Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

*Principles of Shielded Metal Arc Weldin*g, Miller Electric Manufacturing Company, Appleton, WI.

Safety in Welding, Cutting, and Allied Processes, ANSI/ASC Z49.1:2005 An American National Standard, American Welding Society, Miami FL, 2005.

Shielded Metal Arc Welding, Hobart Institute of Welding Technology , Troy Ohio,1998.

Welding and Allied Processes, S9086-CH-STM-010/CH-074R4, Commander, Naval Sea Systems Command, Washington Navy Yard, Washington D.C.,1999*.*

Welding Theory and Application, TC 9-237, Department of the Army Technical Manual, Headquarters, Department of the Army, Washington D.C., 1993.

Welding Theory and Application, TM 9-237, Department of the Army Technical Manual, Headquarters, Department of the Army, Washington D.C., 1976.

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Chapter 9

Gas Tungsten Arc Welding

Topics

To hear audio, click on the box.

Overview

The gas tungsten arc welding (GTAW) process, also known as tungsten inert gas (TIG) welding, uses a non-consumable tungsten electrode to produce the weld. A shielding gas (usually an inert gas such as argon), protects the weld area from atmospheric contamination, and the process normally uses a filler metal, though some welds, known as ***autogenous*** (aw-t**oj**-*uh-nuhs*) welds, do not require a filler metal.

A constant-current welding power supply produces energy that is conducted across the arc through a column of highly ionized gas and metal vapors known as plasma. Welders most commonly use TIG to weld thin sections of stainless steel and non-ferrous metals such as aluminum, magnesium, and copper alloys.

TIG provides the welder with greater control over the weld than competing procedures such as shielded metal arc welding (SMAW) and gas metal arc welding (GMAW), thus allowing for stronger, higher quality welds. However, GTAW/TIG is comparatively more complex and difficult to master (closer tolerance requirements and filler metal usually added by other hand), and is significantly slower than most other welding techniques as well.

This chapter will present a basic understanding of the GTAW/TIG process and equipment, along with the key variables that affect the quality of welds. It will also cover core competencies such as setting up equipment, preparing materials, fitting up, starting an arc, welding pipes and plates, and repairing welds. Lastly, you will get an understanding of the safety precautions for GTAW/TIG and an awareness of the importance of safety in welding.

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

Objectives

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

1. Describe the process of gas tungsten arc welding.
2. Describe the principles of operation used for gas tungsten arc welding.
3. Describe the equipment associated with gas tungsten arc welding.
4. Describe the processes for installation, setup, and maintenance of equipment for gas tungsten arc welding.
5. State the shielding gas and electrodes for gas tungsten arc welding.
6. Identify the welding applications for gas tungsten arc welding.
7. Describe the welding metallurgy of gas tungsten arc welding.
8. Identify weld and joint designs used for gas tungsten arc welding.
9. Describe the welding procedure variables associated with gas tungsten arc welding.
10. Identify welding procedure schedules used for gas tungsten arc welding.
11. Describe preweld preparations for gas tungsten arc welding.
12. Identify defects and problems associated with gas tungsten arc welding.
13. Describe postweld procedures for gas tungsten arc welding.
14. State the welder training and qualifications associated with gas tungsten arc welding.
15. Describe the welding safety associated with gas tungsten arc welding.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	STEELWORKER BASIC
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet-Metal and Fiberglass Duct		
Welding Quality Control		
Flux Core Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features that make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 INTRODUCTION to the PROCESS

Gas tungsten arc welding (GTAW) is an arc welding process that produces coalescence of metals by heating them with an arc between a tungsten (non-consumable) electrode and the work. Shielding comes from a gas or gas mixture (*Figure 9-1*). Both pressure and filler metal may or may not be used. This process is also known as TIG welding, which stands for tungsten inert gas welding, unless you are on deployment in Europe, where you may hear it called WIG welding, using Wolfgram, the German word for tungsten. Throughout this chapter, the process will be referred to as TIG.

Figure 9-1 — Gas tungsten arc welding.

The gas tungsten arc welding process is very versatile. This process may be used to weld ***ferrous*** and a wide variety of ***non-ferrous*** metals. It is an all-position welding process. Welding in other than flat positions depends on the base metal, the welding current, and the skill of the welder. The process was developed for the "hard-to-weld" metals and can be used to weld more different kinds of metals than any other arc welding process.

Gas tungsten arc welding has an arc and a weld pool clearly visible to the welder. It produces no slag for entrapment in the weld, and no filler metal carries across the arc, so there is little or no spatter. Because the electrode is non-consumable, you can make a TIG weld by fusing the base metal without a filler wire.

The TIG welding process was invented by Russell Meredith of Northrop Aircraft's welding group in 1941. Mr. Jack Northrop's dream was to build a magnesium airframe for lighter, faster warplanes. This new process was called "Heliarc," as it used an electric arc to melt the base material and helium (He) to shield the molten puddle. The Linde Division of Union Carbide bought the patents, developed a number of torches for different applications, and sold them under the brand name Heliarc. Linde also developed procedures for using argon (Ar) gas, a more readily available and less expensive gas than helium.

At first, only direct current with a positive electrode was used. However, the electrode tended to overheat and deposit particles of the tungsten electrode in the weld. This problem was overcome by making the electrode negative, which then also made it satisfactory for welding stainless steel.

During World War II, welding machines producing alternating current and high frequency stabilization were developed. Alternating current with a superimposed high frequency, high voltage current over the basic welding current achieved good quality welding of aluminum and magnesium. With helium largely replaced by argon due to its greater availability, the gas tungsten arc welding process became more widely accepted by the early 1950s, and today is classified by the American Welding Society by that term.

1.1.0 Methods of Application

Welders can apply the gas tungsten arc welding process by the manual, semiautomatic, machine, or automatic methods, although the manual method produces the greatest majority of work; the torch is operated by hand, and filler metal, if used, is added with the other hand. A foot pedal is an additional refinement that controls the amount of welding current and switches the current on and off. TIG allows the welder extreme control for precision work by very closely controlling the heat and accurately directing the arc.

Operators can also use TIG semi automatically, that is by operating the torch by hand with a wire feeder adding the filler metal automatically. Semiautomatic gas tungsten arc welding is rarely used; however, machine and automatic methods are becoming increasingly popular for many applications.

TIG machine welding occurs when equipment performs the welding only under the control and observation of the welding operator.

Automatic welding occurs when the equipment performs the welding without adjustment or control by a welding operator. The amount of automation or mechanization applied to the process depends on the accessibility of the joint, quality control requirements, number of identical welds to be made, and the availability of capital.

1.2.1 Advantages and Limitations

TIG welding generally produces welds far superior to those produced by metallic arc welding electrodes. Especially useful for welding aluminum, it is quite useful for welding many other types of metals as well. The TIG process is most effective for joining metals up to 1/8 inch thick, although you can use it to weld thicker material with appropriate preheating.

Gas tungsten arc welding has many advantages over most other types of welding processes. The outstanding features are the following:

1. It makes high quality welds in almost all metals and ***alloys.***
2. There is no slag, so very little, if any, postweld cleaning is required.
3. There is no filler metal carried across the arc, so there is little or no spatter.
4. Welding can be performed in all positions.
5. Filler metal is not always required.
6. Pulsing may be used to reduce the heat input.
7. The arc and weld pool are clearly visible to the welder.
8. Because the filler metal does not cross the arc, the amount added is not dependent on the weld current level.

The limitations of the gas tungsten arc welding process include the following:

1. The welding speed is relatively slow.
2. The electrode is easily contaminated.
3. It is not very efficient for welding thick sections because deposition rates are low.
4. The arc requires protection from wind drafts that can blow the stream of shielding gas away from the arc.

2.1.1 PRINCIPLES of OPERATION

TIG uses the heat produced by the arc between the non-consumable tungsten electrode and the base metal. An inert shielding gas supplied through the torch shields the molten weld metal, heated weld zone, and non-consumable electrode from the atmosphere. The gas protects the electrode and molten material from oxidation, and provides a conducting path for the arc current.

An electric current passing through an ionized gas produces an electric arc. In this process, the inert gas atoms are ionized by losing electrons and leaving a positive charge. Then the positive gas ions flow to the negative pole and the negative electrons flow to the positive pole of the arc. The intense heat developed by the arc melts the base metal and filler metal (if used) to make the weld. As the molten metal cools, coalescence occurs and the parts join.

There is little or no spatter or smoke. The resulting weld is smooth and uniform, and requires minimum finishing (*Figure 9-2*).

You do not need to add filler metal when welding thinner materials, edge joints, or flange joints. This is known as autogenous welding. For thicker materials, an externally fed or "cold" filler rod is generally used. The filler metal in gas tungsten arc welding does not transfer across the arc, but is melted by it.

Figure 9-2 — TIG process.

You strike the arc in one of three ways:

1. By briefly touching the electrode to the work and quickly withdrawing it a short distance.
2. By using an apparatus that will cause the arc to jump from the electrode to the work.
3. By using an apparatus that starts and maintains a small pilot arc. This pilot arc provides an ionized path from the main arc.

The torch then progresses along the weld joint manually or mechanically after remaining in one place until a weld puddle forms. Once the welder obtains adequate fusion, the torch moves along the joint so the adjacent edges join and the weld metal solidifies along the joint behind the arc, thus completing the welding process.

2.1.0 Arc Systems

The TIG process uses a constant current power source, either direct or alternating current. A constant current welding machine provides nearly constant current during welding, so both stick (SMAW) and TIG (GTAW) can operate from the same power supply. The exception is that you do not need a high frequency attachment, often added for gas tungsten arc welding, to scratch start the arc.

The constant current output is obtained with a drooping volt-ampere characteristic, which means that the voltage is reduced as the current increases. The changing arc length causes the arc voltage to increase or decrease slightly, which in turn changes the welding current. Within the welding range, the steeper the slope of the volt-ampere curve, the smaller the current change for a given change in the arc voltage. *Figure 9-3* shows volt-ampere curves for different welding machine performance characteristics. This shows several slopes, all of which can provide the same normal voltage and current.

Figure 9-3 — Volt-ampere curves.

Differences in the basic power source design cause the variations in power sources. A machine with a higher short circuit current will give more positive starting. A steep volt-ampere characteristic is generally the most desirable when the welder wants to achieve maximum welding speeds on some welding jobs. The steeper slope gives less current variation with changing arc length, and gives a softer arc.

The types of machines that have this kind of curve are especially useful on sheet metal. These types of machines are also typically used for welding at high current levels. On some applications, such as all-position pipe welding, a welder may want a less steep volt-ampere characteristic for better arc control with high penetration capability. Machines with a less steep volt-ampere curve are also easier to use for depositing the root passes on joints that have varying fitup. This power source characteristic allows the welder to control the welding current in a specific range by changing the arc length. This type of machine also produces a more driving arc.

Test your Knowledge (Select the Correct Response)

1. The predominant shielding gas used for TIG is ________.

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

2. How is the arc struck using the manual TIG process?

   A. Holding the electrode to the work until a puddle is formed.
   B. Briefly tapping the electrode on the work.
   C. Depressing the torch trigger and the arc will start.
   D. Clipping the grounding strap on the workpiece.

3.1.1 EQUIPMENT for WELDING

A typical TIG welding system usually consists of the following elements:

1. Welding power supply
2. Welding torch
3. Tungsten electrode
4. Welding cables
5. Gas shielding system

Since welders can apply TIG by various methods with a wide variety of equipment configurations, often they will include several available items of optional equipment such as water circulators, foot rheostats, programmers, motion devices, oscillators, automatic voltage controls (AVC), and wire feeders. *Figure 9-4* shows a diagram of the equipment used for a manual welding setup.

Figure 9-4 — Equipment for gas tungsten 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. Manufacturers offer several various sizes and types of power sources for gas tungsten arc welding. Most of these power sources operate on 230 or 460 volt input electric power. Power sources that operate on 200 or 575 volt input power are available as options.

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. For rating a welding machine, a ten minute time period is used. Thus, for a machine rated at a 60% duty cycle, the rated welding current load could be safely applied continuously for six minutes and be off for four minutes. Most power sources used for gas tungsten arc welding have a 60% duty cycle. For the machine and automatic methods, a welding machine with 100% duty cycle rating would be best, but these are not normally available.

The formula for determining the duty cycle of a welding machine for a given current load is:

$$\%\ Duty\ Cycle = \frac{(Rated\ Current)^2}{(Load\ Current)^2} \times (Rated\ Duty\ Cycle)$$

For example, if a welding machine is rated at a 60% duty cycle at 300 amperes, the duty cycle of the machine when operated at 250 amperes would be:

$$\%\ Duty\ Cycle = \frac{(300)^2}{(250)^2} \times 60 = 86\%$$

Figure 9-5 represents the ratio of the square of the rated current to the square of the load current, multiplied by the rated duty cycle. This chart can be used instead of working out the formula. A line is drawn parallel to the sloping lines through the intersection of the subject machine’s rated current output and rated duty cycle. For example, a question might arise whether a 300 amp 60% duty cycle machine could be used for a fully automatic requirement of 225 amps for a 10-minute welding job. The chart shows that the machine can be safely used at slightly over 230 amperes at a 100% duty cycle. Conversely, there may be a need to draw more than the rated current from a welding machine, but for a shorter period. This graph can be used to compare various machines. All machines should be rated to the same duty cycle for comparison.

Figure 9-5 — Duty cycle vs. current load.

3.2.0 Types of Welding Current

The type of power source determines the type of current available. The most important factor in selecting the type of current is the type of metal to be welded. The thickness of the metal can also have an influence. You can use either alternating or direct current for both gas tungsten arc welding and high frequency arc ignition, and you may pulse the welding current.

3.2.1 Direct Current

You can connect direct current in one of two ways: electrode negative (straight polarity)DCEN or electrode positive (reverse polarity)DCEP. The electrically charged particles flow between the tip of the electrode and the work (*Figure 9-6*). You can use electrode negative for welding all metals.

Follow special procedures to weld alloys of magnesium and aluminum, which have a refractory surface oxide that hinders their fusion. You can make welds on aluminum and magnesium with a short arc length using electrode negative and a helium-bearing shielding gas, but you can weld these metals more easily by using electrode positive because this connection breaks down the oxide layers on the surfaces.

Figure 9-6 — Negative and positive polarity.

The main problem with using electrode positive is that the current carrying capacity of the electrode is extremely low. In fact, the electrode will begin to melt if the currents are too high. For this reason, you should rarely use electrode positive except for welding thin sheet metal.

3.2.2 Pulsed Current

The pulsed current method of TIG employs two levels of welding current instead of a steady current. The welding current switches periodically between the high and low levels to produce a pulsating current or arc. See *Figure 9-7* for a diagram of pulsed direct current. This pulsed current produces a continuously welded seam consisting of overlapping arc spot welds. *Figure 9-8* shows a cross-sectional view of the pulsed current weld bead. Each of the spots is produced by the high level welding current after which the current is switched to the lower level. This lower level allows the weld to solidify partially between spots and maintains the arc to avoid re-ignition problems. Pulsed current may be used with direct or alternating current, but it is most commonly used with direct current.

Figure 9-7 — Pulsed current terminology.

Figure 9-8 — Weld produced by pulsed current.

The pulsed direct current method of gas tungsten arc welding has several advantages over steady direct current for welding thin materials. The pulsed method is more tolerant of edge misalignment, normal fixturing can be used with thinner materials, and it gives better distortion control and root penetration. For open root welding, the high pulse provides high current for complete penetration, but the low pulse cools the puddle down to prevent burning through at the root of the joint. Pulsing reduces the heat input to the base metal. This is particularly good for welding thin stainless steel sheet metal, which distorts very easily without pulsed current. Another advantage of pulsed current is that it is very good for welding in the vertical and overhead positions because good penetration is obtainable with less heat input. Pulsing keeps the weld puddle from getting too large to control because of the partial solidification that occurs during the low current.

The number of pulses used can vary from about ten per second down to about one or one-half per second. The length of time the high current is on and the length of time the low current is on are variable, as well as the percentage of low current with respect to the high current.

3.2.3 Alternating Current

Alternating current is a combination of both polarities that alternate in regular cycles. In each cycle, the current starts at zero, builds up to a maximum value in one direction, decays back to zero, builds up to a maximum value in the other direction, and decays back to zero. The arc goes out during the zero portion of the cycle, so a high frequency current in the welding circuit reignites the arc.

Using alternating current provides the advantages of both direct current electrode positive (reverse polarity) without the current limitations, and direct current electrode negative without the oxide cleaning problems. For this reason, welders generally use alternating current for manual welding aluminum and magnesium.

However, in the alternating current circuit, there is a tendency for the current to become unbalanced. The arc current flows more easily in one direction because it takes greater energy to obtain electrons from the base metal than from the tungsten electrode. The tungsten electrode emits electrons more easily because it becomes much hotter during welding than the base metal does. The amplitude of the current in the cycle, when the electrode is negative, is normally higher than it is during the cycle when the electrode is positive. This tends to produce an unbalanced current. Operators can use either series connected capacitors or insert a direct current voltage in the welding circuit to balance the current. Balanced current is desirable for some applications like high-speed mechanized welding, but it is not necessary for most manual welding applications.

Balanced current flow has three main advantages:

1. Better oxide-cleaning action
2. Better and smoother welding action
3. No reduction in the output rating of a conventional welding transformer

Disadvantages of a balanced current flow are the following:

1. It requires larger electrodes.
2. Wave balancing systems are more expensive.

3.2.4 High-Frequency Current

The high-frequency current is a separate, superimposed current used to maintain a pilot arc and help start the arc. The pilot arc does not do any welding, but it is needed to start the welding arc without touching the electrode to the work when using either direct or alternating current.

When using alternating current, the high frequency current keeps the arc from going out when the alternating current changes cycles, from positive to negative or negative to positive.

When using direct current, the high frequency only helps to start the arc and may be turned off after establishing the arc. Using a high frequency current is the best starting method because touching the tip of the electrode to the work or starting on a piece of carbon can contaminate the tungsten electrode.

When using this superimposed high frequency current with AC TIG, you need to take certain precautions because the high frequency spark gap oscillators in the power sources radiate power at frequencies that can interfere with commercial, police, and aviation radio broadcasts. It can also interfere with television transmissions. Because of this, the operation of high frequency for AC is subject to control by the Federal Communication Commission in the United States, and most other countries have similar regulations.

When installing a welding machine that uses high frequency stabilizers, you must pay special attention to provide earth grounding and special shielding. Manufacturers provide special installation instructions that also require all metal conductors in the area of the machine to be earth grounded. These requirements help limit high frequency radiation. If you follow these instructions carefully, you can post a certificate stating that you reasonably expect the high frequency stabilizer to meet FCC regulations.

3.3.0 Types of Power Sources

Constant current (cc) machines can produce AC or DC welding power; they can be rotating (generators), static (transformer/rectifier), or three phase ***inverter*** machines.

3.3.1 Generator and Alternator Welding Machines

For shop use, an electric motor can power a generator welding machine, or an internal combustion engine (gasoline or diesel) can do it for field use. You can adjust generator welding machines intended for shielded metal arc welding to function for gas tungsten arc welding if you add an inert gas and a high frequency attachment.

You can adapt engine-driven, either water- or air-cooled welding machines as well, many of which also provide auxiliary power for emergency lighting, power tools, etc. Generator welding machines can provide DC power, and in some cases both AC and DC power to the arc, depending on the machine design.

You can also adapt alternator welding machines (also called rotating or revolving field machines) for gas tungsten arc welding. These machines consist of an electric generator made to produce AC power.

