluminum, stress relieving is performed to avoid problems with stress corrosion. On parts and metals that are likely to crack due to the internal stress created by welding, the parts should be put into stress relief immediately after welding without being allowed to cool to room temperature. The terms normalizing and annealing are misnomers for this heat treatment.

Quenching and tempering is another postweld heat treatment that is commonly used; the metal is heated up and then quenched to form a hard and brittle metallurgical structure. The weldment is then tempered by reheating to a particular temperature dependent on the degree of ductility, strength, toughness, and hardness desired. Tempering reduces the hardness of the part as it increases the strength, toughness, and ductility of the weld.

Test Your Knowledge

16. What causes inclusions?

  A. Steady travel speed
  B. Too narrow a weaving motion
  C. Slag left on the previous weld pass
  D. Too small an electrode being used

17. Why is a common non-stainless steel wire br ush NOT used on non-ferrous metals?

  A. It causes etching.
  B. The metal is too soft.
  C. It will cause a static charge to build up.
  D. It causes contamination in the form of carbon deposits.

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14.0.0 WELDER TRAINING AND QUALIFICATION

14.1.0 Welder Training

Gas metal arc welding requires a certain degree of welder skill to produce good quality welds. Semi-automatic GMAW requires that the welder must still control the manipulation of the welding gun and the speed of travel. This process will generally take less skill to operate when compared to the manual welding processes because the machine controls the arc length and feeds the filler wire. A welder who is skilled in the manual welding processes (SMAW, GTAW) will generally have less difficulty learning to weld with this process, but since the settings on the welding machine are more important, a higher knowledge of how the equipment works is needed.

The exact content of a training program will vary depending on the specific applications of the process. A training program should have enough flexibility so it can be adapted to changing needs and applications. Because of this, emphasis may be placed on certain areas of training based on the complexity of the parts to be welded, and the type of metal and governing code or specification. A pipe welding course would take more training than a plate welding course.

Because of the wide variety of ferrous and non-ferrous metals welded and the wide variety of equipment used, the exact content of a training course will vary. For example, welding aluminum takes different equipment and has different welding characteristics compared to welding steel. The major purpose of a training program is to give the welder the skill and knowledge to be able to do the best job possible. A training program may be broken up into several areas depending on the training requirements of the student. The training discussed in the rest of the course has been divided into several different areas.

14.1.1 Basic Gas Metal Arc Welding

The basic gas metal arc welding training program is used to teach the students the basic skills necessary to weld plate. This course provides training on how to make tack welds, strike the arc, make weld beads, and produce good quality fillet and groove welds. This course also gives the student the knowledge of the process of setting up the equipment and cleaning the metal, the basic operating principles, and the difficulties that are commonly encountered. The training obtained by the student should give the skill to perform a job welding plate material. This course should also provide the background skill and knowledge required to take an advanced course for welding pipe. The following is an outline for a course approximately 70 hours long.

1. Gas Metal Arc Welding Introduction
2. Safety and Health of Welders
3. Preparation for Welding
4. Surface Weld-Flat Position
5. Adjustment of Equipment
6. Square-Groove and Fillet Weld-Butt, Lap, Tee Joints-Flat Position (1 G, 1F)
7. Square-Groove and Fillet Weld-Butt, Lap, Tee Joints-Horizontal Position (2G, 2F)
8. Quality Butt and Fillet Welds
9. Square-Groove and Fillet Welds-Butt, Lap, Tee-Joints-Vertical Position, Down (3G, 3F)

10. Square-Groove and Fillet Weld-Butt, Lap, Tee-Joints-Vertical Position, Up (3G, 3F)
11. Metal Transfer and Shielding Gas
12. Square-Groove and Fillet Weld-Butt, Lap, Tee Joints-Overhead Position (4G, 4F)
13. Single-V-Groove Weld-Butt Joint-Horizontal Position (2G)
14. Single-V-Groove Weld-Butt Joint-Guided Bend Tests
15. Single-V-Groove Weld-Butt Joint-Vertical Position, Down (3G)
16. Single-V-Groove Weld-Butt Joint-Guided Bend Test
17. Variations of Gas Metal Arc Welding (Spray Transfer, Globular Transfer, Short-Circuiting Transfer, Spot Welding)
18. Single-V-Groove Weld-Butt Joint-Flat Position
19. Single-V-Groove Weld-Butt Joint-Overhead Position (4G)
20. Fillet Weld-Lap and Tee-Joints-Horizontal Position (2F)
21. Fillet Weld-Lap and Tee-Joints-Vertical Position, Down (3F)