3.3.2 Transformer-Rectifier Welding Machines

Transformer-rectifier welding machines are used much more widely for gas tungsten arc welding than motor-generator welding machines. Transformer-rectifier machines provide both AC and DC welding current to the arc. A single phase transformer producing alternating current is connected to the rectifier, which then produces DC current for the arc. The rectifier is an electrical device which changes alternating current into direct current.

Transformer-rectifier welding machines operate on single phase input power (*Figure 9-9*), and because of this, an unbalance may be created in the power supply lines, which is objectionable to most power companies.

Figure 9-9 — Welding machine.

However, this type of welding machine is the most versatile for TIG because you can use it for welding a variety of base metals. A programmable type of transformer-rectifier power source is often used for TIG welding; the welder can select either AC or DC current for the application by simple means of a switch which can change the output terminals to the transformer or to the rectifier.

The transformer-rectifier welding machines are available in different sizes and have several advantages over rotating power sources:

1. Lower operating costs
2. Lower maintenance costs
3. Quiet operation
4. Lower power consumption while idling
5. No rotating parts

3.3.3 Inverter Power Sources

A recently developed machine uses the inverter and different levels of programming. These machines operate on three-phase input power. The three-phase input helps overcome the line unbalance that occurs with the single-phase transformer-rectifier machines. Inverters provide power down to .5 ampere with a very fast response time of one millisecond and less than 1 % ripple. Different programming is available, depending on the complexity of the job. The high frequency inverters are very quiet and provide outstanding arc stability.

3.3.4 Transformer Welding Machines

Transformer welding machines are not used often for gas tungsten arc welding except at home shops or small job shops where gas tungsten arc welding is used only occasionally. Transformer welding machines produce AC power only and operate on single-phase input power. Like generator welding machines intended for SMAW, you can also adapt transformer welding machines for TIG by adding an inert gas and a high frequency attachment.

The transformer welding machine takes power directly from the line, transforms it to the power required for welding, and by means of various magnetic circuits, inductors, etc., provides the volt-ampere characteristics proper for welding. The main advantage of the transformer is that it has the lowest initial investment cost and uses electric power efficiently. However, movable parts tend to vibrate, wear, and become loose, which creates undesirable noise.

3.3.5 Square Wave Power Source

To overcome the arc extinguishing-restriking problem, a square wave AC output power source was developed. Either the conventional constant current type or the constant voltage type of power source can use the square wave output form. In either case, the time for switching from positive to negative or negative to positive current pulse is approximately 50 to 150 microseconds; thus the arc is difficult to restart and is unstable.

Power electronics can be used to vary the positive and negative output of the machine. The area above the zero point on the curve (the direct current positive area) and the area below the curve (the negative area) can be equalized or balanced.

A power source developed specifically for gas tungsten arc and plasma arc welding provides a square-wave output form but also allows a balance or imbalance between the straight polarity and reverse polarity half-cycles of each cycle.

Figure 9-10 — Square wave output: balanced and unbalanced.

In welding aluminum, the electrode negative (straight polarity half-cycle) gives maximum penetration, whereas the electrode positive (reverse polarity half-cycle) provides for the cleaning action. It is advantageous to provide the most straight polarity half-cycle, and this is possible, as shown in *Figure 9-10*. This machine also has programming ability and encloses a high-frequency oscillator plus gas and water valves.

3.4.1 Controls

TIG welding machines have some or all of the following controls to operate the welding:

1. On-off power switch.
2. Polarity selection switch — for machines that produce DC power.
3. Welding current control — a knob or tap switch on the front of the welding machine that controls the amount of welding current delivered to the arc.
4. Foot pedal — an optional piece of equipment for manual welding. It starts the current flow, varies the current during welding, and reduces the current at the end of the weld. This control also starts the high frequency current when high frequency current is used.
5. High frequency control — turns the high frequency current on and off, and selects the type of high frequency current used. Continuous high frequency current is used for AC welding where high frequency current is needed only for arc starting with DC welding current. Also included is a knob to control the amount of high frequency current.
6. Hot start — a knob on some welding machines. When in use, this control causes the machine to furnish momentarily a surge of current substantially above the welding current to get the arc initiated. The knob can also set the amount of "hot start" current required.
7. Pulsation controls. When pulsed current is desired, several controls are usually needed.
8. Up-slope and down-slope controls — optional controls that are timers. The up-slope control allows the welding current to build up gradually at a set rate at the beginning of the welding. The down-slope control allows the welding current to decay gradually at a set rate at the end of the welding to prevent crater cracking.
9. Shielding gas controls — timers that can be set to start the flow of shielding gas before the welding current starts and to maintain gas shielding after the welding arc has been broken. Both of these controls are used to prevent oxidation of the tungsten electrode and contamination of the weld puddle when hot.

Several or all of these controls are used with a programmable panel (*Figure 9-11*) and are available in wide variety depending on the programmer used.

Figure 9-11 — Programmer.

3.5.0 Welding Torches

Torches for TIG welding, designed and used only for this process, are available in a variety of types and sizes. The torch conducts the welding current to the arc and the shielding gas to the arc area. It usually includes various cables, hoses, and adaptors for connecting the torch to the power, gas, and cooling supplies. Manual torches should also have a handle so the welder can manipulate the arc. *Figure 9-12* shows a manual gas tungsten arc welding torch. Manual torches can weigh from as little as three ounces (85 grams) to about sixteen ounces (450 grams), and are rated according to their maximum usable welding current. These torches can utilize various types and sizes of electrodes and nozzles while the angle of the electrode to the handle (the head angle) may vary from torch to torch. The most common head angle is 120 degrees, but some torches use 90-degree head angles and others have adjustable heads.

Figure 9-12 — Manual TIG torch.

There are two major types of welding torches used for TIG: air-cooled and water-cooled. The air-cooled torches are cooled by the flow of the shielding gas (which means that they really are gas-cooled). The only air cooling occurs from the heat radiating into the atmosphere.

Water-cooled torches have water circulating through the torch, which accounts for most of the cooling (*Figure 9-13*); the shielding gas does the rest. Air-cooled torches are

Figure 9-13 — Cross-section view of water-cooled torch.

usually small, lightweight, and less expensive than water-cooled torches, and with a maximum welding current of 200 amperes, they are used normally for welding thin metal. These torches are more versatile than water-cooled torches because no water is needed, but they are for low duty cycle welding because the tungsten electrode in an air-cooled torch becomes hotter than in a water-cooled torch, which can transfer tungsten to the weld, thus causing inclusions.

Water-cooled torches can operate continuously up to about 200 amperes, with some especially designed for welding currents up to 500 amperes. These torches are usually heavier (water hose and connectors usually come with the torch) and more expensive than the air-cooled types.

There are four types of nozzles or gas cups used for gas tungsten arc welding: ceramic, metal, fused-quartz, and dual-shield nozzles. They provide shielding gas to the welding electrode and metal. As a general rule the inside diameter of the gas nozzle should be three times larger than the electrodes diameter.

Ceramic nozzles are the cheapest and most popular type, but they are brittle. Ceramic nozzles are the best kind to use with high frequency current to prevent cross-firing to the nozzle.

Metal nozzles can be either the slip-on type or the water-cooled type. The slip-on type is limited to low current welding, whereas the water-cooled nozzles are usable with high welding current.

Fused-quartz nozzles are transparent and some welders prefer them for increased visibility, but the inside of the nozzle can be dulled by vapors when the electrode is contaminated, which impairs the vision.

Dual-shield nozzles allow a small amount of helium or argon around the electrode to shield the immediate weld puddle. Around the central part of the nozzle, an ***annular*** grooved section sends an atmosphere of carbon dioxide or nitrogen to keep air from contact with the central inert-gas shield. The industry rarely uses the dual-shield nozzle.

Inside the nozzle is the gas orifice. The gas orifice is a series of holes in the end of the collet body around the electrode that supplies the shielding gas into the nozzle. This gives a more even flow of shielding gas around the electrode (*Figure 9-14*).

Figure 9-14 — Parts of a manual torch.

Orbital welding heads are designed specifically to produce high quality welds in critical welding applications (*Figure 9-15*). Because companies related to the aircraft, pharmaceutical, semiconductor, food processing, and related industries require superior weld quality in terms of bead shape, integrity, and cleanliness, these advanced systems incorporate computer technology to control the variables in a weld.

Torch oscillation speed and width are independently adjustable and automatically synchronized to allow precise positioning of filler wire entry into the weld puddle, and compact wire feeders are controlled electronically for accuracy and repeatability.

Figure 9-15 — Tube-to-tube welding heads.

3.6.0 Gas Shielding System

Single cylinders, portable or stationary manifold systems, or pipes connected to bulk storage torches may supply the shielding gas. The most widely used form of gas flow control is the combination regulator and flowmeter (*Figure 9-16*). Flowmeters must be appropriate for the various shielding gases because they must be calibrated for a specific gas. Use only the regulators and flowmeters designed for a specific gas. There is a fundamental difference between the regulators used for oxy-fuel welding and those used for TIG/MIG welding. While both have a gauge that provides a tank/cylinder pressure and a second gauge, with oxy-fuel welding, the second gauge displays *pressure* as the working unit, and with TIG/MIG, the second gauge displays *flow* and the working unit. The working pressure on the oxy-fuel regulator is in pounds per square inch (psi), while the regulator for TIG/MIG is in cubic feet per hour (cfh) or liters per minute (lpm). See *Figure 9-16*.

Figure 9-16 — Regulator and flowmeter.

The flowmeter consists of a plastic or glass tube that contains a loosely fitting ball. As the gas flows up the tube, it passes around the ball and lifts it up: the more gas that moves up the tube, the higher the ball lifts.

The shielding gas regulator has a constant outlet pressure to the flowmeter of about 50 psig. This is important because the flowmeter scales are accurate only if the gas entering them is at that approximate pressure. If you use higher inlet pressures, the gas flow rate will be higher than the actual reading. The reverse is true if the inlet pressure is lower than 50 psig; therefore, it is important to use accurately adjusted regulators. With an accurate flowmeter, these regulators can deliver inert gas flows up to 60 cfh; read the scale by aligning the top of the ball with the cfh increment lines.

To obtain an accurate reading, you must mount the meter in a vertical position. Any slant will create an off-center gas flow and result in an inaccurate reading. As already mentioned, you need to use different flowmeters for different gases.

The flow of gas necessary for good TIG welding depends primarily on the thickness of the material, but there are other factors as well, including welding current, size of nozzle, joint design, speed of welding, and a draft-free area in the location of the welding. This last factor can affect gas coverage and usage considerably

Plastic hoses bring the shielding gas to the welding torch because helium will diffuse through the walls of rubber or rubber-fabric hoses. To standardize the hose system, these same plastic hoses are used for argon also. They may connect straight to the torch, or go through the power source or the inert gas attachment to the torch.

3.7.0 Welding Cables

The welding cables and connectors connect the power source to the torch and to the work, essentially the same as those used for SMAW. The cables are normally made of copper or aluminum and consist of hundreds of fine wires enclosed in an insulated casing of natural or synthetic rubber. The cable connecting the work to the power source is the work lead, which typically connects to the work by pincher, clamps, bolt, or special connection. The cable connecting the torch to the power source is the electrode lead, and it is part of the torch assembly.

The size of the welding cable used depends on the output capacity of the welding machine and the distance between the welding machine and the work. Cable sizes range from the smallest at ***AWG*** NO. 8 to AWG No. 4/0 with amperage ratings of 75 amperes and upward. *Table 9-1* shows recommended cable sizes for use with different welding currents and cable lengths.

Table 9-1 ─ Suggested copper welding cable sized for gas tungsten arc welding.

Weld Type	Weld Current	Length of cable circuit in feet – cable size A.W.G.					
		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			

3.8.0 Other Equipment

TIG is a very versatile process, and because of its versatility, there is a need for multiple types of torches, wire feeders, water circulators, and motion devices. The following presents some of the most common devices.

3.8.1 Filler Wire Feeders

When you use semiautomatic, machine, and automatic welding, and a filler metal is necessary, you need a filler wire feeder. For manual welding, you feed the filler metal by hand. You can feed filler metal into the pool either preheated (hot) or at room temperature (cold).

A cold wire feeding system consists of a wire drive mechanism, a speed control, and a wire guide attachment that directs the wire into the molten weld pool. The wire drive consists of a motor and gear train, which power a set of drive rolls to push the filler wire. A constant speed governor, either electronic or mechanical, functions as the wire feed speed control, and a flexible conduit connected to the drive mechanism usually guides the filler wire to the weld puddle. Often, the wire guide attaches to the torch, and it maintains the angle of approach to the weld puddle. For heavy duty applications, the wire guide is water-cooled.

Filler wires used for this application range from 1/32 inch (0.8 mm) to 3/32 inch (2.4 mm) in diameter. Generally, cold wire feeds into the leading edge of the weld puddle.

The equipment for a hot wire system is similar to that for cold wire, except it electrically preheats the wire with an alternating current from a constant voltage to the desired temperature before it reaches the weld pool. In many cases, a shielding gas protects the filler wire from oxidation.

The TIG hot wire method will give a high deposition rate comparable to using MIG. Sometimes this method is used to weld carbon and low alloy steels, stainless steels, copper alloys, and nickel alloys. Feed hot wire into the trailing edge of the weld puddle, but do not use hot wire for aluminum, aluminum alloys, and copper; they require very high heating currents which cause uneven melting and arc blow.

3.8.2 Water Circulators

When you use a water-cooled torch, you must have a continuous water supply via a water circulator or directly from a hose connection to a water tap. Hoses, which may or may not go through a valve in the welding machine, carry the water to the welding torch. *Figure 9-17 shows* a water circulator.

Figure 9-17 — Water circulator.

3.8.3 Motion Devices

Machine welding and automatic welding use motion devices to move the welding head, workpiece, or torch depending on the type and size of the work and the preference of the user.

Often, motor-driven carriages run on tracks or directly on the workpiece. Carriages are useful for straight line contour, vertical, or horizontal welding. Side beam carriages are supported on the vertical face of a flat track, and they can be used for straight line welding.

You can use welding head manipulators 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 be used also for semiautomatic welding with mounted welding heads.

Oscillators are optional equipment used to oscillate the torch for surfacing, vertical-up welding, and other welding operations that require a wide bead. Oscillators can be either mechanical or electromagnetic devices.

Orbital heads are compact, rugged, and clamp on a pipe or tube (*Figure 9-18*). To weld the smallest to the largest tubes, you will need a family of heads. These heads will rotate the torch around the pipe, continuously carrying the tungsten electrode. Multiple adjustments and computer control allow for precise positioning

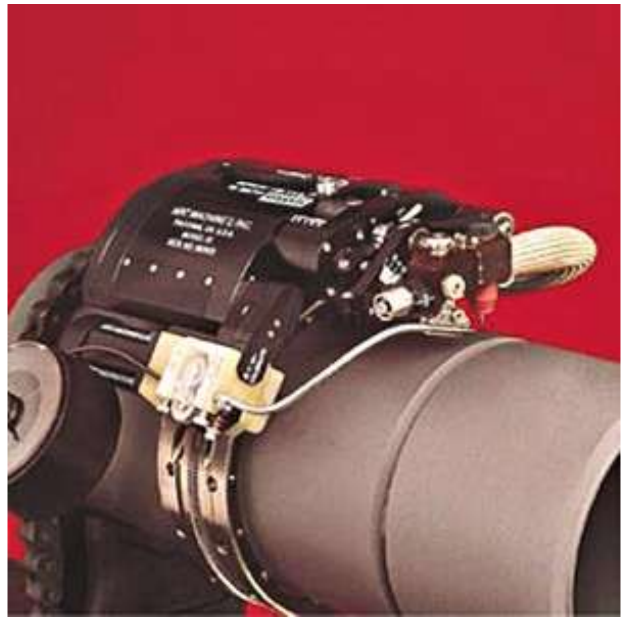

Figure 9-18 — Orbital welding head designed for low clearances.

Test your Knowledge (Select the Correct Response)

3. What is the most important factor in selecting power supply?

   A. Availability and type of power available
   B. Type of shielding gas to be used
   C. Type and thickness of the metal to be welded
   D. Skill level of the welder

4. Welding cables are most commonly made of which material?

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

4.0.0 EQUIPMENT SETUP, ADJUSTMENT, and SHUTDOWN

A basic knowledge of equipment setup, adjustment, and shutdown is necessary to make effective and efficient welds. This section will give you the basics of setup and electrode preparation. Always refer to the manufacturer's safety precautions and proper tip preparation. Also, always wear your safety glasses when you are in the welding area.

Attach the remote control to the remote control outlet on the power source.

Check torch cables and connect them to the power source.

Select the appropriate electrode for the job.

Ceriated tungstens (orange band) and lanthanated tungstens (black band) are the recommended alternatives to thoriated tungstens for DCEN applications if they are available. Use pure or zirconiated tungstens for AC welding with conventional sine wave or conventional square wave power sources.

4.2.0 Preparing the Electrode Tip

Taper the electrodes for DCEN welding to direct and control the arc. The taper angle of the electrode is the *included angle*. For most applications, a 30° taper about 2 1/2 to 3 electrode diameters long works well (*Figure 9-19*).

Round off pure and zirconiated electrodes for AC welding with conventional square wave power sources to withstand the heat generate during the electrode positive portion of the AC cycle.

Figure 9-19 — Preparing the tip.

The rounded tip should not exceed the diameter of the electrode. Otherwise, the arc may wander around the surface, making it hard to control (*Figure 9-20*).

Figure 9-20 — Rounded tip for conventional square wave.

You can use any of the alloyed tungstens for AC welding with inverters because you can adjust the positive portion of the AC cycle to provide just enough amperage for cleaning without overheating the tip of the electrode.

Match the collet and collet body to the electrode diameter.

Check the nozzle to make sure it is the proper size and is in good condition.

The nozzle should be a minimum of 3 times the diameter of the electrode.

Replace nozzles that are chipped, cracked, or badly worn. Damaged or dirty nozzles can alter the gas flow pattern and cause defects or discontinuities in the weld.

4.3.0 Assembling the Torch

Thread the collet body into the torch head.

Insert the collet into the collet body.

Install the nozzle.

Insert the electrode so the tip extends about 1/2 inch beyond the nozzle.

Screw the cap into the back of the torch head and tighten it lightly so the electrode will move with finger pressure.

Adjust the electrode stickout and tighten the cap to secure the electrode in place.

Place the torch on its hanger so it will not arc when you turn the power switch on. Do not lay it across the welding table.

Refer to *Figure 9-21* for assembly.

Figure 9-21 — Torch assembly.

4.4.0 Setting Up the Shielding Gas System

Chain the cylinder in place and remove the cap.

Stand away from the valve port. Open and close the valve quickly to blow out any dirt before attaching the regulator.

Install the regulator and flow meter assembly.

Attach the gas hose to the flow meter.

Attach the other end of the hose to the connection on the power source.

Open the cylinder valve slowly until pressure registers on the regulator; then open the valve all the way.

Turn the power source on and tap the foot pedal to start the flow of gas.

Adjust the flow meter to approximately 15 to 20 cubic feet per hour (cfh) for argon.

Set the post flow time on the power source (1 second for every 10 amps).

Test for leaks by closing the cylinder valve. If the regulator pressure drops, check the hose and the connections at the power source, flow meter, and cylinder for leaks.

4.5.0 Setting Up the Welding Parameters

Set the amperage control to the maximum setting required for the job.

Set the high-frequency switch to start (automatic) for DC welding, or to continuous for conventional square wave AC.

Adjust the high frequency intensity control.

Run a few test welds on scrap material to fine tune the settings.