A specific program could then be taken for welding the different non-ferrous metals. A program should explain the specific properties and welding characteristics of the metal. Other parts of the program should explain the types and compositions of the different alloys, the selection of filler metal and shielding gas, the equipment variations, and the special precautions such as cleaning and postweld operations. This training program should provide the student the basic skills necessary for the welding of these metals. The following course outline is for training of gas metal arc welding of aluminum and aluminum alloys. It is approximately 35 hours in length.

1. Introduction to "Gas Metal Arc Welding of Aluminum"
2. Safety and Health of Welders
3. Stringer Bead-Flat Position (Machine Adjustment)
4. Fillet Weld-Lap and Tee-Joint-Horizontal Position (2F)
5. Fillet Weld-Lap and Tee-Joints-Vertical Position, Up (3F)
6. Weldability of Aluminum Alloys
7. Fillet Weld-Tee-Joint-Overhead Position (4F)
8. Fillet Weld-Outside Corner and Tee-Joint Flat Position (1 F)
9. Shielding Gases for Gas Metal Arc Welding of Aluminum
10. Single-Vee-Groove Weld-Butt Joint-Flat Position (with backing) (1 G)
11. Fillet Weld-Outside Corner and Tee-Joint Vertical Position ,Up (3F)
12. Fillet Weld-Tee-Joint-Vertical Position Up (Visual and Etch Tests) (3F)
13. Fillet Weld-Tee-Joint-Overhead Position (4F)
14. Gas Metal Arc Welding of Non-ferrous Metals Other than Aluminum

14.1.2 Gas Metal Arc Welding Steel Pipe

Since pipe welding is more difficult than plate welding, the student should be skilled in welding groove joints in all positions on plate before welding pipe. Pipe welding usually involves fixed position welding. Vertical position, downhill welding is used on cross-country transmission pipelines. Vertical position, uphill welding is used on power plants, refinery, and chemical installation applications. The following outline is for a general course on pipe welding and is approximately 70 hours in length.

1. Introduction to Gas Metal Arc Pipe Welding
2. Safety and Health of Welders
3. Preparation of Equipment for Gas Metal Arc Pipe Welding
4. Preparation and Assembly of a Pipe Workpiece
5. Single-V-Groove Weld Butt Joint, Horizontal
6. Fixed Position Downhill Travel (5G)
7. Single-V-Groove Weld, Horizontal Fixed Position Travel, Guided Bend-Test (5G)
8. Single-V-Groove Weld, Butt Joint, Horizontal Fixed Position (5G), Downhill Travel-Root Pass, Uphill Travel-Fill and Cover Passes
9. Welding Discontinuities in Gas Metal Arc Pipe Welding

10. Single-V-Groove Weld, Butt Joint, Vertical Fixed Position (2G)
11. Single-V-Groove Weld, Vertical Fixed Position (2G), Guided Bend Test
12. Single-V-Groove Weld, Butt Joint, 45° Fixed Position (6G)

14.2.0 Welder Qualification

Before the welder can begin work on any job covered by a welding code or specification, the welder must become certified under the code that applies. Many different codes are in use today, and it is very important that the specific code is referred to when taking qualification tests. In general, the following types of work are covered by codes: pressure vessels and piping, highway and railway bridges, public buildings, tanks and containers, cross-country pipelines, ordnance material, ships and boats, and nuclear power plants. Several of the specifications include consideration of the GMAW process:

- ANSI/API 1104 Standard for Welding Pipelines and Related Facilities
- ASME Boiler and Pressure Vessel Code, Section IX, Welding and Brazing Qualifications
- ANSI/AWS 01.1 Structural Welding Code Steel
- AWS 05.2 Standard for Welded Steel Elevated Tanks, Standpipes, and Reservoirs for Water Storage
- AWS 010.9 Specification for Qualification of Welding Procedures and Welders for Piping and Tubing
- ANSI/AWS 014.1 Specification for Welding Industrial and Mill Crane and Other Material Handling Equipment
- ANSI/AWS 014.2 Specification for Metal Cutting Machine Tool Weldments
- ANSI/AWS 014.3 Specification for Welding Earthmoving and Construction Equipment
- ANSI/ASME B96.1 Specification for Welded Aluminum Alloy Storage Tanks
- Marine Engineering Regulations and Material Specifications (CG 115)

These specifications do not provide qualifications of the GMAW process for all applications and service requirements. For applications where AWS or other specifications are not available and generalized criteria for qualification are desired, AWS B3.0, Welding Procedure and Performance Qualification is often used. Certification is obtained differently under the various codes. Certification under one code will not necessarily qualify a welder to weld under a different code. In most cases, certification for one employer will not allow the welder to work for another employer. If the welder uses a different process or the welding procedure is altered drastically, recertification is required. In most codes, if the welder is continually employed, welding recertification is not required providing the work performed meets the quality requirements.

Qualification tests may be given by responsible manufacturers or contractors. On pressure vessel work, the welding procedure must also be qualified and this must be done before the welders are qualified; under other codes, this is not necessary. To become qualified, the welder must make specified welds using the required process, base metal, thickness, electrode type, position, and joint design.

Because of the versatility of the GMAW process, the type of metal transfer and shielding gas must also be considered. For example, in the AWS Structural Welding Code (01.1), certain joint designs are considered prequalified for gas metal arc welding in the spray and globular metal transfer modes. The short-circuiting mode is not considered prequalified for these joint designs because of the lower welding voltage and welding current values used, which can more easily cause an incomplete penetration discontinuity if the process is not used properly.

Test specimens must be made according to standardized sizes and under the observation of a qualified person. For most government specifications, a government inspector must witness making the weld specimens. Specimens must be properly identified and prepared for testing.

The most common test is a guided bend test. In some cases, radiographic examinations, fracture tests, or other tests are employed. Satisfactory completion of test specimens, providing they meet acceptability standards, will qualify the welder for specific types of welding. Again, the welding that will be allowed depends on the particular code. In general, the code indicates the range of thicknesses which may be welded, the positions which may be employed, and the alloys which may be welded.

Qualification of welders is a highly technical subject and cannot be covered fully here. You should obtain and study the actual code prior to taking any tests.

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15.0.0 WELDING SAFETY

Safety is an important consideration when welding. Every welding shop should have a safety program and take adequate safety precautions to protect welders. Every welder should be made aware of safety precautions and procedures. Employees who fail to follow adequate safety precautions can cause physical injury to themselves and others as well as damage to property. Failure to take safety precautions can result in physical discomfort and loss of property, time, and money. Welding is a safe occupation when safety rules and common sense are followed. A set of safety rules which should be followed is presented in the American National Standard Z49.1, "*Safety in Welding and Cutting*," published by the American Welding Society.

There are a number of hazards associated with gas metal arc welding. These do not necessarily result in serious injuries. They can also be of a minor nature which can cause discomforts that irritate and reduce the efficiency of the welders. These hazards are:

- Electrical shock
- Arc radiation
- Air contamination
- Compressed gases
- Fire and explosion
- Weld cleaning and other hazards

15.1.0 Electrical Shock

You can take several precautions to prevent an electrical shock hazard. First, make sure that the arc welding equipment is properly installed, grounded, and in good working condition. The electrical equipment should be maintained and installed in accordance with the National Electrical Code and any state and local codes that apply. Equipment should be operated within NEMA Standards usual operating conditions for proper safety and equipment life. The case or frame of the power supply should be connected to an adequate electrical ground such as an approved building ground, cold water pipe, or ground rod. Welding cables with frayed or cracked insulation and faulty or badly worn connections can cause electrical short circuits and shocks. An improperly insulated welding cable is both an electrical shock hazard and a fire hazard.

The welding area should be dry and free of any standing water. When it is necessary to weld in a damp or wet area, wear rubber boots and stand on a dry, insulated platform.

15.2.0 Arc Radiation

Gas metal arc welding produces an intense welding arc that emits ultraviolet and infrared rays. Skin exposed to the arc for a short time can suffer serious ultraviolet and infrared burns, which are essentially the same as sunburn, but the burn caused by welding can take place in a much shorter time and can be very painful. Because of this, you should always wear protective clothing suitable for the welding to be done. These clothes should be fairly heavy and not easily burned. Leather is often used to make jackets, capes, and bibs, or other similar arrangements to shield the arms, shoulders, chest, and stomach from the arc radiation and arc spatter. Leather is also used to make gloves for the welder.

You should also protect your eyes from the radiation emitted by the welding arc; otherwise, arc-burn can result. Arc-burn of the eye is similar to sunburn of the skin, and it is extremely painful for about 24 to 48 hours. Usually arc-burn does not permanently injure the eyes, but it can cause intense pain. There are several commercial solutions available to soothe the skin and eyes during the period of suffering. Infrared arc rays can cause fatigue of the retina of the eye.

The effects of infrared rays are not nearly as noticeable or immediate as the effects of ultraviolet rays. Infrared rays are probably more dangerous in that their effects can be longer lasting and result in impaired vision. Gas metal arc welding produces a brighter arc than shielded metal arc welding because there is no smoke and it is often used on bright shiny metals such as aluminum and stainless steel.

Protect your eyes and face by a head shield that has a window set in it with a filter lens in the window. Head shields are generally made of fiberglass or a pressed fiber material so they will be lightweight. The filter lens is made of a dark glass capable of absorbing infrared rays, ultraviolet rays, and most visible light coming from the arc. The type of lens used varies for different welders, but it should be dark enough so that you can view the arc without discomfort but not so dark that the you cannot see the puddle clearly while welding. Table 34 shows the different lenses commonly recommended for use in shielded metal arc welding (SMAW). The higher the lens numbers the darker the lens. A clear glass should be put on the outside of the welding lens to protect it from spatter and breakage. Never weld with a broken filter lens or cracks in your head shield.

Table 34 — Recommended Filter Lens Shades Used in Shielded Metal Arc Welding (ANSI/AWS Z49.1).

Electrode Diameter-In. (mm)	Lens Shade Number
1/16 (1.6), 3/32 (2.4), 1/8 (3.2), 5/32 (4.0)	10
3/16 (4.8), 7/32 (5.6), 1/4 (6.4)	12
5/16 (7.9), 3/8 (9.5)	14

15.3.0 Air Contamination

Provide enough ventilation wherever welding and cutting are performed. Proper ventilation will protect you from the evolving noxious fumes and gases. The degree and type of ventilation will depend on the specific welding and cutting operation. It varies with the size of work area, the number of operators, and types of materials to be welded or cut. Potentially hazardous materials may exist in certain fluxes, coatings, and filler metals, and they can be released into the atmosphere during welding and cutting.

In some cases, general natural-draft ventilation may be adequate. Other operations may require forced-draft ventilation, local exhaust hoods or booths, or personal filter respirators or air supplied masks. Welding inside tanks, boilers, or other confined spaces requires special procedures, such as the use of an air-supplied hood or hose mask. Check the welding atmosphere and ventilation system if workers develop unusual symptoms or complaints. Measurements may be needed to determine whether adequate ventilation is being provided. A qualified person, such as an industrial hygienist, should survey the welding operations and environment. Follow their recommendations for improving the ventilation of the work area. Do not weld on dirty plate or plate contaminated with unknown material; the fumes and gases formed could be hazardous to your health. Remove all paint and galvanized coatings before welding. Consider all fumes and gases as potentially hazardous. More complete information on health protection and ventilation recommendations for general welding and cutting can be found in the American National Standard Z49.1,"*Safety in Welding and Cutting*."