4.6.0 System Shutdown and Clean Up

Shut the system down when the job is completed. Close the valve on the gas cylinder.

Tap the foot pedal to bleed off the shielding gas.

Close the valve on the flow meter.

Turn off the power source.

Clean up your work area.

As a safety precaution, turn the power switches on the wire feeder and the power source to the off position before checking electrical connections.

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

5.0.0 ELECTRODES, SHIELDING GAS, and FILLER METAL

The electrodes used for this process are non-consumable, so a tungsten electrode is needed as well as a filler rod if any filler metal is to be added. The shielding gas is an important consumable of gas tungsten arc welding because its main purpose is to shield the electrode and molten weld puddle from the atmosphere. Filler metal may or may not be added, depending on the specific welding application.

5.1.1 Electrodes

TIG uses a non-consumable or nearly non-consumable electrode made of tungsten or tungsten alloys that melt at 6170 degrees Fahrenheit (3410 degrees Celsius), which is the highest melting point of all metals. It is virtually impossible to vaporize a tungsten electrode during welding, provided you use the electrode within the current-carrying capacity range for its specific type and diameter, with sufficient inert shielding gas. Tungsten retains its hardness, even at red heat.

There are several types of electrodes for gas tungsten arc welding. These are made of pure tungsten or alloyed with thoria, zirconia, ceria, lanthana, or a combination of oxides (*Table 9-2*). Welding electrodes are classified by chemical composition and are identifiable by colored markings in the form of bands, dots, etc. on the surface of the electrode. The AWS classification uses letters to distinguish differences in the electrodes. The first two letters of a tungsten electrode are E for electrode and W for tungsten the next letter represents the material the electrode is made of.

Tungsten electrodes usually come in lengths of 3 to 24 inches (76-610 mm) in diameters from .01 to 1/4 inch (.25 to 6.4 mm). *Table 9-3* shows the types of tungsten electrodes used for welding different metals. *Table 9-4* shows the welding current ranges for tungsten electrodes.

Generally, you will use pure tungsten electrodes (green marking) on the less critical applications with alternating current; they have a relatively low current-carrying capacity and a low contamination resistance, but they give good arc stability.

The tungsten electrodes alloyed with 1% (yellow marking) or 2% (red marking) thoria have several advantages over pure tungsten electrodes. These electrodes have higher current-carrying capacities, longer life, higher electron emissivity, and greater contamination resistance. Thoriated tungsten electrodes also give easier arc starting and a more stable arc.

Ceriated tungsten electrodes (orange marking) contain cerium oxide and have a reduced rate of vaporization or burn-off, as compared with pure tungsten electrodes.

The EWLa (black marking) electrodes contain lanthanum oxide and are very similar to the ceriated tungsten electrodes. EWZr (brown marking) electrodes contain a small amount of zirconium oxide. Their welding characteristics generally fall between those of pure and thoriated tungsten, but they have a higher resistance to contamination. The EWG (gray marking) electrodes contain an unspecified addition of oxides (rare earth or others) which affect the characteristics of the arc.

Table 9-2 — Chemical composition requirements for electrodes (AWS A5.12).

		Weight Percent					
AWS Classification	**UNS Number[b]**	**W Min. (difference)[c]**	**CeO^2**	**La_2O_3**	**ThO_2**	**ZrO_2**	**Other Oxides or Elements Total**
EWP	R07900	99.5					.5
EWCe-2	R07932	97.3	1.8-2.2				.5
EWLa-1	R07941	98.3		.9-1.2			.5
EWTh-1	R07911	98.3			.8-1.2		.5
EWTh-2	R07912	97.3			1.7-2.2		.5
EWZr-1		99.1				.15-.4	.5
EWG[d]	R07920	94.5					.5

Notes

a. The electrode shall be analyzed for the specific oxides for which values are shown in this table. If the presence of other elements or oxides is indicated, the amount of those elements or oxides shall be determined to ensure that their total does not exceed the limit specified for “Other Oxides or Elements, Total” in the last column of the table

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

c. Tungsten content shall be determined by calculating the measures content of all specified oxides and elements and subtracting the total form a 100%.

d. Classification EWG must contain some oxide or element additive and the manufacturer must identify the type and nominal content of the oxide or element additive.

Table 9-3 — Types of tungsten electrodes and shielding gasses.

Type of Metal	Thickness	Type of Current	Electrode	Shielding Gas
Aluminum	All Thick Only Thin Only	AC DCEN DCEP	Pure, Zirconium Thoriated Thoriated, Zirconium	Argon, Argon-helium Argon-helium, Argon Argon
Copper + Copper Alloys	All Thin Only	DCEN AC	Thoriated Pure, Zirconium	Argon, Argon-helium Argon
Magnesium Alloys	All Thin Only	AC DCEP	Pure, Zirconium Zirconium Thoriated	Argon Argon
Nickel + Nickel Alloys	All	DCEN	Thoriated	Argon
Plain Carbon +Low Alloy Steels	All	DCEN	Thoriated	Argon, Argon-helium
Stainless Steel	All	DCEN	Thoriated	Argon, Argon-helium
Titanium	All	DCEN	Thoriated	Argon

Table 9-4 — Typical current ranges for tungsten electrodes. (AWS A5.12).

Electrode Diameter		DCEN (DCSP)	DCEP (DCRP)	Alternating Current Unbalanced Wave		Alternating Current Balanced Wave	
		A	A	A		A	
in.	mm	EWX-X	EWX-X	EWP	EWX-X	EWP	EWX-X
.010	.30	Up to 15	na[b]	Up to 15	Up to 15	Up to 15	Up to 15
.020	.50	5-20	Na	5-15	5-20	10-20	5-20
.040	1.00	15-80	Na	10-660	15-80	20-30	20-60
.060	1.60	70-150	10-20	50-100	70-150	30-80	60-120
.093	2.40	150-250	15-30	100-160	140-235	60-130	100-180
.125	3.20	250-400	25-40	150-200	225-325	100-180	160-250
.156	4.00	400-500	40-55	200-275	300-400	160-240	200-320
.187	5.00	500-750	55-80	250-350	400-500	190-300	290-390
.250	6.40	750-1000	80-125	325-450	500-630	250-400	340-525
Notes							

Notes:

a. All are values based on the use of argon gas. Other current values may be used depending on the shielding gas, type of equipment, and application.

b. na = not applicable

5.2.0 Shielding Gases

Argon and helium or mixtures of the two gases are the most widely used shielding gases for gas tungsten arc welding. The characteristics most desirable for shielding purposes are chemical inertness and an ability to produce smooth arc action at high current densities. Argon and helium are both inert, which means that they do not form compounds with other elements. Inert shielding gas is used because it will protect the tungsten electrode as well as the molten weld metal from contamination. Special applications may call for the addition of hydrogen and nitrogen as well. In addition to showing the types of tungsten electrodes used for welding different metals, *Table 9-3* shows the type of shielding gas recommended when welding different metals.

Gas purity can have a considerable effect on welding. Metals such as carbon steel, stainless steel, copper, and aluminum will usually tolerate very small amounts of impurities. For the best results, the purity rating should be 99.99+%. Titanium and zirconium have a very low tolerance to impurities, and you should use only the very purest shielding gas.

5.2.1 Argon

Argon is a heavy gas obtained from the atmosphere by the liquefaction of air, and is available as a compressed gas or a liquid, depending on the volume of use. It is obtained at much lower prices in the bulk liquid form compared to the compressed gas form, and it is the most widely used type of shielding gas for gas tungsten arc welding.

Argon has several advantages over helium:

1. Quieter and smoother arc action.
2. Easier arc starting.
3. Lower arc voltage for current settings and arc lengths. This is good on thin metals.
4. Good cleaning action, which is preferred for the welding of aluminum and magnesium
5. Lower flow rates are required for good shielding. Argon is heavier than air.
6. Lower cost and more availability.
7. Better resistance to cross-drafts.
8. Better for welding dissimilar metals.
9. Better weld puddle control in the overhead and vertical positions.

5.2.2 Helium

Helium is a light gas obtained by separation from natural gas. It is available as a liquid but used more often as compressed gas in cylinders. Since helium is lighter than air, it leaves the welding area quicker and therefore requires higher flow rates. Another disadvantage is that it is more expensive and is less available than argon. Helium does have several advantages over argon shielding gas:

1. Gives a smaller heat affected zone.
2. Produces higher arc voltages for given current settings and arc lengths. This is good on thicker metals and metals with high conductivity.
3. Is better for welding at higher speeds.
4. Gives better coverage in vertical and overhead positions.
5. Provides deeper penetration because of more heat input.
6. Tends to flatten out the root pass of the weld bead when used as a backing gas.

5.2.3 Argon-Helium Mixtures

The argon-helium mixtures provide the better control of argon and the deeper penetration of helium. Common mixtures of these gases by volume are 75% helium-25% argon, or 80% helium-20% argon. A wide variety of mixtures is available, particularly for their wide usage in automatic welding.

5.2.4 Argon-Hydrogen Mixtures

Welders use mixtures of argon and hydrogen when welding stainless steel, Inconel, Monel, and when porosity is a problem; in some cases, no other shielding gas can prevent porosity.

Argon-hydrogen mixtures increase the welding heat, help control the weld bead profile, and give the weld puddle better wetting action and a more uniform weld bead. This gas mixture is not completely inert.

Do not use argon-hydrogen mixtures for welding plain carbon or low alloy steels, but you can use it for stainless steel with the hydrogen percentage up to 15%. A typical argon hydrogen mixture is 95% argon and 5% hydrogen.

5.2.5 trogen

You can use nitrogen as a shielding gas to obtain higher voltage and produce higher current, but it is rarely done. The efficiency of heat transfer is higher than for either helium or argon, which makes nitrogen good for welding copper and copper alloys. However, nitrogen will reduce arc stability and contaminate the electrodes because it is not an inert gas. If you use thoriated electrodes, there is negligible contamination by the nitrogen.

5.3.0 Filler Metals

Since the TIG process can weld a wide variety of metals, it generates a need for various filler metals. *Table 9-5* lists the American Welding Society specifications covering the different filler metals used for gas tungsten arc welding. The selection of the proper filler metal is primarily dependent on the chemical composition of the base metal; filler metals are often similar to the base metal, although not necessarily identical.

Manufacturers produce filler metals with closer control on chemistry, purity, and quality than for base metals. The choice of a filler metal for a given application depends on the suitability for the intended operation, the cost, and the metallurgical compatibility. The required tensile strength, impact toughness, electrical conductivity, thermal conductivity, corrosion resistance, and weld appearance of a weldment are also important considerations. Deoxidizers added to the filler metals can give better weld soundness as well.

Table 9-5 — American Welding Society filler metal specifications that cover the different metals welded by the gas tungsten arc welding process.

Metals	AWS Filler Metal Specification Number
Copper and Copper Alloys	A5.7
Stainless Steel	A5.9
Aluminum and Aluminum Alloys	A5.10
Surfacing Welding Rods and Electrodes	A5.13
Nickel and Nickel Alloys	A5.14
Titanium and Titanium Alloys	A5.16
Carbon Steels	A5.18
Magnesium Alloys	A5.19
Composite Surfacing Welding Rods and Electrodes	A5.21
Zirconium and Zirconium Alloys	A5.24
Copper and Copper Alloy Gas Welding Rods	A5.27
Low Alloy Steels	A5.28
Consumable Inserts	A5.30

5.3.1 Classification

The American Welding Society devised the classification system for filler metal used with gas tungsten arc welding. In this system, designations for filler metal rods consist of the letters ER (for electrode or rod) and an alloy number in most cases. The difference between an electrode and a rod is that an electrode carries welding current and the metal transfers across the arc, but a filler rod is added directly to the weld puddle without electricity running through it.

Because gas tungsten arc welding filler rods are generally chosen based on chemical composition, they are also classified according to their chemical composition. This is not true of the specification for carbon and low alloy steel welding rods, which are classified according to mechanical properties and chemical compositions.

An example of a classification is an ER4043 aluminum welding rod. The ER indicates that the wire is usable as either an electrode or a filler wire, and the 4043 indicates the chemical composition as shown in *Table 9-6*.

The classification of other non-ferrous metals and stainless steels are similar; *Table 9-7* shows manganese classifications, *Table 9-8 the* copper and copper alloys, *Table 9-9* the stainless steels, and *Table 9-10* the nickel and nickel alloys.

Table 9-6 —Aluminum filler metal classifications (AWS A5.10).

		Weight Percentage [a,b]									Other Elements		
AWS Classification	UNS Number[c]	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Each	Total	Al
ERII00	A91100	d	d	.05-0.20	0.05				0.1		0.05e	0.15	99.0 min[f]
RII00	A91100	d	d	.05-0.20	0.05				0.1		0.05e	0.15	99.0 min[f]
ERI188g	A91188	0.06	0.06	0.005	0.01	0.01			0.03	0.01	0.01e		99.88 min[f]
R1188g	A91188	0.06	0.06	0.005	0.01	0.01			0.03	0.01	0.01e		99.88 min[f]
ER2319h	A92319	0.2	0.3	5.8-6.8	0.20-0.40	0.02			0.1	0.10-0.20	0.05e	0.15	Remainder
R2319h	A92319	0.2	0.3	5.8-6.8	0.20-0.40	0.02			0.1	0.10-0.20	0.05e	0.15	Remainder
ER4009	A94009	4.5-5.5	0.2	1.0-1.5	0.1	0.45-0.6			0.1	0.2	0.05e	0.15	Remainder
R4009	A94009	4.5-5.5	0.2	1.0-1.5	0.1	0.45-0.6			0.1	0.2	0.05e	0.15	Remainder
ER4010	A94010	6.5-7.5	0.2	0.2	0.1	0.30-0.45			0.1	0.2	0.05e	0.15	Remainder
R4010	A94010	6.5-7.5	0.2	0.2	0.1	0.30-0.45			0.1	0.2	0.05e	0.15	Remainder
R4011k	A94011	6.5-7.5	0.2	0.2	0.1	0.45-0.7			0.1	0.04-0.20	0.05e	0.15	Remainder
ER4043	A94043	4.5-6.0	0.8	0.3	0.05	0.05			0.1	0.2	0.05e	0.15	Remainder
R4043	A'I4043	4.5-6.0	0.8	0.3	0.05	0.05			0.1	0.2	0.05e	0.15	Remainder
ER4047	A94047	11.0-13.0	0.8	0.3	0.15	0.1			0.2		0.05e	0.15	Remainder
R4047	A94047	11.0-13.0	0.8	0.3	0.15	0.1			0.2		0.05e	0.15	Remainder
ER4145	A94145	9.3-10.7	0.8	3.3-4.7	n.15	0.15	0.15		0.2		0.05e	0.15	Remainder
R4145	A94145	9.3-10.7	0.8	3.3-4.7	0.15	0.15	0.15		0.2		0.05e	0.15	Remainder
R4643	A94643	3.6-4.6	0.8	0.1	0.05	0.10‡0.30			0.1	0.15	0.05e	0.15	Remainder
R4643	A94643	3.6-4.6	0.8	0.1	0.05	0.10-0.30			0.1	0.15	0.05e	0.15	Remainder
ER5183	A95183	0.4	0.4	0.1	0.50-1.0	4.3-5.2	0.05-0.25		0.25	0.15	0.05e	0.15	Remainder
R5183	A95183	0.4	0.4	0.1	0.50-1.0	4.3-5.2	0.05-0.25		0.25	0.15	0.05e	0.15	Remainder
ER5356	A95356	0.25	0.4	0.1	0.OS-0.20	4.5-5.5	0.05-0.20		0.1	0.06-0.20	0.05e	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	0.05e	0.15	Remainder
ER5554	A95554	0.25	0.4	0.1	0.50-1.0	2.4‡3.0	0.05-0.20		0.25	0.05-0.20	0.05e	0.15	Remainder
R5554	A95554	0.25	0.4	0.1	0.50-1.0	2.4-3.0	0.05-0.20		0.25	0.05-0.20	0.05e	0.15	Remainder
ER5556	A95556	0.25	0.4	0.1	0.50-1.0	4.7-5.5	0.05-0.20		0.25	0.05-0.20	0.05e	0.15	Remainder
R5556	A95556	0.25	0.4	0.1	0.50-1.0	4.7-5.5	0.05-0.20		0.25	0.05-0.20	0.05e	0.15	Remainder
ER56S4	A95654			0.05	0.01	3.1-3.9	0.15-0.35		0.2	0.05-0.15	0.05e	0.15	Remainder
R5654	A95654			0.05	0.01	3.1-3.9	0.15-0.35		0.2	0.05-0.15	0.05e	0.15	Remainder
R206.0j	A02060	0.1	0.15	4.2-5.0	0.20-0.50	0.15‡0.35		0.05	0.1	0.15-0.30	0.05	0.15	Remainder
R-C355.0	A33550	4.5-5.S	0.2	1.0-1.5	0.1	0.40-0.6			0.1	0.2	0.05	0.15	Remainder
R-A356.0	AI3560	6.5-7.5	0.2	0.2	0.1	0.25-0.45			0.1	0.2	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	0.2	0.05	0.15	Remainder
R-A357.0k	A13570	6.5-7.5	0.2	0.2	0.1	0.40‡0.7			0.1	0.04-0.20	0.05	0.15	Remainder

Notes:

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 Slim 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 9-7 —Magnesium filler metal classifications (AWS A5.19).

AWS Classification	UNS Numberc	Weight Percentage a,b Mg	Al	Be	Mn	Zn	Zr	Rare Earth	Other Elements Cu	Fe	Ni	Si	Total
ER AZ61A R AZ61A	M111611	Remainder	5.8 to 7.2	0.0002 to 0.0008	0.15 to 0.5	0.4 to 1.5			0.05	0.005	0.005	0.05	0.3
ER AZ92A R AZ92A	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	0.3
ER AZ101A R AZ101A	M11101	Remainder	9.5 to 11	0.0002 to 0.0008	0.15 to 0.5	0.75 to 1.25			0.05	0.005	0.005	0.05	0.3
ER EZ33A R EZ33A	M12331	Remainder		0.0008		2 to 3.1	0.45 to 1	2.5 to 4					0.3

Notes:

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, Total".

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

\- SAE/ASTM Unified Numbering System for Metals and Alloys.

Table 9-8 —Copper filler metal classification (AWS A5.7).

AWS Classification	UNS Number[d]	Common Name	Composition, weight percentage[a,b,c] Cu Including Ag	Zn	Sn	Mn	Fe	Si	Ni Including Co	P	A1	Pb	Ti	Total other elements
ERCu	C18980	Copper	98 min		1	0.5		0.5		0.15	0.01	0.02		0.5
ERCuSi-A	C6S600	Silicon bronze (copper-silicon)	Remainder	1	1	1.5	0.5	2.8 4			0.01	0.02		0.5
ERCuSn-A	C51800	Phosphor bronze (copper-tin)	Remainder		4 6					0.1 0.35	0.01	0.02		0.5
ERCuNi'	C71580	Copper-nickel	Remainder			1	0.4 0.75	0.25	29 32	0.02		0.02	0.2 to 0.5	0.5
ERCuA1-A1	C61000	AlumInum bronze	Remainder	0.2		0.5		0.1			6 8.5	0.02		0.5
ERCuA1-A2	C61800	Aluminum bronze	Remainder	0.02			1.5	0.1			8.5 11.0	0.02		0.5
ERCuA1-A3	C62400	AlumInum bronze	Remainder	0.1			2 4.5	0.1			10	0.02 11.5		0.5
ERCuNiA1	C63280	Nickel-aluminum bronze	Remainder	0.1		0.6 3.5	3 5	0.1	4 5.5		8.5 9.5	0.02		0.5
ERCuMnN1A1	C63380	Manganese-nickel aluminum bronze	Remainder	0.15		11 14	2 4	0.1	1.5 3		7 8.5	0.02		0.5

Table 9-9 — Chemical compositions of bare stainless steel filler wire and rods (AWS A5.9).