15.4.0 Compressed Gasses

Use compressed gases only for their intended purpose. Store cylinders containing oxygen separately from cylinders containing fuel gases. Securely fasten cylinders in use, or in stores or cargo, to prevent their shifting or falling under any weather conditions. Open the valve of the cylinder slowly and stand away from the face of the regulator when doing this. Never strike the welding arc on a compressed gas cylinder. When not in use, store gas cylinders with their caps on; caps should also be on when they are moved. If the valve should get knocked off, the cylinder acts like a missile because of the escaping gas and can cause injury and damage. When compressed gas cylinders are empty, the valve should be closed and they should be marked empty. This is done by marking the letters "MT" or "EMPTY" on the cylinder.

Move cylinders by tilting and rolling them on their bottom edges; avoid dragging and sliding cylinders. When cylinders are transported by vehicle, secure them in position. Cylinders should not be dropped, struck, or permitted to strike each other violently. Discontinue the use of any cylinder before the pressure falls to zero. In particular, oxygen cylinders should not be used in welding or cutting operations after the pressure falls below approximately 25 lb/in2 .

15.5.0 Fires and Explosions

Fires and explosions are hazards that can exist in a welding area if the proper precautions are not taken. The GMAW process produces sparks and spatters which can start a fire or explosion in the welding area if it is not kept free of flammable, volatile, or explosive materials. Welding should never be done near degreasing and other similar operations. Welders need to wear leather clothing to protect from burns because the leather is fireproof.

Fires can also be started by an electrical short or by overheated worn cables. In case of a fire that is started by a flammable liquid or an electrical fire, a CO_2 or dry chemical type of fire extinguisher is used. Fire extinguishers should be kept at handy spots around the shop and the welders should make a mental note of where they are located. Welders should not have disposable butane or propane lighters when welding. Sparks or weld spatter hitting them can cause an explosion which may cause injury.

Other precautions that have to do with explosions are also important. A welder should not weld on containers that have held combustibles unless it is certain that there are no fumes or residue left. Welding should not be done on sealed containers without providing vents and taking special precautions. When the welding gun is set down or not in use, it should never be allowed to touch a compressed gas cylinder.

15.6.0 Weld Cleaning and Other Hazards

You can also encounter hazards during the weld cleaning process. Take precautions to protect your skin and eyes from hot slag particles. The welding helmet, gloves, and heavy clothing protect your skin from slag chipping and grinding of the weld metal. Wear safety glasses with side shields underneath the welding helmet to protect your eyes from particles that could get inside the welding helmet. Set up screens if there are other people in the area to protect them from arc burn.

15.7.0 Summary of Safety Precautions

1. Make sure your arc welding equipment is installed properly, grounded, and in good working condition.
2. Always wear protective clothing suitable for the welding to be done.
3. Always wear proper eye protection when welding, grinding, or cutting.

4. Keep your work area clean and free of hazards. Make sure no flammable, volatile, or explosive materials are in or near the work area.
5. Handle all compressed gas cylinders with extreme care. Keep caps on them when they are not in use.
6. Make sure compressed gas cylinders are secured to the wall or other structural supports.
7. When compressed gas cylinders are empty, close the valve and mark the cylinder “Empty” or “MT.”
8. Do not weld in a confined space without extra special precautions.
9. Do not weld on containers that have held combustibles without taking extra special precaution.
10. Do not weld on sealed containers or compartments without providing vents and taking special precautions.
11. Use mechanical exhaust at the point of welding when welding lead, cadmium, chromium, manganese, brass, bronze, zinc, or galvanized steel.
12. When it is necessary to weld in a damp or wet area, wear rubber boots and stand on a dry, insulated platform.
13. Shield others from the light rays produced by your welding arc.
14. Do not weld near degreasing operations.
15. When the welding gun is not in use, do not hang it on a compressed gas cylinder.

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Summary

This course has introduced you to the GMAW process from the types of power sources, controls, and welding guns to the types of training and qualifications needed. It described the industries that use the GMAW process and its applications. Welding metallurgy, weld and joint design, and welding procedure variables were also discussed. The course concluded with a description of possible weld defects and how to identify them, and safety precautions used for the GMAW process. As always, refer to the manufacturer’s operator manuals for the specific setup and safety procedures of the welding machine you will be using.

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REVIEW QUESTIONS

1. What type of current is used in gas metal arc welding?

   A. Constant
   B. Indirect
   C. Unmodulated low frequency
   D. Modulated high frequency

2. How can the gas metal arc welding process be applied?

   A. Semi-automatically and manually
   B. Semi-automatically only
   C. Semi-automatically and mechanized
   D. Semi-automatically, mechanized, and automatically

3. What factors determine the size of a welding cable needed for a job?

   A. Size of the electrode and number of lock connections
   B. Amperage rating of the machine and distance from the work to the machine
   C. Size of the ground cable and capacity of the electrode holder
   D. Distance from the ground clamp and type of electrode

4. The use of a good ground clamp that provides proper grounding is essential to the production of quality welds. Which condition could develop without this proper grounding?

   A. Circuit voltage that fails to produce enough heat
   B. Damaged welding machine
   C. Damaged cables
   D. All of the above

5. Which safety device should you use to protect other personnel in a welding work area from eye flash burns?

A. Welding helmets
B. Flash goggles
C. Face masks
D. Welding screens

6. Electrodes manufactured in the U.S. must conform to what standards?

A. AISC/CRSI
B. AWS /ASTM
C. NAVOP 1061 (welding)
D. Engineering Standards, U.S.

7. When the gun is positive and the workpiece is negative, the electrons flow from the workpiece to the gun. What polarity is being used?

A. Straight
B. Negative
C. Positive
D. Reverse

8. What kind of sound does improper polarity emit?

A. Cracking
B. Humming
C. Whistling
D. Hissing

9. Which step do you take to correct arc blow?

A. Changing the position of the ground clamp
B. Welding away from the ground clamp
C. Changing to alternating current
D. All of the above

10. What is the first thing you should do to start an arc by the striking method?

A. Hold the electrode at right angles to the work and strike it sharply against the base metal.
B. Bring the electrode into contact with the work by using lateral motion.
C. Slowly lower the electrode onto the work until the arc strikes.
D. Place the electrode on the work until the base metal melts.

11. Upon striking an arc, you immediately start the weld to ensure good fusion and penetration.

A. True
B. False

12. What condition occurs when the welding current is too high?

A. Overlap
B. Poor fusion
C. Undercutting
D. Porosity

13. What condition(s) can develop when the welding current is too low?

A. Overlap only
B. Poor fusion only
C. Undercutting and poor fusion
D. Overlap and poor fusion

14. What kind of sound does a good arc produce when the electrode, current, and polarity are correct?

A. Sharp cracking
B. Humming
C. Whistling
D. Hissing

15. What is the maximum thickness, in inches, a plate can be welded in one pass, without edge preparation?

A. 1/16
B. 1/8
C. 3/16
D. 1/4

16. For what purpose do you use a backing strip when making a butt weld on 3/16- inch plate or heavier in the flat position?

A. To reinforce the weld.
B. To hold plates in position while tack welding in place.

C. To obtain complete fusion at the root pass of the weld.
D. To reflect the heat from the electrode.

17. What (a) width and (b) thickness, in inches, of backing strip should be used on plate over ½ inch thick?

A. (a.) 1 1/2 (b.) 1/4
B. (a.) 1 1/4 (b.) 3/8
C. (a.) 1 1/4 (b.) 1/8
D. (a.) 1 1/2 (b.) 1/4

18. What angle from the vertical should you hold the electrode when welding a lap joint on plates of varying thicknesses?

A. 15° to 20°
B. 20° to 30°
C. 30° to 40°
D. 40° to 50°

19. When vertical welding upwards, how many degrees do you hold the electrode to the vertical?

A. 30°
B. 45°
C. 60°
D. 90°

20. Which mistake can cause excessive spatter in welds?

A. Arc too short
B. Arc too long
C. Current too low
D. Rigid joints

21. Which mistake can cause cracked welds?

A. Improper welding procedures
B. Improper welder techniques
C. Improper welding materials
D. All of the above

22. Which mistake can cause poor penetration?

A. Current too low
B. Current too high
C. Welding speed too slow
D. Rigid joints

23. Which mistake can cause brittle welds?

A. Current too low
B. Current too high
C. Rigid joints
D. Faulty preheating

24. Only the single U-type of butt joint should be used to weld joints between pipes when pipe has what wall thickness?

A. ¼-inch or less
B. ½-inch or less
C. ½-inch or more
D. ¾-inch or more

25. A tack weld should not exceed what size when applied to a pipe with a wall thickness of ½ inch?

A. 1 inch long and two thirds of the thickness of the pipe in depth
B. ¾ inch long and two thirds of the thickness of the pipe in depth
C. ½ inch long and 2/3 inch deep
D. 1 ¼ inches long and 1/8 inch deep