AWS Classification	UNS Number	C	Cr	Ni	Mo	Mn	Si	P	S	N	Cu	Element	Amount
		Composition, Wt% a,b											
ER209	S20980	0.05	20.5-24.0	9.5-12.0	1.5-3.0	4.0-7.0	0.9	.03	.03	.10-.30	.75	V	0.10-0.30
ER218	S21880	0.1	16.0-18.0	8.0-9.0	0.75	7.0-9.0	3.5-4.5	.03	.03	.08-.18	.75		
ER219	S521980	0.05	19.0-21.5	5.5-7.0	0.75	8.0-10.0	1	.03	.03	.10-.30	.75		
ER240	S24080	0.05	17.0-19.0	4.0-6.0	0.75	10.5-13.5	1	.03	.03	.10-.30	.75		
ER307	S30780	.04-.14	19.5-22.0	8.0-10.7	0.5-1.5	3.3-4.75	.30-.65	.03	.03		.75		
ER308	S30880	0.08	19.5-22.0	9.0-11.0	0.75	1.0-2.5	.30-.65	.03	.03		.75		
ER308H	S30880	.04-.08	19.5-22.0	9.0-11.0	0.5	1.0-2.5	.30-.65	.03	.03		.75		
ER308L	S30883	0.03	19.5-22.0	9.0-11.0	0.75	1.0-2.5	.30-.65	.03	.03		.75		
ER308Mo	S30882	0.08	IS.0-21.0	9.0-12.0	2.0-3.0	1.0-2.5	.30-.65	.03	.03		.75		
ER308LMo	S30886	0.04	IS.0-21.0	9.0-12.0	2.0-3.0	1.0-25	.30-.65	.03	.03		.75		
ER308Si	S30881	0.08	19.5-22.0	9.0-11.0	0.75	1.0-2.5	.65-1.00	.03	.03		.75		
ER308LSi	S30888	0.03	19.5-22.0	9.0-11.0	0.75	1.0-2.S	.65-1.00	.03	.03		.75		
ER309	S30980	0.12	23.0-25.0	12.0-14.0	0.75	1.0-25	.30-.65	0.G3	.03		.75		
ER309L	S30983	0.03	23.0-25.0	12.0-14.0	0.75	1.0-25	.30-.65	.03	.03		.75		
ER309Mo	S30982	0.12	23.0-25.0	12.0-14.0	2.0-3.0	1.0-2.5	.30-.65	.03	.03		.75		
ER309LMo	S30986	0.03	23.0-25.0	12.0-14.0	2.0-3.0	1.0-25	.30-.65	.03	.03		.75		
ER309Si	S30981	0.12	23.0-25.0	12.0-14.0	0.75	1.0-2.5	.65-1.00	.03	.03		.75		
ER309LSi	S30988	0.03	23.0-25.0	12.0-14.0	0.75	1.0-2.5	.65-1.00	.03	.03		.75		
ER310	S31080	.08-.15	25.0-28.0	20.0-22.5	0.75	1.0-2.5	.30-.65	.03	.03		.75		
ER312	S31380	0.15	28.0-32.0	8.0-10.5	0.75	1.0-2.5	.30-.65	.03	.03		.75		
ER316	S31680	0.08	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	.30-.65	.03	.03		.75		
ER316H	S31680	.04-.08	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	.30-.65	.03	.03		.75		
ER316L	S31683	0.03	18.0-20.0	11.0-14.0	2.0-3.0	1.0-25	.30-.65	.03	.03		.75		
ER316Si	S31681	0.08	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	.65-1.00	.03	.03		.75		
ER316LSi	S31688	0.03	18.0-20.0	11.0-14.0	2.0-3.0	1.0-25	.65-1.00	.03	.03		.75		
ER317	S31780	0.08	18.5-20.5	13.0-15.0	3.0-4.0	1.0-2.5	.30-.65	.03	.03		.75		
ER317L	S31783	0.03	18.5-20.5	13.0-15.0	3.0-4.0	1.0-2.5	.30-.65	.03	.03		.75		
ER318	S31980	0.08	18.0-20.0	11.0-14.0	2.0-3.0	1.0-2.5	.30-.65	.03	.03		.75	Cb'	8XC min/1.0 max
ER320	N08021	0.07	19.0-21.0	32.0-36.0	2.0-3.0	25	0.6	.03	.03		3.0-4.0	Cb'	8XC min/1.0 max
ER320LR	N08022	0.025	19.0-21.0	32.0-36.0	2.0-3.0	1.5-2.0	0.15	.02	.02		3.0-4.0	Cb'	8XC min/0.40 max
ER321	S32180	0.08	18.5-20.5	9.0-10.5	0.75	1.0-2.5	.30-.65	.03	.03		.75	Ti	9XC min/1.0 max
ER330	N08331	.18-.25	15.0-17.0	34.0-37.0	0.75	1.0-2.5	.30-.65	.03	.03		.75		
BR347	S34780	0.08	19.0-21.5	9.0-11.0	0.75	1.0-2.5	.30-.65	.03	.03		.75	Cb'	10XC min/1.0 max
ER347Si	S34788	0.08	19.0-21.5	9.0-11.0	0.75	1.0-2.5	.65-1.00	.03	.03		.75	Cb'	10XC min/1.0 max
ER383	Noso28	0.025	26.5-28.5	30.0-33.0	3.2-4.2	1.0-25	0.5	.02	.03		.70-1.5		
ER385	N08904	0.025	19.5-21.5	24.0-26.0	4.2-5.2	1.0-25	0.5	.02	.03		1.2-2.0		
ER409	S40900	0.08	10.5-13.5	0.6	0.5	0.8	0.8	.03	.03		.75	Ti	10XC min/1.0 max
ER409Cb	S40940	0.08	10.5-13.5	0.6	0.5	0.8	1	.04	.03		.75	Cb'	10XC min/0.75 max
ER410	S41080	0.12	11.5-13.5	0.6	0.75	0.6	0.5	.03	.03		.75		
ER410NiMo	S41086	0.06	11.0-12.5	4.0-5.0	0.4-0.7	0.6	0.5	.03	.03		.75		
ER420	S42080	.25-.40	12.0-14.0	0.6	0.75	0.6	0.5	.03	.03		.75		
ER430	S43080	0.1	15.5-17.0	0.6	0.75	0.6	0.5	.03	.03		.75		
ER446LMo	S44687	0.015	25.0-27.5	f	.75-1.50	0.4	0.4	.02	.02	0.015	f		
ER502'	SS0280	0.1	4.6-6.0	0.6	.45-0.65	0.6	0.5	.03	.03		.75		
ER505'	S50480	0.1	8.0-10.5	0.5	0.8-1.2	0.6	0.5	.03	.03		.75		
ER630	S17480	0.05	16.0-16.75	4.5-5.0	0.75	0.25-0.75	0.75	.03	.03		3.25-4.00	Cb'	0.15-0.30
ER19-10H	S30480	.04-.08	18.5-20.0	9.0-11.0	0.25	1.0-2.0	.30-.65	.03	.03		.75	Cb'	0.05
												Ti	0.05
ER16-8-2	S16880	0.1	14.5-16.5	7.5-9.5	1.0-2.0	1.0-2.0	.30-.65	.03	.03		.75		
ER2209	S39209	0.03	21.5-23.5	7.5-9.5	2.5-3.5	0.50-2.0	0.9	.03	.03	.08-.20	.75		
ER2553	S39553	0.04	24.0-27.0	4.5-6.5	2.9-3.9	1.5	1	.04	.03	.10-.25	1.5-2.5		
ER3556	R305S6	.05-.15	21.0-23.0	19.0-22.5	2.5-4.0	0.50-2.00	.20-.80	.04	.02	.10-.30		Co	16.0-21.0
												W	2.0-3.5
												Cb	0.3
												Ta	0.30-1.25
												A1	0.10-0.50
												Zr	0.001-.10
												La	0.005-.10
												B	0.02

Notes:

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.

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 "Q" 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

Table 9-10 — Chemical compositions of filler wire and rods used for welding nickel and nickel alloys (AWS A5.14).

AWS Classification	UNS Number	C	Mn	Fe	P	S	Si	Cu	Nid	Co	A1	Ti	Cr	Cb plus Ta	Mo	V	W	Other Elements Total
								Weight percent										
ERNi-1	N02061	0.15	1.0	1.0	0.03	0.015	0.75	0.25	93.0		1.5	2.0						0.50
									min			to						
												3.5						
ERNieu-7	N04060	0.15	4.0	2.5	0.02	0.015	1.25	Rem	62.0		1.25	1.5						0.50
									to			to						
									69			3						
ERNier-1	N060X2	0.10	2.5	3.0	(un	0.015	0.50	0.50	67.0	e		0.75	I8.0	2.0				0.50
			to						min				to	to				
			3.5										22	3.0f				
ERNICrFe-5	N06062	0.0K	1.0	6.0	0.03	0.015	0.35	0.50	70.0	e			14.0	1.5				0.50
				to					min				to	to				
				10									17	3f				
ERNICrFc-6	N07092	00K	2.0	80	0.03	0.015	0.35	'0.50	67.0			2.5	14.0					0.50
			to						mln			to	to					
			2.7									3.5	17					
ERNiFcCr-1	N08065	0.05	1.0	22.0	003	0.03	0.50	1.50	35.0		0.20	0.60	19.5		2.5			0.50
				min.				to	to			to	to		to			
								3	46			1.2	23.5		3.5			
ERNiFeCr-2g	N07715	0.05	0.35	Rem	0.015	0.015	0.35	0.30	50.0		0.20	0.65	17.0	4.75	2.80			0.50
									to		to	to	to	to	to			
									55.0		0.80	1.15	21.0	5.50	3.30			
ERNiMo-1	N1000I	0.05	1.0	4.0	0.025	0.03	1.0	0.50	Rem	2.5			1.0		26.0	0.20	1.0	0.50
				to											to	to		
				7.0											30.0	0.40		
ERNiMo-2	N10003	0.04	1.0	5.0	0.015	0.02	1.0	0.50	Rem	0.20			6.0		15.0	0.50	0.50	0.50
		to											to		to			
		0.08											8		18			
ERNiMo-3	N10004	0.12	1.0	4.0	0.04	0.03	1.0	0.50	Rem	2.5			4.0		23.0	0.60	1.0	0.50
				to									to		to			
				7									6		26			
ERNiMo-7	NI0665	0.02	1.0	2.0	0.04	0.03	0.10	0.50	Rem	1.0			1.0		26.0		1.0	0.50
															to			
															30			
ERNiCrMo-1	N06007	0.05	1.0	I5.0	0.04	0.Q3	1.0	1.5	Rem	2.5			21.0	1.75	5.5		1.0	0.50
			to	to				to					to	to	to			
			2.0	21.0				2.5					23.5	2.5	7.5			
ERNiCrMo-2	N06002	0.05	1.0	17.0	0.04	0.03	1.0	0.50	Rem	0.50			20.5		8.0		0.20	0.50
		to		to						to			to		to		to	
		0.15		20.0						2.5			23		10		1	
ERNiCrMo-3	N06625	0.10	0.50	5.0	0.02	0.015	0.50	0.50	58.0		0.40	0.40	20.0	3.15	8.0			0.50
									min				to	to	to			
													23	4.15	10			
ERNiCrMo-4	N10276	0.02	1.0	4.0	0.04	0.Q3	0.05	0.50	Rem	2.5			14.5		15.0	0.35	3.0	0.50
				to									to		to		to	
				7									16.5		17		4.5	
ERNiCrMo-7	N06455	0.015	1.0	3.0	0.04	0.03	0.05	0.50	Rem	2.0		0:70	14.0		14.0		0.50	0.50
													to		to			
													18		18			
ERNiCrMo-8	N06975	0.03	1.0	Rem	0.03	0.03	1.0	0.7	47.0			0.70	23.0		5.0			0.50
								to	to			to	to		to			
								1.2	52			1.5	26		7			
ERNiCrMo-9	N06955	0.015	1.0	I8.0	0.04	0.03	1.0	1.5	Rem	5.0			21.0	0.50	6.0		1.5	0.50
				to				to					to		to			
				21				2.5					23.5		8			
ERNiCrMo-10	N06022	0.015	0.50	2.0	0.02	0.010	0.08	0.50	Rem	2.5			20.0		12.5	0.35	2.5	0.50
				to									to		to		to4.5	
				6									22.5		14.5			
ERNiCrMo-1I	N06030	0.03	1.5	13.0	0.04	0.02	0.80	1.0	Rem	5.0			28.0	0.30	4.0		1.5	0.50
				to				to					to	to	to		to	
				17.0				2.4					31.5	1.5	6		4	
ERNiCrCoMo-1	N06617	0.05	1.0	3.0	0.03	0.DI5	1.0	0.50	Rem	10.0	0.80	0.60	20.0		8.0			0.50
		to								to	to		to		to			
		0.15								15	1.5		24.0		10			

Notes:

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. SAEIASTM Unified Numbering System for Metals and Alloys.

d. Includes incidental cobalt.

e. Cobalt-D.12 maximum, when specified.

f. Tantalum-D.30 maximum, when specified.

g. Boron is 0.006 percent maximum.

5.3.2 Sizing

Filler metals come either in straight cut lengths that are 36 inches (914mm) long for manual welding or in continuous spooled wire for mechanized welding. The diameter of the filler wire ranges from about .020 inches (.50mm) for delicate or fine work, to about 1/4 inch (6.4mm) for high current welding and surfacing.

5.4.1 Selection of Filler Metal

The type of base metal and the specific mechanical and chemical properties desired are the major factors in determining the choice of a filler metal. You must be able to identify the base metal to select the proper filler metal. If you do not know the base metal's composition, you need to test it based on appearance and weight with magnetic checks, chisel tests, flame tests, fracture tests, spark tests, and chemistry tests.

The selection of the proper filler metal for specific job applications is quite involved, but you should base it on the following factors:

1. Base metal strength properties — This is done by choosing a filler metal to match the tensile strength of the base metal. This is usually most important with steel.
2. Base metal composition — The chemical composition of the base metal must be known. Matching the chemical composition is not as important for mild steel as it is for stainless steels and non-ferrous metals. Closely matching the filler metal to the base metal is needed when corrosion resistance and color match are important considerations.
3. Thickness and shape of base metal weldments — Thick sections or complex shapes may require maximum ductility to avoid weld cracking. Filler metal types that give best ductility should be used.
4. Service conditions and/or specifications — When weldments are subjected to severe service conditions, such as low temperatures, high temperatures, or shock loading, a filler metal that closely matches the base metal composition, ductility, and impact resistance properties should be used.

Topic 7 Welding Metallurgy will provide more exact recommendations for choosing filler metals.

5.5.0 Conformances

Filler metals must conform to written specifications for many applications of gas tungsten arc welding. The three major code-making organizations that issue filler metal specifications are the American Welding Society (AWS), the American Society for Mechanical Engineers (ASME), and the military. The ASME recognizes the AWS specifications or makes its own specifications. The filler wire must meet particular requirements in order to conform to filler metal specifications.

Test your Knowledge (Select the Correct Response)

5. What should be the purity rating of the shielding gas?

   A. 96.99%
   B. 97.99%
   C. 98.99%
   D. 99.99%

6. **(True or False)** SAE devised the filler metal classifications.

A. True
B. False

6.0.0 WELDING APPLICATIONS

Gas tungsten arc welding is widely used because of its versatility. When weld purity is important, this process welds stainless steel, low alloy steel, ***maraging*** (mahr-ey-jing) steel, nickel, cobalt, titanium, aluminum, copper, magnesium, and most other metals in all positions and produces clean weld deposits. The clean weld deposits TIG produces usually avoids the need of grinding and finishing, and all methods are usable: manual, semiautomatic, mechanized, and fully automatic.

6.1.0 Industries

Welding pipe or nuclear power components are typical examples of the wide variety of TIG applications. This process can also weld thin metals and small objects such as transistor cases, instrument diaphragms, and other delicate parts.

6.1.1 Industrial Piping

Manual TIG is appropriate for welding pipe and tubing in all positions. The excellent control of heat input gives maximum penetration while preventing melt-through on the root pass. Welders use TIG in both the manual and automatic methods to weld industrial piping made of various metals and thicknesses, from 1/32 inch (.8 mm) and up (*Figure 9-22*).

Figure 9-22 — Industrial pipe welding.

The maximum thickness welded depends on the equipment available and the type of metal. In some critical welds with metal thicknesses greater than 1/4-3/8 inch (6.4-9.5 mm), the root pass of the pipe is deposited by TIG and then completed with SMAW, GMAW, or FCAW. Sometimes, pipe welders will use consumable inserts in critical service applications. These inserts reduce porosity when alloyed with deoxidizers, improve the contour of the underside of the weld, and minimize cracking in the weld. In thin pipe wall (depending on the base metal), complete fusion is obtainable without using filler metal, but of course filler metals are used with thicker sections to fill the joint.

Thus, the different ways of depositing the first layer on a pipe or tube are the following:

1. Ends abutted and fused.
2. Ends abutted or slightly separated with filler metal added to the arc area.
3. Ends abutted against a filler ring and then completely fused.

If deep penetration with controlled heat input is necessary, then pulsed current may be used.

Automatic circumferential or orbital TIG is another option to weld tube and pipe. The programmed procedure can produce a quantity of identical welds with a high degree of quality and efficiency. Industries with high quality control requirements and those that demand accessibility to the joint use this method extensively.

Power piping, air piping, refrigeration piping, chemical industry process piping, and nuclear power piping are some of the different industries that apply the gas tungsten arc welding process for welding piping and tubing. Vacuum jacketed piping and pressure piping are a couple cases where critical welding is required.

6.1.2 Nuclear Power Facilities

The construction and repair of nuclear power facilities requires critical welding. . Many nuclear applications use both the manual and automatic methods because of their precise control of the welding.

Gas tungsten arc welding performs the welding for end closure caps and plugs to fuel rods, and the airtight sealing of the end closures on fuel rods.

This process is also a primary welding method for rod type fuel elements. It is used to close a backfilling hole that was used to pressure the fuel rods after welding the end closures.

6.1.3 Ships

TIG applies also to the shipbuilding industry because it uses different materials like aluminum, stainless steel, and molybdenum.

On hydrofoils, which are primarily made of aluminum, light gauge material and root passes of heavier sections are welded by this process, with GMAW usually completing the weld on the heavier sections. Stainless steel hydrofoils and struts are virtually all welded by the TIG process. Liquefied natural gas (LNG) tanks have a stainless steel liner inside the vessel that is completely TIG welded.

6.1.4 Aerospace

The gas tungsten arc welding process is the major welding process used in the aerospace industry. This industry includes the welding of aircraft, spacecraft, and launch vehicles. Some of the materials welded include aluminum, titanium, low alloy steel, maraging steel, magnesium, nickel, stainless steel, and super alloys in both the manual and automatic methods.

In the aircraft industry, examples of the many different welded parts and assemblies include the fuselage, wing and tail assemblies, landing wheels, engine parts, engine motor cases, and conventional aircraft assemblies such as ducts, fittings, accumulators, check valves, exhaust mufflers, and fairing and cowling components.

Launch vehicles and spacecraft are other major applications of the TIG process. Most aluminum tank fabricators use TIG for the critical pressure vessel butt welds. Titanium alloys used in the liquid propellant tanks, high pressure gas storage tanks, and solid rocket motor cases are almost exclusively TIG welded.

From landing gears and re-entry capsules, to large diameter rocket booster cases made of high strength, high carbon, low alloy steel, with thicknesses ranging 0.04-2.0 inches (1.0-5.1 mm), all are welded by this process.

Maraging steels used to make solid rocket motor chambers are fabricated reliably using TIG, but additional sufficient inert gas shielding must protect the face and root of the weld from oxidation. Often, manufacturers accomplish this by welding within inert gas chambers or by using a backing gas to protect the root of the joint and a trailing gas to protect the cooling weld metal behind the torch.

6.1.5 Transportation

The automotive and railroad industries only use TIG to a small extent, mainly for welding non-ferrous metals, for maintenance, and for small components. Fabrication of aluminum radiators 3/32-1/8 inch (2.4-3.2 mm) thick is one application these industries (*Figure 9-23*).

In the railroad industry, several of the interior components made of aluminum, Monel, stainless steel, and copper are sometimes welded by this process, and there are some maintenance and repair of passenger trains with TIG.

Figure 9-23 — TIG on aluminum radiator.

6.1.6 Pressure Vessels, Boilers, and Heat Exchangers

Gas tungsten arc welding has wide applications in the pipe and tube industry for welding pressure vessels, boilers, and heat exchangers. This industry uses it for full fusion welding from one side without the use of permanent backing rings, and on girth butt welds with a smooth internal contour. By choosing the correct filler metal and welding conditions, you can obtain adequate mechanical strength and corrosion resistance for a particular service. Virtually all tube-to-tube sheet welding of heat exchangers is done by the automatic method.

6.1.7 Maintenance and Repair

TIG can provide maintenance and repair by both the manual and automatic methods. Several industries use this process because its versatility and weldability permit quality welding for various applications.

The TIG process repairs cast aluminum engine blocks and heads. The area of a defect is puddle melted, scraped out with a steel rod, and finally filled. This process also repairs stainless valves and copper heat-sealing dies for heat exchangers. Repairing the part instead of buying a new one saves money and time.

There are many other possible applications for gas tungsten arc welding in maintenance and repair.

Figure 9-24 — Repair of a roll bar.

6.1.8 Miscellaneous

There are numerous general applications for TIG throughout industry.

The TIG process welds all the following:

- stainless aeration parts for pollution control equipment
- thin steel brackets on lift trucks
- low alloy steel stop rings to the accumulator on shock absorbers
- small-sized pressure sensing cells
- stainless steel jackets around the coil of superconducting magnets
- stainless steel adapter bushings to stainless steel bulbs for self- actuated thermostatic regulators
- aluminum frame for elevating platforms
- hospital equipment

Figure 9-25 — TIG welding of a brace.

- mixers
- vats
- tanks
- freezers
- coolers
- cold rooms made from stainless steel

Welders often use TIG for a wide variety of applications where the parts are made out of non-ferrous metals, and there are other applications too numerous to discuss in this course.

6.2.0 Arc Spot Welding

Obtained through the melting and fusion of the metal joint, gas tungsten arc spot welding is a method used for making small localized fusion welds from one side of a lap joint. Welding thick metals tends to cause depressions and surface cracking in the center of the weld, so gas tungsten arc spot welding is limited to welding metal about 16 gauge (1 .5 mm) thick or less.

Operators may or may not add filler metal depending on the metal thickness and size of the weld puddle. The equipment used is similar to that used for TIG except that TIG spot welding uses a timing device and a specially designed torch and nozzle (*Figure 9-26*).

Primarily used on mild steel, low alloy steel, stainless steel, and aluminum, this method of spot welding can replace resistance spot welding and riveting for many applications, including garage doors, radar cabins, electrical fittings, cable sheaths, and domestic hardware.

Figure 9-26 — Gas tungsten arc spot welding torch.

The advantages of this process are the high production rates and low costs obtained; the cost of the equipment is low compared to resistance welding equipment. In addition, when the equipment for gas tungsten arc spot welding uses the proper settings, visual inspection is more reliable than when resistance spot welding is done.

Test your Knowledge (Select the Correct Response)

7. What industry uses TIG almost exclusively?

   A. Transportation
   B. Aerospace
   C. Ships
   D. Nuclear power facilities

8 What is the maximum metal thickness limitation on TIG spot welding?

   A. 10 gauge
   B. 14 gauge
   C. 16 gauge
   D. 20 gauge

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 TIG process.

7.1.0 Properties of the Weld

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

7.1.1 Chemical Properties

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

In the welding of steel, the carbon and other alloy content influence the hardness and hardenability of the weld metal, which in turn influences the amount of preheat needed. The two terms, hardness and hardenability, are not the same. The maximum hardness of a steel is the resistance to indentation. Hardenability is a measure of how easily a martensite structure forms 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. Steels with high hardenability will form martensite even when they are slow-cooled in air. The 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 some of the alloying elements used. There are several different formulas used. One of these is:

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

Steels with lower carbon equivalents generally are readily weldable and require fewer precautions such as the use of preheat and postheat.

Steels with higher carbon equivalents are usually more difficult to weld. In the welding of many of the steels, matching the chemical composition of the filler metal to the base metal is not as important as matching the mechanical properties. Often, filler metal with a lower carbon content than the base metal is used because the weld metal absorbs carbon from the base metal during solidification. The carbon content is kept low to minimize the tendency toward weld cracking. Alloys are used in the filler metal to maintain weld strength. In the welding of stainless steels and non-ferrous metals, the chemical composition of the weld is often the most important property. The chemical composition of the weld must match the composition of the base metal when corrosion resistance, thermal and electrical conductivity, and appearance are major considerations.

Preheating helps reduce 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 equivalents generally need more preheating than those with lower carbon equivalents. For the non-ferrous metals, this will often depend on the melting points and thermal conductivity of the metal. *Table 9-11* shows typical preheat values for various metals welded by this process.

Another major factor that also 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. It would increase the cooling rate of the weld if the same preheat temperature were used on thick base metals 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 stress build up, and higher preheat temperatures are needed as the amount of joint restraint increases. Slower cooling rates reduce the amount of internal stress that build up as the weld cools.

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.

Table 9-11 — Preheats for various metals.

Type of Steel	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' (6.4 mm) thick	Room Temperature
-More than ¼' (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 .150%	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	150-500°F (66-260°C)
Martensitic Stainless Steel	150-300°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 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.

7.1.2 Mechanical Properties

The mechanical properties that are most important in the weld are the tensile strength, yield strength, elongation, reduction of area, and 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 important in gas tungsten arc welding, especially for welding steel and the non-ferrous alloys that have been developed to give maximum strength, ductility, and toughness.

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 9-27* shows a tensile bar before and a tensile bar 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 9-27 — 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 9-28* shows some typical Charpy V-notch test bars. These bars are usually 10 mm square and have v-shaped 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 9-28 — Charpy V-notch bars.

7.1.3 Microstructure

There are three basic microstructural areas within a weldment. These are 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

Figure 9-29 — Cross section of a weld.

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 9-29* shows a cross section of a weld showing the different areas.

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

1. The maximum temperature that the weld metal reached.
2. The time that the weld spent at that temperature.
3. The chemical composition of the base metal.
4. The cooling rate of the weld.

The weld metal zone, which is the area that is melted, generally 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 9-30* 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 9-30 — 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 that is 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 Weldable Metals

TIG is used to weld most metals and their alloys. Some of the most common metals welded by this process are aluminum, copper, magnesium, nickel, mild steel, low alloy steel, titanium, zirconium, and the refractory metals. Lead and zinc are difficult to weld because of their low melting points and tendency to contaminate the tungsten electrode, but TIG is widely used for welding lead.

7.2.1 Aluminum and Aluminum Alloys

The gas tungsten arc welding process 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 9-12* shows how 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. Alloys of the 1 XXX, 3XXX, 4XXX, and 5XXX series are non-heat treatable, so they derive their strength from working.

Table 9-12 — 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

Generally, you would use TIG to weld the thinner materials, with manual welding done on thicknesses ranging from .030 inch (1 mm) to 3/8 inch (9.5 mm), and automatic welding performed on metal ranging in thickness from .01 0 inch (.25 mm) to 1 inch (25.4 mm). You can use either alternating current or direct current welding power, but alternating current is the most popular for almost all manual and automatic welding applications.

Direct current electrode positive is used only for some very thin metal applications. Direct current electrode negative is used sometimes for high current automatic welding applications.

Pure or zirconium tungsten electrodes are the most commonly used types for aluminum. The thoriated tungsten electrodes have a tendency to spit and cause inclusions when used with alternating current, and are not very popular for welding aluminum. Argon shielding gas is normally used, but argon-helium mixtures are used sometimes to give deeper penetration and allow faster travel speeds. When direct current electrode negative is used, mixtures of argon and helium are preferred.

Depending upon the joint and the application, you may or may not use a filler metal; often, thin metal is welded without a filler metal. 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.

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. You should not use aluminum filler metal with magnesium contents greater than 3% at service temperatures greater than 1500 F because they become sensitive to stress corrosion cracking. *Table 9-13* shows a filler metal selection chart based on the specific properties desired. *Table 9-14* shows a filler metal selection chart for welding different aluminums together.

The oxide layer on the surface of the aluminum is what makes aluminum more difficult to weld than many other 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. This type of current can be used only at very low current levels because the heat buildup on the tungsten electrode can cause it to melt. Direct current electrode negative can be used at high current levels, but it has difficulty removing the oxide layer. For these reasons, alternating current is the most popular for the welding of aluminum.

During the electrode positive portion of the cycle, the oxide layer is broken down, and during the electrode negative portion of the cycle, penetration is obtained. Alternating current prevents the electrode from overheating and permits the use of enough welding current to give good penetration. Remove the oxide chemically or mechanically before welding.

Table 9-13 — Aluminum Filler Metal Selection Based on Properties.

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 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, so preheating is seldom used. The maximum preheat normally used on aluminum is 300° F (150° C). It is usually preferable to increase the voltage and current levels to obtain adequate heat input rather than use preheating. However, a preheat of 200-300° F (93-15° C) is used often when using alternating current on metal thicknesses greater than 3/16 inch (4.8 mm). Some alloys such as 5083, 5086, and 5456 should not be preheated to between 200 and 300° F (95-150° C) because their resistance to stress corrosion cracking will be reduced due to high magnesium contents.

Table 9-14 — 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, 357.0 413.0, 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, 6061 6151, 6201 6351, 6951	5456	5454
1060,1070,1080,1350	ER4145	ER4145	ER4043ab	ER5356cd	ER5356cd	ER4043ab	ER4043ab	ER5356cd	ER4043ab
1100,3003, A1c 3003	ER4145	ER4145	ER4043ab	ER5356cd	ER5356cd	ER4043ab	ER4043ab	ER5356cd	ER4043ab
2014, 2036	ER4145e	ER4145'	ER4145			ER4145	ER4145		
2219	ER2319a	ER4145e	ER4145bc	ER4043	ER4043	ER4043ab	ER4043ab		ER4043b
3004, A1c 3004		ER4043b	ER4043b	ER5356f	ER5356f	ER4043b	ER4043b.1	ER5356d	ER5356f
5005, 5050		ER4043b	ER4043b	ER5356f	ER5356f	ER4043b	ER4043bf	ER5356d	ER5356f
5052, 5652i		ER4043b	ER4043f	ER5356f	ER5356f	ER4043b	ER5356cJ	ER5356f	ER5356f
5083			ER5356cd	ER5356d	ER5183d		ER5356d	ER5183d	ER5356d
5086			ER5356cd	ER5356d	ER5356d		ER5356d	ER5356d	ER5356d
5154, 5254i			ER4043f	ER5356f	ER5356f		ER53561	ER5356f	ER5356f
5454		ER4043b	ER4043f	ER5356f	ER5356f	ER4043b	ER5356cf	ER5356f	ER5554cf
5456			ER5356cd	ER5356d	ER5556d		ER5356d	ER5556d	
6005, 6061, 6063	ER4145	ER4145bc	ER4043bJg	ER5356f	ER5356cJ	ER4043abg	ER4043bfg		
6101, 6151, 6201	ER4145	ER4145bc	ER4043bJg	ER5356f	ER5356cJ	ER4043abg	ER4043bfg		
6351, 6951	ER4145	ER4145bc	ER4043bJg	ER5356f	ER5356cJ	ER4043abg	ER4043bfg		
6009, 6010, 6070	ER4145	ER4145bc	ER4043abg	ER4043	ER4043	ER4043abg			
7004, 7005, 7039		ER4043b	ER4043bJ	ER5356'	ER5356d				
710.0, 712.0		ER4043b	ER4043bJ	ER5356'	ER5356d				
511.0, 512.0, 513.0			ER4043f	ER5356f					
514.0, 535.0			ER4043f	ER5356f					
356.0, A3560, 357.0	ER4145	ER4145bc	ER4043bh						
357.0, 413.0	ER4145	ER4145bc	ER4043bh						
443.0	ER4145	ER4145bc	ER4043bh						
319.0, 333.0	ER4145e	ER4145bch							
354.0, 355.0	ER4145e	ER4145bch							
C355.0	ER4145e	ER4145bch							
201.0, 206.0, 224.0	ER2319ah								

Base Metal	5154 5254i	5086	5083	5052 5652'	5005 5050	3004 A1c.3004	2219	2014 2036	1100 3003 A1c.3003	1060 1070 1080 1350
1060, 1070, 1080, 1350	ER5356cd	ER5356d	ER5356d	ER4043bd	ER1100bc	ER4043bd	ER4145bc	ER4145	ER1100bc	ER1188bchj
1100, 3003, A1c.3003	ER5356cd	ER5356d	ER5356d	ER4043bd	ER1100bc	ER4043bd	ER4145bc	ER4145	ER1100bc	
2014, 2036					ER4145	ER4145	ER4145e	ER4145e		
2219	ER4043			ER4043b	ER4043ab	ER4043ab	ER2319a			
3004, A1c.3004	ER5356f	ER5356d	ER5356d	ER5356cJ	ER5356cf	ER5356cf				
5005, 5050	ER5356f	ER5356d	ER5356d	ER5356cd	ER5356cJ					
5052, 5652'	ER53561	ER5356d	ER5356d	ER5654cf						
5083	ER5356d	ER5356d	ER5183d							
5086	ER5356d	ER5356d								
5154, 5254'	ER5654fi									

Notes:

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 ER5183, 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 oxy-fuel gas welding, only ER 1188, ERll00, 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; (1) improved color match after anodizing treatment, (2) highest weld ductility, and (3) 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 base 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; ER40JO and R4010 as R-A356.0; and R40J I 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. jERll00 may be used for some applications

7.2.2 opper and Copper Alloys

Gas tungsten 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 very high thermal conductivity and the heat is conducted away from the weld zone quite 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 are TIG weldable, but some are easier to weld than others.

The most weldable are the deoxidized coppers, the silicon bronzes, and the copper nickels. The most difficult alloys to weld are those with the highest zinc content, which have a high cracking tendency, and electrolytic tough pitch copper, which causes problems with porosity. *Table 9-15* shows the relative ease of welding copper and copper alloys.

TIG welding copper and copper alloys is usually done with direct current electrode negative because of the high current capacity. Exceptions to this include welding beryllium coppers and aluminum bronzes, where you should use alternating current to prevent the buildup of oxides. You must take care when welding beryllium coppers; the fumes given off are dangerous to your health, so you need to wear a gas mask.

Thoriated or zirconium tungsten electrodes are recommended with the 2% thoriated type being the most popular for welding copper and copper alloys. Generally, argon shielding gas is used on the thinner sections while helium and mixtures of argon and helium are used more commonly on the thicker sections. Preheating is not necessary on the thinner sections, but frequently it is required on sections thicker than 1/8 inch (3.2 mm) so the heat does not leave the weld area too quickly. A temperature of 500-800 F (260-4250 C) is typical for preheating copper and copper alloys.

Gas tungsten arc welding is primarily used for welding metal thicknesses up to 1/8 inch (3.2 mm) and for repairing welding or castings. Welding currents used for copper are 50-75% higher than for aluminum because of the high thermal conductivity of copper.

Filler metal is frequently eliminated for welding thinner material, but for thicknesses greater than 1/8 inch (3.2 mm), filler metal is usually used. About ½ inch (12.7 mm) is the maximum practical thickness for TIG welding copper, above this thickness, you should use MIG.

Table 9-15 — 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

When filler metal is used, it is usually selected so the chemical composition of the filler rod closely matches the base metal. This is often necessary to obtain a strong weld joint in some of the copper alloys.

However, 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 the base metal is, with consideration for the metal's application as well.

7.2.3 Magnesium and Magnesium Alloys

TIG is the most popular process for welding magnesium and magnesium alloys. The major alloying elements used with magnesium are aluminum, zinc, and thorium. Most magnesium alloys are weldable with this process, but the weldability will vary with the alloy. *Table 9-16* shows the main alloying elements used and the relative weldability of the alloys. The rating is based mainly on the susceptibility to cracking. Aluminum content up to about 10% helps the weldability because it promotes grain size refinement, and zinc content above about 1% will increase the tendency towards hot cracking. Alloys that have a 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. Alternating current is used for most magnesium and magnesium alloy welding applications because of its good oxide cleaning action, which allows higher welding speeds. Direct current electrode positive is often used for welding metal thicknesses from less than 3/16 inch (4.8 mm) up to 3/8 inch (4.8 mm). Above this thickness, gas metal arc welding is often used.

Inert gases such as argon, argon-helium mixtures, and helium are required for shielding because magnesium will react chemically with an active gas. Preheating is often used on thin sections and on highly restrained joints to prevent weld cracking. Thicker sections generally do not require preheating unless there is a high degree of joint restraint. All of the different types of tungsten electrodes are used, especially the pure and zirconium tungsten electrodes.

Filler metal for the gas tungsten arc welding of magnesium and magnesium alloys generally is one of four different types. Filler metals with lower melting points and wider freezing ranges than the base metal are often used to avoid cracking. *Table 9-17* also shows a filler metal selection chart. The type of filler metal used is governed by the chemical composition of the base metal.

Table 9-16 — Magnesium alloy classification, weldability and filler selection (1=excellent, 2=good, 3=fair, 4 =poor).

Magnesium Alloy	Major Alloying Elements	Weldability Rating	Filler Metal
Wrought Alloys			
AZ10A	Aluminum Zinc	1	AZ61A AZ92A
AZ31B	Aluminum Zinc	1	AZ61A AZ92A
AZ31C	Aluminum Zinc	1	AZ61A AZ92A
AZ61A	Aluminum Zinc	2	AZ61A AZ92A
AZ80A	Aluminum Zinc	2	AZ61A AZ92A
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
Cast Alloys			
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

Table 9-17 — Magnesium filler metal selection chart.