26. The root of a fillet weld is where the _______.

A. edge of the weld intersects the base metal
B. back of the weld intersects the base metal surfaces.
C. face of the weld and the base metal meet
D. face and the toe meet

27. Which description refers to the face of a fillet weld?

A. Exposed surface of the weld
B. Edge of the weld that intersects the base metal
C. Groove face adjacent to the root joint
D. Separation between the members to be joined

28. Which description refers to the toe of a fillet weld?

    A. Junction between the face of the weld and the base metal
    B. Rippled surface of the weld
    C. Root of the weld to the face
    D. Edge of the weld that intersects the base metal

29. The leg of the weld is the _______.

    A. length of the weld
    B. distance from the root of the joint to the toe
    C. groove face adjacent to the root joint
    D. exposed surface of the weld

30. The throat of a fillet is the shortest distance from the _______.

    A. face to the toe
    B. root of the weld to the face
    C. root to the toe
    D. toe to the leg

31. The welding arc gives off ultra-violet rays which can cause eye injury. How can you prevent this injury?

    A. Wear the proper lens shade in the helmet
    B. Use eye drops
    C. Close your eyes
    D. Turn your head away from the arc

32. Ultra-violet rays from the arc _______.

    A. do not damage skin
    B. can cause skin damage similar to sunburn
    C. are a good source of vitamin C
    D. are harmful if inhaled

33. Welding on contaminated metal surfaces can create gases that are________.

    A. hazardous
    B. inert
    C. used as shielding gases
    D. benign

34. Compressed gas cylinders_______.

    A. should be kept at below freezing
    B. should be handled and stored with care
    C. need no special care
    D. should be painted fluorescent green

35. Compressed gases_______.

    A. are extremely expensive and should be used sparingly
    B. are not temperature sensitive
    C. may be used to blow dirt off clothes and work area
    D. are to be used only for the purpose intended

36. Safety glasses with side shields______.

    A. are not needed in welding areas
    B. should be worn during welding and cleaning operations
    C. are not authorized at any time during welding operations
    D. provide adequate protection for welding operations

37. When welding over a previously deposited bead, ______.

    A. hold a long arc to melt the slag on the previous bead
    B. use a weaving motion for deep penetration
    C. tap the weld bead and electrode several times
    D. clean the previous bead thoroughly before depositing the next weld

38. In a groove weld, the axis of a weld is ______.

    A. an imaginary line drawn through the weld along its length
    B. an imaginary line drawn through the weld across its width
    C. the rippled surface of the weld
    D. parallel to the leg of the weld

39. In the flat position welding, the face of the weld is approximately_____.

    A. perpendicular
    B. at a right angle

C. horizontal
D. vertical

40. Horizontal position fillet welding is performed . _____

A. with the electrode in the horizontal position
B. with the electrode in the vertical position
C. on the upper side of an approximately horizontal surface and against an approximately vertical surface
D. on the lower side of an approximately vertical surface against an approximately horizontal surface

41. When making a horizontal fillet weld in a lap joint, the electrode should be positioned with a______ work angle and a _______ travel angle.

A. 30°; 15°
B. 10°; 45°
C. 45°; 30°
D. 30°; 45°

42. Tack welds should be______.

A. cleaned before the weld is made
B. half the length of the weld joint
C. welded over without cleaning
D. only on opposite corners

43. Excess weld metal beyond the toe line of the weld is called______.

A. excessive penetration
B. dross
C. overlap
D. fingernailing

44. The distance that the fusion zone extends below the surface of the base metal is called______.

A. intrusion
B. penetration
C. undercutting
D. a crater

45. The metal particles expelled during welding which do not form a part of the weld are called______.

A. porosity
B. spatter
C. dross
D. inclusions

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