	Base Metal											
	AM100A	**AZ10A**	**AZ31B**	**AZ61A AZ31C**	**AZ63A**	**AZ80A**	**AZ81A**	**AZ91C**	**AZ92A**	**EK41A**	**EZ33A**	**HK31A**
Base Metal	**Filler Metal[ab]**											
AM100A	AZ101A AZ92A											
AZ10A	AZ92A	AZ61A AZ92A										
AZ31B AZ31C	AZ92A	AZ61A AZ92A	AZ61A AZ92A									
AZ61A	AZ92A	AZ61A AZ92A	AZ61A AZ92A	AZ61A AZ92A								
AZ63A	c	c	c	c	AZ101A AZ92A							
AZ80A	AZ92A	AZ61A AZ92A	AZ61A AZ92A	AZ61A AZ92A	c	AZ61A AZ92A						
AZ81A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ101A AZ92A					
AZ91C	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ101A AZ92A				
AZ92A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ92A	AZ101A			
EK41A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ92A	AZ92A	EZ33A		
EZ33A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ92A	AZ92A	EZ33A	EZ33A	
HK31A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ92A	AZ92A	EZ33A	EZ33A	EZ33A
HM21A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ92A	AZ92A	EZ33A	EZ33A	EZ33A
HM31A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ92A	AZ92A	EZ33A	EZ33A	EZ33A
HZ32A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ92A	AZ92A	EZ33A	EZ33A	EZ33A
K1A	AZ92A	AZ92A	AZ92A	AZ92A	c	AZ92A	AZ92A	AZ92A	AZ92A	EZ33A	EZ33A	EZ33A
LA141A	d	d	EZ33A	c	c	c	c	c	c	d	d	d
M1A MG1	AZ92A	AZ61A AZ92A	AZ61A AZ92A	AZ61A AZ92A	c	AZ61A AZ92A	AZ92A	AZ92A	AZ92A	AZ92A	AZ92A	AZ92A
QE22A	d	d	AZ92A	d	c	d	d	d	d	EZ33A	EZ33A	EZ33A
ZE10A	AZ92A	AZ61A AZ92A	AZ61A AZ92A	AZ61A AZ92A	c c	AZ61A AZ92A	AZ92A	AZ92A	AZ92A	EZ33A AZ92A	EZ33A AZ92A	EZ33A AZ92A
ZE41A	d	d	d	d	c	d	d	d	d	EZ33A	EZ33A	EZ33A
ZK21A	AZ92A	AZ61A AZ92A	AZ61A AZ92A	AZ61A AZ92A	c	AZ61A AZ92A	AZ92A	AZ92A	AZ92A	AZ92A	AZ92A	AZ92A
ZH62A ZK51A ZK60A ZK61A	c	c	c	c	c	c	c	c	c	c	c	c

	Base Metal										
	HM21A	HM31A	HZ32A	K1A	1A141A	M1A MG1	QE22A	ZE10A	ZE41A	ZK21A	ZH62A ZK51A ZK60A ZK61A
Base Metal	Filler Metalab										
HM21A	EZ33A										
HM31A	EZ33A	EZ33A									
HZ32A	EZ33A	EZ33A									
K1A	EZ33A	EZ33A	EZ33A	EZ33A							
LA141A	EZ33A	d	d	d	EZ33A						
M1A MG1	AZ92A	AZ92A	AZ92A	AZ92A	d AZ92A	AZ61A					
QE22A	EZ33A	EZ33A	EZ33A	EZ33A	EZ33A	c	EZ33A				
ZE10A	EZ33A AZ61A AZ92A	EZ33A AZ92A	EZ33A AZ92A	EZ33A AZ92A	EZ33A AZ92A	AZ61A	EZ33A AZ92A	AZ92A			
ZE41A	EZ33A	EZ33A	EZ33A	EZ33A	d	d	EZ33A	d	EZ33A		
ZK21A	AZ92A	AZ92A	AZ92A	AZ92A	d	AZ61A AZ92A	AZ92A	AZ61A AZ92A	AZ92A	AZ61A AZ92A	
ZH62A ZK51A ZK60A ZK61A	c	c	c	c	c	c	c	c	c	c	EZ33A

Notes:

a. When more than one filler metal is given, they are listed in order of preference.

b. The letter prefix (ER or R), designating usability of the filler metal, has been deleted, to reduce clutter in the table.

c. Welding not recommended.

d. No data available.

7.2.4 Nickel and Nickel Alloys

Gas tungsten 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. The classification system for nickel and nickel alloys is shown in *Table 9-18*. TIG is used for welding both the solid solution strengthened alloys and the precipitation-hardenable alloys, but it is especially the preferred method for precipitation-hardenable alloys because of the difficult of transferring hardening elements across the arc in the other welding processes. Many of the cast alloys, especially ones with high silicon contents, are more difficult to weld.

Table 9-18 — 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.

Direct current electrode negative (DCEN) is usually recommended for both manual and mechanized welding, with argon, argon-helium mixtures, and helium for shielding. Generally, helium is better for welding if you will not be adding a filler metal. When porosity is a problem for single pass welding of nickels, you should use argon-hydrogen mixtures.

All of the different types of tungsten electrodes are used, but the alloyed tungsten electrodes are the most common.

A filler metal is usually used when welding 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

TIG can weld steel, but because the process is relatively slow and expensive, it is not as popular for welding the plain carbon and alloy steels as it is for welding stainless steel and the non-ferrous metals. Its best usage is for critical applications and for stainless steel.

7.2.5.1 Plain Carbon and Low Alloy Steels

Functionally, you can use the gas tungsten arc welding process to weld all of the different kinds of steel that can be welded by the other arc welding processes, such as mild, low alloy, heat treatable, and chromium-molybdenum steels. The major alloying elements in these steels are carbon, manganese, silicon, nickel, chromium, and molybdenum. The weldability of the steel depends largely on the carbon content. The higher the carbon content of the steel, the more susceptible to cracking it becomes and the need for preheating and postheating increases.

Low carbon steels have carbon contents up to .14%; mild steels have carbon contents ranging from .15 to .29%. These are generally the easiest to weld and usually do not require preheat and postheat.

Alloy steels with carbon contents greater than .20% generally require preheating and postheating due to the increased alloy content.

Medium carbon steels have carbon contents ranging from .30% to .59%, and high carbon steels have carbon contents ranging from .60% to 1.00%. Many of the very high carbon steels are not welded, except for repair work, because they are very susceptible to cold cracking.

Generally, TIG is more sensitive to sulfur, phosphorous, and oxygen in the steel because there are forms to help remove these elements from the weld puddle. Silicon in the base metal and filler metal helps the weld puddle to wet out better at the edges, and it improves the bead shape.

An extremely low silicon content in the base metal will make welding difficult, so a filler metal is required to provide the silicon for the weld bead. Conversely, an excessively high amount of silicon in the base metal can promote cracking.

Direct current electrode negative is the most commonly used type of welding current, but sometimes alternating current is used for welding thin sheets.

All of the different types of shielding gases used for TIG may be used for welding steel. Argon is the most common with argon-hydrogen mixtures used when you need better weld puddle wetting and bead shape. The thoriated tungsten electrodes are the most popular for welding steel.

You should select the filler metal for the low carbon and low alloy steels by matching the tensile strength of the filler metal to that of the base metal. For welding heat treatable and chromium-molybdenum steels, base your selection by approximately matching the chemical composition to achieve similar hardenability, corrosion, and/or heat resistant properties.

7.2.5.2 Cast Iron

You can make sound welds using the TIG welding process in three principal grades of cast iron: gray, white, and ***malleable***, but you must always preheat cast-iron parts before welding. Preheat gray cast iron to a temperature ranging between 500°F to 1250°F; the required temperature depends on the size and shape of the workpiece.

In either TIG or MIG welding, you should allow the workpiece to cool slowly after welding. You can accomplish this by covering the workpiece in a bed of lime or ashes. This slow cooling prevents cracking and residual stresses.

7.2.5.3 Free Machining Steels

Free machining steels are steels that have additions of sulfur, phosphorous, selenium, or lead in them to make them 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, which cause 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. If you must weld free machining steel, high manganese filler metal and low base metal dilution will help give the best results possible.

7.2.5.4 Stainless Steels

Most types of stainless steels can be TIG welded. 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.

Chromium is the major alloying element that distinguishes stainless steels from the other types of steel. . Steels with 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. A 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. The use of extra low carbon base and filler metal (.03% carbon max). Examples are 304L and 316L.
3. The use of a stabilized alloy containing columbium, ***tantalum*** (**tan**-tl-*uh* m) or titanium. Examples are 347 and 321.
4. The 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.

TIG is especially well suited for welding stainless steel because the filler metal does not cross the arc and therefore change the composition. The process provides an inert atmosphere and leaves no slag to react with the base metal. 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 generally lower melting points of stainless steel. The lower thermal conductivity and higher thermal expansion cause more distortion and warpage for a given heat input.

Use direct current electrode negative (DCEN) for most applications, and the most widely used tungsten electrode is the 2% thoriated type, with argon, argon-helium mixtures, and helium shielding gases. Argon is the preferred shielding gas, but argon-hydrogen mixtures are sometimes used to improve the bead shape and the wetting.

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.

The 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 9-19* shows filler metal selection for stainless steels.

Table 9-19 — Filler metal selection for welding stainless steel.

AISI Type No.	C%	Mn%	Si%	Cr%	Ni%	Filler Other Elements	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	19.00-22.00	-	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	16.00-1S.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 3.00-4.00	317
321	0.08 max	2.00	1.00	17.00-19.00	9.00-12.00	Ti 5 x C min	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 10 x C 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	-	Al 0.10-0.30	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	1S.00-23.00	-	-	309 310
446	0.20 max	1.50	1.00	23.00-27.00	-	N2 0.25 max	309 310

7.2.6 Titanium and Titanium Alloys

You can TIG weld titanium and many of the titanium alloys. 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 the 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. 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), but in many cases, welding is done in an inert gas-filled chamber.

Thoriated tungsten electrodes are the best types for welding these metals with the 2% thoriated type being the most widely used with direct current electrode negative. Preheating is used rarely except when removing moisture from the surface of the metal.

For welding thicknesses greater than .10 in. (2.5 mm), filler metal is required, usually of the same chemical composition as the base metal. However, to improve the joint ductility, you can use a filler metal with a lower yield point than the base metal.

7.2.7 Other Metals

You can also use TIG to weld the reactive and refractory metals. Reactive metals include zirconium and beryllium. Refractory metals are metals such as tungsten, molybdenum, columbium, and tantalum. The weldability of zirconium is similar to that of titanium. Because this metal, when hot, is highly reactive with the atmosphere, welding must be protected by adequate shielding and is frequently done in vacuum chambers using direct current electrode negative and an argon or helium shielding gas.

Occasionally, beryllium is welded using TIG, but welders must closely control the heat input to prevent very large grains from being formed and to avoid cracking caused by its inherent low ductility. In addition, beryllium is very toxic, and you must take strict safety measures such as wearing special safety clothes and gas masks to prevent contact with the fumes. Usually, alternating current with an argon shielding gas is used, and a low heat input is essential when welding beryllium.

TIG is used commonly to weld tungsten and molybdenum. In the welding f these metals, good cleaning is necessary. Usually, welding is performed using direct current electrode negative, often in a vacuum chamber, with required preheating.

Columbium and tantalum have good weldability, and TIG is the most popular process for welding these metals with direct current electrode negative, often in a vacuum chamber. A vacuum chamber is recommended for welding tantalum, but columbium can be welded without one.

Test your Knowledge (Select the Correct Response)

10. What term is used for the grains that form on the edge of a weld?

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

11. 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.

8.1.1 WELD JOINT DESIGN

The weld joint design used for gas tungsten arc welding is determined by the design of the weldment, metallurgical considerations, and codes or specifications. Good joint designs are those that provide accessibility and economy during construction to help reduce the cost and generally raise the quality of the weld joint.

A weld joint consists of a specific weld made in a specific joint. A joint is defined as being the junction of members that are to be joined or have been joined.

Figure 9-31 — Five basic weld joints.

Figure 9-31 shows the five basic joint types. Different types of welds can join each of the different joint types. In *Figure 9-32*, the most common types of welds are shown. The type of weld made is governed by the joint configuration. *Figure 9-33* lists the nomenclature used for groove and fillet welds.

Several factors influence the joint design to be used:

1. Metal composition
2. Strength required
3. Welding position
4. Metal thickness
5. Joint accessibility

Figure 9-32 — Types of welds.

The purpose of any joint design is to produce a sound weld deposit with the desired properties as economically as possible. The edge and joint preparation are important because they will affect both the quality and the cost of welding. The exactness of the joint and edge preparation is dependent on the method of welding. Manual welding applications can tolerate greater irregularities in joint fitup than machine and automatic applications.

Of the five basic types of joints, the butt and T are the most commonly used. Since TIG is often used on thinner material, proper fitup can eliminate the need for filler metal when welding square groove butt joints.

Lap joints have the advantage of not requiring much preparation other than squaring the edges and making sure the metal is in close contact. Lap joints in thinner metals do not always require filler metal, nor do edge joints, which are used often on thin material. For example, on tubing, the end of the tubes are often flared or flanged so that the edges may be melted and provide the filler metal for the weld (*Figure 9-34*). Corner joints use edge preparations similar to those used for T-joints and usually require a filler metal.

Figure 9-33 — Weld nomenclature.

Figure 9-34 — Edge joint without use of filler metal.

8.1.0 Types of Metal

Due to the variety of base metals and their individual characteristics such as surface tension, fluidity, melting temperature, etc., joint designs should be developed to use optimum welding conditions.

For a given joint design, the type of metal influences the maximum base metal thickness that can be sensibly welded. The maximum thickness for a full penetration square-groove butt joint is about 5/16 inch (7.9 mm) in stainless steel, and about 3/16 inch (4.8 mm) in aluminum and magnesium. The differences are in the current used; you weld stainless steel using direct current electrode negative, which gives better penetration than the alternating current used on aluminum and magnesium.

In aluminum, the weld puddle will become larger and form quicker, making it more difficult for the welder to control. This is due to the higher thermal conductivity, the wider, shallower bead produced by alternating current, and the narrower melting temperature range of aluminum. For example, on 1/4-inch (6.4 mm) thick metal, a V-groove would be used in aluminum while a square-groove would allow full penetration in stainless steel. This difference between the metals will also affect the size of the root face used. In general, larger root faces can be used in mild, low alloy and stainless steel than can be used in aluminum and magnesium because of the difference in the penetration capability.

In nickel and high nickel alloys, the weld puddle is very sluggish when molten. The puddle does not spread or wet out very well, so you must place the filler metal at the proper location in the joint. As a result, to permit enough space for manipulation, you need to use larger root openings for nickel than the root openings you would use in carbon and low alloy steels.

8.2.0 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.

8.3.0 Position

TIG can be used in all welding positions. The welding position selected often affects the shape of the joint. A diagram of the welding position capabilities is shown *in Figure 9-35*. Good quality welding in flat, horizontal, vertical, and overhead positions depends on the skill of the welder.

Figure 9-35 — Welding test positions.

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.

The groove angle is often varied for different positions. Wider groove angles are often used when welding in the vertical and horizontal positions. Some groove joints welded in the horizontal position have unsymmetrical groove angles. Usually the lower groove face is horizontal or nearly horizontal and the upper groove face is raised accordingly (*Figure 9-36*).

Figure 9-36 — V-groove joint in the horizontal position.

8.4.0 Thickness

The thickness of the base metal has a large influence on the type of groove that gives the best weld joint possible. The thickness of the base metal welded by this process is not limited, but gas tungsten arc welding is particularly well adapted for welding thin metal. Thicknesses down to .005 inch (.1 mm) can be welded.

The TIG process, because of its relatively low deposition rate, does generally not weld thick metal sections. GMAW is used on many of the thicker applications, especially on the non-ferrous metals.

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 configurations are also used for T-joints; these preparations are used to make it possible to get full or adequate penetration.

Square-groove welds are the most commonly used weld joints for TIG because most applications of this process are on thin metal. The square-groove joint design is the easiest to prepare and requires the least addition of filler metal, and in many cases, filler metal is not used at all. Thicknesses up to 3/16 inch (4.8 mm) or 5/16 inch (7.9 mm) can be welded with full penetration, depending on the type of metal. Many square-groove joints are welded in one pass. A backing strip may be used so that the root can be opened to ensure adequate penetration.

V-grooves for groove welds on butt joints and bevel-grooves for T-joints are commonly used for thicker metal up to about ½ inch (12.7 mm), but these joints are more difficult to prepare, which increases the cost of preparation, and filler metal must be used for V-grooves and bevel-grooves. The included angle for a V-groove is usually up to 90 degrees, the wider angles providing better accessibility to the root. Root faces usually range from 1/8 inch (3.2 mm) to ¼ inch (6.4 mm) depending on the thickness and type of metal.

U- and J-grooves are generally used in metal thicknesses over ½ inch (12.7 mm) to reduce the filler metal required for thicker sections. These joint configurations are also the most difficult and expensive to prepare, but greatly add to the ease of depositing the root pass. When possible in thick sections, the fill passes in this type of joint are deposited by the higher deposition welding processes.

8.5.0 Accessibility

A major consideration in TIG welding joint design is the provision for proper accessibility. Since TIG typically applies to thinner metals, often welds can be made from either one side or both sides of the joint. On thicker metals, when both sides of the joint are accessible, double-grooves are usually made. Double-grooves have less area to fill than single-grooves, therefore requiring less filler metal and developing less distortion with proper weld bead sequencing. When double-grooves are used, the roots of the welds are usually near the center of the base metal.

Welding from both sides of a square-groove usually ensures complete penetration, and on thicker metal is better than complete penetration welding from one side. Also, smaller root openings may be used, which will require less filler metal.

When the joints are accessible only from one side, you can use backing strips and consumable inserts for wider root openings to provide better accessibility to the root of the joint.

Often, on thick metal accessible from only one side, V-, U-, and J-grooves are used, although U- and J-grooves are preferred because they provide better accessibility to the root of the joint and require less filler metal than V-grooves. However, U- and J-grooves are more difficult to prepare, thus increasing time and costs.

8.6.0 Consumable Inserts

Consumable inserts are widely used in welding tube and pipe, and have an effect on joint design. They are used when the joint is accessible from only one side and a uniform, high quality root pass is required. Consumable inserts also provide full penetration to the root of the weld as long as enough heat is available to melt the insert to the root of the joint.

Consumable inserts can help line up the joint during the fitup procedure. For best results, joints with consumable inserts should be precisely prepared and closely fitted, but often they are used when there is joint misalignment.

Consumable inserts also serve as a type of backing. Inserts usually require the use of a different joint design, depending on the type used. Consumable inserts are available in various shapes and sizes (*Figure 9-37*).

When an insert is used, the dimensions of the joint must be compatible with the particular insert, and an insert may require the use of a different size root face and root opening than a normal joint. On square-groove joints, wider root openings are often used so the insert will fit.

An example of this is shown in *Figure 9-38*, where a V-groove weld joint of the same type and thickness is shown with and without a consumable insert. In this case, a smaller root face and root opening are used with a consumable insert because the insert reduces the danger of melt-through.

Figure 9-37 — Consumable inserts.

Figure 9-38 — A V-groove joint with and without a consumable insert.

8.7.0 Weld Joint Designs

The weld joint designs shown in the rest of the chapter are those typically used for TIG. Thickness limitations on the weld joints are approximate numbers and vary, depending on the type of base metal. While the thickness limits are generally smaller than what can be used for steels and silicon bronze, they may be slightly large for aluminum and magnesium applications.

These joint designs are generally for thinner material. Thick material is not included because it is rarely TIG welded. Several joint designs used with consumable inserts are included. *Figures 9-39* through *9-47* show the "Standard Welding Symbols" of the American Welding Society. Some of these are shown in the weld joint designs.

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.

Figure 9-39 — Welding symbols.

Figure 9-40 — **Welding symbols (cont.).**

Figure 9-41 — Welding symbols (cont.).

Figure 9-42 — Welding symbols (cont.).

Figure 9-43 — Welding symbols (cont.).

Figure 9-44 — Welding symbols (cont.).

Figure 9-45 — Welding symbols (cont.).

Figure 9-46 — Welding symbols (cont.).

Figure 9-47 – Welding symbols (cont.).

8.8.0 Welding Positions

As it is with other welding processes, in TIG welding the proper positions of the welding torch and weldment are important. The position of the torch and filler metal (if used) in relation to the plate is called the work and travel angle. Work and travel angles are shown in *Figure 9-48*. 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 9-48 — Travel angle and work angle for TIG.

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 9-49*).

The pulling or drag technique is for heavy-gauge metals, and thus not as applicable to TIG. 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. Typically, TIG uses the pushing technique for light-gauge metals. Welds made with this technique are less penetrating and wider because the welding speed is faster.

Figure 9-49 — Pulling and pushing travel angle techniques.

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-percent reduction in amperage.

If you must weld a heavier thickness of metal with the TIG welding process, you should use the multi-pass technique (buildup sequence discussed in Chapter 3). This is accomplished by overlapping single small beads or making larger beads, using the weaving technique. Various multipass welding sequences are shown in *Figure 9-50*. The numbers refer to the sequences in which you make the passes.

Figure 9-50 — Multi-pass welding.

As presented earlier with gas tungsten arc welding, the maximum thickness for a full penetration square-groove butt joint is about 5/16 inch (7.9 mm) in stainless steel, and about 3/16 inch (4.8 mm) in aluminum and magnesium. The following sections on welding positions will include greater thicknesses in the examples, which will have more application for shielded metal arc welding (SMAW or stick), gas metal arc welding (MIG or MAG), and flux core arc welding (FCAW), each with greater deposition rates.

However, the topics are included in this chapter on gas tungsten arc welding (TIG) as well, because often a precision root pass with TIG may be the best process before applying one of the alternate, higher deposition processes.

8.8.1 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— After you strike the arc, hold the torch at a 90-degree angle to the workpiece surface, and with small circular motions, as shown in *Figure 9-51*, form a molten puddle. After you form the molten puddle, hold the torch at a 75-degree angle to the work surface and move it slowly and steadily along the joint at a speed that produces a bead of uniform width. Move the torch slowly enough to keep the puddle bright and fluid. No oscillating or other movement of the torch is necessary except the steady forward movement.

When you must use a filler metal, form the molten puddle as described previously. When the puddle becomes bright and fluid, you should move the arc to the rear of the puddle and add the filler metal by quickly touching the rod to the front edge of the puddle. Hold the rod at about a 15-degree angle from the work. Because the electrode is pointing toward the filler metal or pushing it, it is known as the *push angle.* Remove the filler rod and bring the arc back to the front edge of the puddle. When the puddle becomes bright and fluid again, you should repeat the steps as described before. *Figure 9-52* shows the correct procedures for adding filler metal. Continue this sequence until the weld joint has been completed. The width and height of the weld bead are determined by the speed of travel, by the movement of the torch, and by the amount of filler metal added.

In welding practice, it is again stressed that good TIG welding depends on following this definite procedure— form the molten pool and then feed filler rod intermittently to the leading edge of the pool as you move the torch forward. DO NOT feed the filler rod into the arc. You should practice making single-pass butt welds until you can produce satisfactory welds.

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 9-51*.

Plates up to 1/8 inch thick can be welded in one pass with no special edge preparation. Plates from 1/8 to 3/16 inch 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 torch motion is the same as that used in making a bead weld.

Figure 9-51 — Butt joints in the flat position.

In welding 1/4-inch 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.

Figure 9-52 — Butt welds with multi-pass beads.

In making multi-pass welds, the second, third, and fourth layers of weld metal are made with a weaving motion of the torch (*Figure 9-52*). Clean each layer of metal before laying additional beads. You may use one of the weaving motions shown in *Figure 9-53*, depending upon the type of joint.

In the weaving motion, oscillate or move the torch uniformly from side to side, with a slight hesitation at the end of each oscillation. Incline the torch 5 to 15 degrees in the direction of welding as in bead welding. When the weaving motion is not done properly,

Figure 9-53 — Weave motions.

undercutting can occur at the joint (*Figure 9-54*). Excessive welding speed also can cause undercutting and poor fusion at the edges of the

Butt joints with backing strips — Welding 3/16-inch 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

Figure 9-54 — Undercutting in butt joint welds.

welding without backing strips. For plates up to 3/8 inch thick, the backing strips should be approximately 1 inch wide and 3/16 inch thick. For plates more than 1/2 inch thick, the backing strips should be 1 1/2 inches wide and 1/4 inch thick. Tack-weld the backing strip to the base of the joint (*Figure 9-55*). 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, you may “wash” off or cut the backing strip away with a cutting torch. When specified, place a seal bead along the root of the joint.

Figure 9-55 — 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.

8.8.2 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 9-56)*. In a fillet weld, the welding is performed on the upper side of a relatively horizontal surface and against an approximately vertical plane (*Figure 9-57*).

Figure 9-56 — Horizontal groove weld.

Figure 9-57 — Horizontal fillet weld.

An inexperienced welder usually finds the horizontal position of arc welding difficult, at least until he has developed 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.

When welding in the horizontal position, start the arc on the edge of the joint. Then hold the torch at a work angle of 15 degrees and a push angle of 15 degrees. After you establish the puddle, dip the rod into the front edge of the puddle on the high side as you move the torch along the joint (*Figure 9-58*). Maintain an arc length as close as possible to the diameter of the electrode. Correct arc length coupled with the correct speed of travel helps prevent undercutting and permits complete penetration.

Figure 9-58 — Horizontal welding angles.

Joint Type

Horizontal-position welding can be used on most types of joints. The most common types of joints it is used on are tee joints, lap joints, 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 (*Figure 9-59*).

Figure 9-59 — Tack-weld to hold the tee joint elements in place.

Figure 9-60 — Position of electrode on a fillet weld.

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 9-60*, *View A*). Hold the torch at an angle of 45 degrees to the two plate surfaces (*Figure 9-60*, *View B*) with an incline of approximately 15 degrees in the direction of welding.

When practical, weld light plates with a fillet weld in one pass with little or no weaving of the torch. Welding of heavier plates may require two or more passes in which the second pass or layer is made with a semicircular weaving motion (*Figure 9-61*). 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-inch plate or heavier, deposit stringer beads in the sequence shown in *Figure 9-62.*

Figure 9-61 — Weave motion for multi-pass fillet weld.

Chain-intermittent or staggered-intermittent fillet welds are used on long tee joints (*Figure 9-63*). 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.

Figure 9-62 — Order of string beads for tee joint on heavy

Figure 9-63 — Intermittent fillet welds.

Lap joints — When you make a lap joint, two overlapping plates are tack-welded in place (*Figure 9-64*), 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 torch 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 torch in

Figure 9-64 — Tack welding a lap joint.

Figure 9-65 — Position of electrode on a lap joint.

relation to the plates is shown in *Figure 9-65*. 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 undercut. Lap joints on 1/2-inch plate or heavier are made by depositing a sequence of stringer beads (*Figure 9-65*),

In making lap joints on plates of different thickness, you should hold the torch so that it forms an angle of between 20 and 30 degrees from the vertical (*Figure 9-66*). Be careful not to overheat or undercut the thinner plate edge.

Figure 9-66 — Lap joints on plates of different thickness.

Figure 9-67 — Horizontal butt joint.

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 that it does not run out of the joint (*Figure 9-67*). Often 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.

The number of passes required for a joint depends on the diameter of the torch and the thickness of the metal. When multiple passes are required, place the first bead deep in the root of the joint (*Figure 9-68*). The torch 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 torch held about 10 degrees upward. For the third pass, hold the torch 10 to 15 degrees downward from the horizontal. Use a slight weaving motion and ensure that each bead penetrates the base metal.

Figure 9-68 — Multiple passes.

8.8.3 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 9-69*). 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.

When welding thin material with the TIG welding process, you should weld from the top, moving downward. This helps you produce an adequate weld without burning through the metal. Filler material is not normally needed for welding downward.

On heavier materials, you should weld from the bottom, upwards. This enables you to achieve adequate penetration. When welding upward, you normally need to use a filler rod.

Figure 9-69 — Vertical weld plate positions.

Current Settings and Torch Movement

In vertical arc welding, the current settings should be less than those used for the same torch 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 torch and the base metal. In welding upward, you should hold the torch at 90 degrees to the vertical (*Figure 9-70, View A*). When weaving is necessary, oscillate the torch as shown in *Figure 9-70*, *View B*.

In vertical down welding, incline the outer end of the torch downward about 15 degrees from the horizontal while keeping the arc pointing upward toward the deposited molten metal (*Figure 9-70*, *View C*). When vertical down welding requires a weave bead, you should oscillate the torch as shown in *Figure 9-70*, *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.

Figure 9-70 — Bead welds in the vertical position.

Hold the torch 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 torch in a triangular weaving motion as shown in *Figure 9-71, 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.

When the weld metal overheats, you should quickly shift the torch away from the crater without breaking the arc, as shown in *Figure 9-71, View B*. This permits the molten metal to solidify without running downward. Return the torch 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 9-71, 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 torch in a triangular weaving motion as shown in *Figure 9-71*, *View E*. Use the same procedure as outlined above for the tee joint, except direct the torch more toward the vertical plate marked G. Hold the arc short, and pause slightly at the surface of plate G. Try not to undercut the plates or allow the molten metal to overlap at the edges of the weave.

Figure 9-71 — Fillet welds in the vertical position.

Lap joints on heavier plate may require more than one bead. If so, clean the initial bead thoroughly and place all subsequent beads as shown in *Figure 9-71, 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 1/4 inch thick can be welded in one pass by using a triangular weave motion, as shown in *Figure 9-72*, *View A.*

Weld made on 1/2-inch plate or heavier should be done in several passes, as shown in *Figure 9-72*, *View B*. Deposit the last pass with a semicircular weaving motion with a slight "whip-up" and pause of the torch at the edge of the bead. This produces a good

Figure 9-72 — Butt joint welding in the vertical position.

cover pass with no undercutting. Welds made on plates with a backup strip should be done in the same manner.

8.8.4 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 Torch Movement

When TIG welding in the overhead position, you should lower the welding current by 5 to 10 percent of what normally is used for flat welding. This reduced welding current enables you to maintain better control of the welding puddle. Conversely, you need a higher flow of shielding gas. Hold the torch and the rod as you do for flat welding. You should try to maintain a small weld puddle to avoid the effects of gravity. Most inexperienced welders find overhead welding awkward; therefore, try to get in as comfortable and relaxed a position as possible when welding. This helps you to maintain steady, even torch and filler rod manipulation.

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 with 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 torch is 90 degrees to the base metal (*Figure 9-73*, *View A*). The travel angle should be 9 to 15 degrees in the direction of welding (*Figure 9-73*, *View B*).

Weave beads can be made by using the motion shown in *Figure 9-73*, *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

Figure 9-73 — Position of electrode and weave motion in the overhead position.

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 the operator takes 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 torch position and the order of deposition of the weld beads when welding on 1/4- or 1/2-inch plate are shown in *Figure 9-74*,

Figure 9-74 — Multi-pass butt joint in the overhead position.

Figure 9-75 — Fillet welds in the overhead position.

Views B and *C*. Make the first pass with the torch held at 90 degrees to the plate, as shown in *Figure 9-74*, *View A*. When you use a torch that is too large, you cannot hold a short arc in the root area. This results in insufficient root penetration and inferior joints.

Fillet welds — In making fillet welds in either tee or lap joints in the overhead position, maintain a short arc and refrain from weaving of the torch. Hold the torch at approximately 30 degrees to the vertical plate and move it uniformly in the direction of welding, as shown in *Figure 9-75*, *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 torch quickly away from the crater and ahead of the weld to lengthen the arc and allow the metal to solidify. Immediately return the torch to the crater and continue welding.

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 9-75*, *View A*. The root pass is a string bead made with no weaving motion of the torch. Tilt the torch about 15 degrees in the direction of welding, as shown in *Figure 9-75*, *View C*, and with a slight circular motion make the second, third, and fourth pass. This motion of the torch 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 reduced flow restrictions 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 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

In the following paragraphs, pipe-welding positions, pipe welding procedures, definitions, and related information are discussed.

You may recall from *Figure 9-35* that there are four positions used in pipe welding. They are known as 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

Figure 9-76 — Butt joints and socket fitting joints.

Pipe Welding Procedures

Welds that you cannot make in a single pass should be made in interlocked multiple layers, with at least 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 of flanges and welding stubs. In making a butt joint, place two pieces of pipe end to end, align them, and then weld them (*Figure 9-76*).

When the wall thickness of the pipe is 3/4 inch or less, you can use either the single V or single U type of butt joint; however, when the wall thickness is more than 3/4 inch, only the single U type should be used.

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 9-77*). Fillet welds are also used in welding screw or socket couplings to pipe, using a single fillet weld (*Figure 9-76)*. Sometimes flanges require alignment. *Figure 9-78* shows one type of flange square and its use in vertical and horizontal alignment.

Figure 9-77 — Flange connections.

Another form of fillet weld used in pipefitting 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 flame-cut edges; however, it is not necessary to remove the temper color.

When you prepare joints for welding, remember that bevels must be cut

Figure 9-78 — Flange alignment.

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 percent 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 9-79*), while a section of channel or I-beam is more suitable for larger diameter pipe.

Figure 9-79 — 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-inch 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

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 before beginning to weld.

Test your Knowledge (Select the Correct Response)

12. How many basic types of pipe weld joints are there?

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

13. In addition to tack welds, what is also used for proper pipe alignment?

    A. Spacers
    B. Back strips
    C. Another welder
    D. Flat, smooth surface to place the work piece on

9.0.0 WELDING PROCEDURE VARIABLES

Welding procedure variables control the welding process and the quality of the welds that are produced. The selection of the welding variables is done after the base metal, filler metal, and joint design are selected. The selection of the filler metal and joint design have been discussed in previous chapters.

A proper selection of welding variables will make the welding easier for the welder, increasing the chance of producing the weld properties required. The three major types of welding variables are the fixed or preselected, the primary adjustable, and the secondary adjustable.

The fixed or preselected variables are set before the actual welding takes place. These are items such as the electrode type and size, the type of current, the type of shielding gas, and the electrode taper angle. These variables cannot be easily changed once the welding starts.

The primary adjustable variables are used to control the welding process after the fixed variables have been selected. They control the formation of the weld bead by affecting the bead width and height, joint penetration, arc stability, and weld soundness (*Figure 9-80*). The primary adjustable variables for gas tungsten arc welding are the welding current, arc length, and travel speed.

Figure 9-80 — Bead height, width, and penetration.

The secondary adjustable variables are used to control the welding process. These are usually more difficult to measure and their effects may not be as obvious. In TIG welding, secondary adjustable variables are things such as the work and travel angles of the electrode and the electrode extension.

The different variables affect the characteristics of the weld including the joint penetration of the weld, the bead height and width, and the deposition rate. The joint penetration is the distance the weld metal extends from its face into a joint, exclusive of weld reinforcement. 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 material deposited in a unit of time.

The welding variables presented in this section focus on joint penetration, bead shape, and the effect they have on the other welding variables. The deposition rate is a lesser issue with TIG. It will vary widely because the filler metal does not cross the arc and is not as dependent on variables such as the type and amount of welding current used, and of course there is no deposition rate when you do not use a filler metal.

9.1.0 Fixed Variables

With gas tungsten arc welding, fixed variables include the type, size, and taper of the electrode, and the types of welding current and shielding gas.

9.1.1 Type of Electrode

The type of tungsten electrode used in gas tungsten arc welding depends on the type of metal and the specific application. Refer to *Table 9-3* for the correct type of electrode to weld various base metals.

For less critical applications, you should use the pure tungsten electrodes rather than the thoriated or zirconium tungsten electrodes. Pure tungsten electrodes have a lower current carrying capacity and a lower resistance to contamination, and tend to leave more tungsten inclusions in the weld metal. However, pure tungsten electrodes are widely used for AC welding of aluminum and magnesium because they do not disintegrate as fast with alternating current, and are the least expensive.

The thoriated tungsten electrodes are more expensive but are preferred for many applications because of the higher current carrying capacity, longer life, easier starting, more stable arc, and greater resistance to contamination.

Zirconium tungsten electrodes generally have properties that fall somewhere in the middle. Zirconium electrodes often give the best characteristics with alternating current and are used to give x-ray quality welds in aluminum and magnesium.

9.1.2 Electrode Size

The size of the electrode used will depend on the intended welding current range. Refer again to an earlier table, *Table 9-4*, which shows the current ranges for various types and sizes of tungsten electrodes. This is not the only determining factor though. For all types of tungsten electrodes, in addition to the electrode diameter, the current-carrying capacity is affected by the electrode extension, type of electrode holder, type of shielding gas, and type of welding current.

Larger electrodes will allow you to use higher welding currents. For a given welding current setting, you will need to use a larger electrode when using direct current electrode positive because of the high heat buildup that occurs in the electrode. Also, for a given size of electrode, direct current electrode negative will be able to carry the largest amount of current. Although larger electrodes are generally used for welding thicker metal, very small electrodes may be used for welding very thin sheet metal.

9.1.3 Type of Welding Current

The type of welding current used depends primarily on the type of metal to be welded, the current levels required, and the availability of a machine that produces that type of welding current. *Figure 9-81* describes some of the characteristics of different polarity electrodes; also, refer once again to *Table 9-3* for the type of recommended current for different base metals.

Direct current electrode positive is often used for welding thin aluminum and magnesium parts. It is popular for these applications because the cathodic cleaning action created at the surface of the workpiece removes the refractory oxide surface that inhibits wetting of the weldment. DCEP also provides shallow penetration and has a low current-carrying capacity because of the high amount of heat that builds up on the electrode. Since this heat buildup can cause electrode melting, using DCEP is limited to welding thin materials at low current levels.

Direct current electrode negative is used to obtain deep penetrating welds and is the most common type of current used for welding metals other than aluminum and magnesium. For aluminum and magnesium, alternating current with a superimposed high frequency current is most commonly used. This type of current provides good oxide cleaning when the electrode is positive and good penetration when the electrode is negative. Overall, alternating current gives moderate penetration and is the second choice of current type on most other metals.

Figure 9-81 — Characteristics of current types for gas tungsten arc welding.

9.1.4 Type of Shielding Gas

Shielding gas is directed by the torch to the arc and weld pool to protect the electrode and the molten weld metal from atmospheric contamination. The inert shielding gas used will affect the penetration of the weld, the heat input, and the cost of the welding operation.

Argon is the most common type of shielding gas used in TIG and can be used for most applications. Argon will give less penetration and heat input than helium but is less expensive to use because it requires lower flow rates, produces the least spatter, and costs less. It provides a smoother, quieter, arc action, better cross-draft resistance, and an easier starting arc. Argon is used exclusively on thin metals because the high heat input of helium causes melt-through.

Helium gives a hotter arc and more heat input into the base metal, which produces deeper penetration and allows faster travel speeds. It is used especially for welding thick sections, for metals with high heat conductivity, and for high-speed mechanized applications.

Mixtures of argon are used to obtain a balance between the characteristics of these two gases. Using helium instead of argon allows you to use lower welding currents and produces higher arc voltages for a given arc length.

9.1.5 Electrode Taper Angle

Electrode taper angle is the angle ground on the end of the tungsten electrode (*Figure 9-82*). This variable applies only to thoriated tungsten electrodes. These are ground to a tip to give better arc starting with high frequency ignition and a more stable arc. The grinding wheel should be reserved for grinding only tungsten to eliminate possible contamination of the tungsten tip with foreign matter during the grinding operation. When grinding thoriated electrodes, you should use exhaust hoods to remove the grinding dust from the work area.

You can taper thoriated tungsten electrodes because of their higher current-carrying capacity. The most common taper angle is approximately 22°. This means that the electrode is tapered about 2 1/2 electrode diameters. The degree of taper also affects the bead shape and penetration. Increasing the taper angle tends to reduce the bead width and increase the weld penetration.

The disadvantage of the smaller taper angles is that they tend to wear away quicker, especially on starts where the tip of the electrode is touched to the work. To reduce the erosion and the number of times you will need to regrind the electrode, you should use a larger taper angle because it does not wear away as quickly.

Figure 9-82 — Electrode taper angle.

Regardless of the electrode tip geometry selected, it is important that you use a consistent taper angle once a welding procedure is established. Changes in the electrode angle can significantly influence the weld bead shape and size. Therefore, the electrode tip configuration is a variable that you need to study during the welding procedure development.

9.2.0 Primary Variables

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

9.2.1 Welding Current

Once you have chosen the fixed or preselected variables, the amount of welding current you use will have the greatest effect on the characteristics of the weld bead. A knob or handle on the front of the welding machine, or a foot pedal rheostat controls the welding current. On some automatic applications, weld programmers may control the weld current.

All of the following help determine the welding current:

- type of electrode
- size of the electrode
- type of welding current
- position
- joint design
- metal thickness
- current range of the machine

The welding current is the best variable for controlling the depth of penetration and the volume of weld metal.

As the other factors remain constant, when you increase the welding current, the penetration and size of the weld bead increases. An excessive weld current can produce undercutting, excessive penetration, and an irregular weld deposit.

While the other factors remain constant, lowering the welding current will reduce the penetration and size of the weld bead. An extremely low weld current can cause piling up of the weld metal, poor penetration, and overlapping at the edges of the weld bead. *Figure 9-83 shows* the effects of different welding currents and speeds.

Figure 9-83 — Effects of different primary variables.

9.2.2 Travel Speed

The travel speed is the rate that the arc travels along the workpiece. For a given welding current and voltage, the travel speed determines the amount of heat that is delivered for a given length of weld. Changes in the travel speed have a strong effect on the shape of the weld bead and the amount of penetration. In manual TIG welding, the welder controls the rate that the arc travels along the work. In mechanized and automatic welding operations, the travel speed is controlled by the equipment.

While the other variables remain constant, increasing the travel speed will reduce the size of the weld bead and decrease the amount of penetration. Conversly, decreasing the travel speed will increase the size of the weld bead and increase the penetration.

If the welding current and travel speed are increased or decreased proportionally together, the weld will maintain the same penetration and width.

An excessive travel speed will produce a weld bead that is too small, has poor penetration, and is irregular in shape. A travel speed that is too slow will give a weld bead with excessive penetration, size, and piling up of the weld metal when filler metal is added.

9.2.3 Welding Voltage (Arc Length)

The welding or arc voltage is dependent on the shielding gas and the distance between the tip of the electrode and the work. In the case of manual TIG welding, the welder controls the distance from the tip of the electrode to the adjacent surface of the weld pool, called arc length.

In mechanized and automatic welding, the arc length is pre-set by the distance from the electrode tip to the work. In automatic welding, arc voltage controllers may be used to move the electrode tip up and down to maintain the desired arc length. The arc voltage controller compares the measured and desired arc voltages to determine which direction and at what speed the welding electrode should be moved. This determination, expressed as a voltage error signal, is amplified to drive motors in a slide that supports the torch. The changing voltage that results from the motion of the welding electrode is detected and the cycle repeats to maintain the desired arc voltage.

The shielding gas has an effect on the arc voltage. Helium will give higher arc voltages for a given arc length than argon, which accounts for the greater penetrating ability of helium.

The arc length has a direct effect on the welding voltage. Increasing the arc length will increase the arc voltage, and decreasing the arc length will decrease the arc voltage. A welding voltage that is too high indicates that the arc is too long. An excessive arc length will produce an irregular welding bead with poor penetration. When the arc length is extremely long, the shielding gas may not provide enough protection, which could cause porosity and a discolored weld bead. *Figure 9*-83 also shows the effect of an excessive arc length. Too short an arc can also cause problems. It increases the danger of electrode contamination because the welder is more likely to dip the end of the electrode in the weld puddle. Another problem is a higher heat buildup on the tungsten electrode and the torch nozzle because they are closer to the weld puddle. This reduces the service life of the electrode.

9.2.4 Starting the Arc

Before starting the arc, you should form a ball on the end of the electrode for AC welding. To do this, simply set the current to DCRP and strike an arc for a moment on a piece of carbon or a piece of copper. The ball diameter should be only slightly larger than the original diameter of the tungsten electrode.

When starting the arc with an AC high-frequency current, you do not have to bring the electrode into contact with the workpiece. To strike the arc, you must hold the torch in a horizontal position about 2 inches above the work surface, as shown in *Figure 9-84*. Then rapidly swing the electrode end of the torch down to within 1/8 of an inch of the work surface. The high-frequency arc will then jump the gap between the electrode and the plate, establishing the arc. *Figure 9-85* shows the torch position at the time the arc strikes.

Figure 9-84 — Torch position for the starting swing to strike the arc.

If you are using a DC machine, hold the torch in the same position, but touch the plate to start the arc. When the arc is struck, withdraw the electrode so it is about 1/8 of an inch above the plate.

To stop the arc, quickly swing the electrode back to the horizontal position. If the machine has a foot pedal, gradually decrease the current before stopping the arc.

9.3.0 Secondary Variables

Secondary variables for TIG include the travel and work angles of the electrode, and electrode extension.

Figure 9-85 — Torch position at the end of the swing.

9.3.1 Angles of the Electrode

The angular position of the electrode in relation to the work may have an effect on the quality of the weld deposit. The position of the electrode may determine the ease at which you can add the filler metal (if used), the quality of the weld bead, and the uniformity of the bead.

The electrode angles are called the travel angle and the work angle. The travel angle of the electrode is the angle between the joint and the electrode in the longitudinal plane. The work angle is the angle between the electrode and the perpendicular plane to the direction of travel. These are shown in *Figure 9-86*. The welder manually controls the electrode angles, and the angles used may vary slightly from welder to welder.

An incorrect work angle can cause undercutting and an inadequate weld bead. An example of this is in the case of making a fillet weld. If the welder favors or directs the arc more toward one plate, undercutting or lack of fusion may result on the other plate, and the bead may have an irregular shape. The travel angle used will have an effect on the penetration and the bead height. Increasing the travel angle in the direction of welding will generally build up the height of the bead. Increasing the travel angle in the opposite direction of welding will decrease the amount of penetration and give a wider bead.

Figure 9-86 — Travel angle and work angle.

9.3.2 Electrode Extension

The distance that the tip of the electrode extends beyond the end of the gas nozzle is known as the electrode extension. Usually, the amount of extension is equal to one or two electrode diameters, as shown in *Figure 9-87*. There are cases where the electrode extension used will be greater or less.

The longer the electrode extension, the greater the chance of contamination by striking the base metal or the filler rod to the tip of the electrode, or by inadequate gas coverage.

Alternatively, the farther the electrode tip is withdrawn into the gas nozzle, the less current the electrode will be able to withstand because some of the heat is reflected back to the electrode from the gas nozzle. Often, longer electrode extensions are used on fillet welds so the electrode may approach the root of the joint and the arc will be visible to the welder.

In some cases, the end of the electrode is withdrawn into the gas nozzle, making it very difficult to contaminate the electrode. This hinders visibility and requires a high degree of welder skill. For welds requiring a very short arc length, a longer than normal extension is used so the welder has better vision. Longer electrode extensions require higher gas flow rates and will not cool as efficiently. The electrode extension should not be longer than absolutely necessary because of the added gas flow rates needed and the added danger of electrode contamination.

Figure 9-87 — Electrode extension.

10.0.0 WELDING PROCEDURE SCHEDULES

The welding procedure schedules in this section give typical welding conditions that can be used to obtain high quality welds under normal welding conditions. The gas tungsten arc welding process can use a wide variety of operating conditions for welding various base metals. The schedules presented here provide only a few examples of the many different welding procedures that can be used. The tables given here 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, when automatic gas tungsten arc welding is used, the travel speeds are often higher than if the welding was performed manually. 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 in the shop or field prior to actual use.

When adjusting or changing the variables for welding, the effect of the variables on each other must be considered. In order to obtain a stable arc and good overall welding conditions, one variable cannot usually be changed very much without adjusting or changing the other variables.

The following schedules are based on welding specific metals and their alloys such as aluminum, magnesium, copper, nickel, and titanium as well as steel. The tables have the type of weld, base metal thickness, number of passes, tungsten electrode size, gas nozzle size, filler rod size, gas flow rate, welding current, and travel speed as the variables that can be changed. The arc voltage is not included because the arc length will vary depending on the welder. Gas tungsten arc welding is done using constant current types of power sources, which allow the welding voltage to vary, while keeping the welding current at approximately the same level. In automatic gas tungsten arc welding, the voltage is easily measured because the machine can hold a constant arc length.

The tables presented in this chapter are the conditions for manual TIG welding. The main emphasis of these schedules is on the welding conditions used for welding thin materials, especially for non-ferrous metals. The type of current, shielding gas, and tungsten electrode used are those recommended for welding these different metals, and will not be considered as variables here.

Because of the wide variety of applications TIG welding is capable of performing, the procedure schedules presented here are not a complete guide to the procedures for TIG. They are not the only conditions that may be used to obtain a specific weld. You should make qualifying tests under actual conditions before using this process or these schedules for production welding. Figures 9-88 through 9-93 are representative of some of the configurations you will encounter when welding.

Figure 9-88 — Square groove welds.

Table 9-20 — Square groove welds in various types of base metal.

Metal Thickness in (mm)	Number of Passes	Tungsten Size in (mm)	Nozzle Size in (mm)	Filler Size in (mm)	Gas Flow ft.3/hr. (l/min.)	Welding Current Amps	Travel Speed in/min(mm/s)
Aluminum and Aluminum Alloys AC, Argon Shield, Pure or Zirconium Tungsten Electrode							
3/64 (1.2)	1	1/16 (1.6)	1/4 (6.4)	1/16 (1.6)	19 (9.0)	20-60	12 (5.1)
1/16(1.6)	1	3/32 (2.4)	5/16 (7.9)	3/32 (2.4)	19 (9.0)	40-90	10 (4.2)
3/32 (2.4)	1	3/32 (2.4)	5/16 (7.9)	3/32 (2.4)	19 (9.0)	50-110	10 (4.2)
1/8 (3.2)	1	1/8 (3.2)	3/8 (9.5	) 1/8 (3.2)	20 (9.4)	100-150	10 (4.2)
Copper and Copper Alloys (Except Silicon Bronze) DCEN, Argon Shield for Thicknesses less than 3/16" (4.8) — Helium for all others, Thoriated Tungsten							
1/16 (1.6)	1	1/16 (1.6)	1/4 (6.4)	1/16 (1.6)	18 (8.5)	100-150	12 (5.1)
1/8 (3.2)	1	3/32 (2.4)	5/16 (7.9)	3/32 (2.4)	18 (8.5)	150-230	10 (4.2)
3/16 (4.8)	1	1/8 (3.2)	3/8 (9.5)	1/8 (3.2)	36 (17)	175-250	10 (4.2)
Silicon Bronze DCEN, Argon Shield, Thoriated Tungsten Electrode							
1/16(1.6)	1	1/16 (1.6)	1/4 (6.4)	1/16 (1.6)	15 (7.1)	60-125	12 (5.1)
1/8 (3.2)	1	1/16 (1.6)	1/4 (6.4)	3/32 (2.4)	20 (9.4)	80-150	12 (5.1)
3/16 (4.8)	1	3/32 (2.4)	5/16 (7.9)	3/32 (2.4)	20 (9.4)	100-195	10 (4.2)
1/4 (6.4)	2	3/32 (2.4)	5/16 (7.9)	1/8 (3.2)	25 (11.8)	150-225	10 (4.2)

Metal Thickness in (mm)	Number of Passes	Tungsten Size in (mm)	Nozzle Size in (mm)	Filler Size in (mm)	Gas Flow ft.3/hr. (l/min.)	Welding Current Amps	Travel Speed in/min(mm/s)
Magnesium Alloys AC, Argon Shield, Pure or Zirconium Tungsten Electrode							
20 ga (.9)	1	1/16 (1.6)	1/4 (6.4)	3/32 (2.4)	15 (7.1)	25-40	15 (6.3)
16 ga (1.5)	1	1/16 (1.6)	1/4 (6.4)	3/32 (2.4)	15 (7.1)	35-70	15 (6.3)
14ga(1.9)	1	1/16 (1.6)	1/4 (6.4)	3/32 (2.4)	15 (7.1)	40-75	13 (5.5)
12 ga (2.7)	1	3/32 (2.4)	5/16 (7.9)	1/8 (3.2)	15 (7.1)	50-100	13 (5.5)
11 ga (3.0)	1	3/32 (2.4)	5/16 (7.9)	1/8 (3.2)	25 (11.8)	65-125	13 (5.5)
Nickel and Nickel Alloys DCEN, Argon Shield, Thoriated Tungsten electrode							
24 ga (.6)	1	1/16 (1.6)	3/8 (9.5)	None	15 (7.1)	8-10	8 (3.4)
16 ga (1.5)	1	3/32 (2.4)	1/2 (12.7)	1/16(1.6)	18 (8.5)	40-70	8 (3.4)
1/8 (3.2)	1	1/8 (3.2)	1/2 (12.7)	3/32 (2.4)	25 (11.8)	75-140	11 (4.7)
1/4 (6.4)	2	1/8 (3.2)	1/2 (12.7)	1/8 (3.2)	30 (14.2)	100-175	8 (3.4)
Carbon and Low Alloy Steel DCEN, Argon Shield, Thoriated Tungsten Electrode							
24 ga (.6)	1	1/16 (1.6)	1/4 (6.4)	1/16 (1.6)	10 (4.7)	15-35	13 (5.5)
20 ga (.9)	1	1/16 (1.6)	14 (6.4)	1/16 (1.6)	10 (4.7)	20-45	13 (5.5)
18 ga (1.2)	1	1/16(1.6)	1/4 (6.4)	1/16 (1.6)	10 (4.7)	25-55	12 (5.1)
16ga(1.5)	1	1/16 (1.6)	1/4 (6.4)	1/16(1.6)	10 (4.7)	35-65	12 (5.1)
14 ga (1.9)	1	1/16(1.6)	1/4 (6.4)	1/16 (1.6)	10 (4.7)	35-70	12 (5.1)
3/32 (2.4)	1	3/32 (2.4)	5/16 (7.9)	3/32 (2.4)	10 (4.7)	35-80	12 (5.1)
1/8 (3.2)	1	3/32 (2.4)	5/16 (7.9)	3/32 (2.4)	12 (5.7)	45-100	11 (4.7)
3/16 (4.8)	1	1/8 (3.2)	3/8 (9.5)	1/8 (3.2)	15(7.1)	65-140	10 (4.2)
1/4 (6.4)	1	1/8 (3.2)	3/8 (9.5)	1/8 (3.2)	18 (8.5)	85-175	10 (4.2)
Stainless Steel DCEN, Argon Shield, Thoriated Tungsten Electrode							
1/16 (1.6)	1	1/16(1.6)	1/4 (6.4)	1/16 (1.6)	12 (5.7)	35-60	12(5.1)
3/32 (2.4)	1	1/16 (1.6)	1/4 (6.4)	3/32 (2.4)	12 (5.7)	45-85	12 (5.1)
1/8 (3.2)	1	1/16 (1.6)	5/16 (7.9)	3/32 (2.4)	12 (5.7)	55-100	12 (5.1)
3/16 (4.8)	1	3/32 (2.4)	5/16 (7.9)	1/8 (3.2)	15 (7.1)	65-130	10 (4.2)
Titanium DCEN, Argon Shield, Thoriated Tungsten Electrode							
24 ga (.6)	1	1/16(1.6)	3/8 (9.5)	None	18 (8.5)	20-35	6 (2.5)
16 ga (1.5)	1	1/16(1.6)	5/8 (15.9)	None	18 (8.5)	45-85	6 (2.5)
3/32 (2.4)	1	3/32 (2.4)	5/8 (15.9)	1/16 (1.6)	25 (11.8)	60-90	8 (3.4)
1/8 (3/2)	1	3/32 (2.4)	5/8 (15.9)	1/16 (1.6)	25 (11.8)	80-125	8 (3.4)
3/16 (4.8)	2	3/32 (2.4)	5/8 (15.9)	1/8 (3.2)	25 (11.8)	90-140	8 (3.4)

Figure 9-89 — V-groove welds.

Table 9-21 — V-groove welds in various types of base metal.

Metal Thickness in (mm)	Number of Passes	Tungsten Size in (mm)	Nozzle Size in (mm)	Filler Size in (mm)	Gas Flow ft.3/hr. (l/min.)	Welding Current Amps	Travel Speed in/min(mm/s)
Aluminum and Aluminum Alloys AC Argon Shield Pure or Zirconium Tungsten Electrode							
3/16 (4.8)	2	5/32 (4.0)	7/16(11.1)	5/32 (4.0)	25 (11.8)	160-180	11 (4.7)
1/4 (6.4)	2	5/32 (4.0)	1/2 (12.7)	3/16 (4.8)	30 (14.2)	200-220	9 (3.8)
3/8 (9.5)	2	3/16 (4.8)	1/2 (12.7)	3/16 (4.8)	30 (14.2)	240-300	8 (3.4)
1/2 (12.7)	2	3 3/16 (4.8)	1/2 (12.7)	3/16 (4.8)	35 (16.5)	300-350	8 (3.4)
Copper and Copper Alloys (Except Silicon Bronze) DC EN Helium Shield Thoriated Tungsten Electrode							
1/4 (6.4)	2	1/8 (3.2)	3/8 (9.5)	1/8 (3.2)	36 (17.0)	220-275	7 (3.0)
3/8 (9.5)	2	3/16 (4.8)	1/2 (12.7)	3/16 (4.8)	45 (21.2)	275-325	7 (3.0)
1/2 (12.7)	2	1/4 (6.4)	5/8 (15.9)	1/4 (6.4)	45 (21.2)	370-500	6 (2.5)
Silicon Bronze DC EN Argon Shield Thoriated Tungsten Electrode							
3/8 (9.5)	3	1/8 (3.2)	3/8 (9.5)	3/16 (4.8)	25 (11.8)	295-355	8 (3.4)
1/2 (12.7)	4	1/8 (3.2)	3/8 (9.5)	1/8 (3.2)	25 (11.8)	245-295	8 (3.4)
3/4(19.1)	9	1/8 (3.2)	3/8 (9.5)	3/16 (4.8)	25 (11.8)	295-355	8 (3.4)
Magnesium Alloys AC Argon Shield Pure or Zirconium Tungsten Electrode							
3/16 (4.8)	1	1/8 (3.2)	3/8 (9.5)	1/8 (3.2)	25 (11.8)	95-115	24 (10.2)
1/4 (6.4)	2	3/16 (4.8)	1/2 (12.7)	5/32 (4.0)	25 (11.8)	110-130	20 (8.5)
3/8 (9.5)	2	3/16 (4.8)	1/2 (12.7)	3/16 (4.8)	30 (14.2)	135-165	18 (7.6)
1/2 (12.7)	2	3 1/4 (6.4)	5/8 (15.9)	3/16(4.8)	35 (16.5)	280-320	10 (4.2)
3/4 (19.1)	3	1/4 (6.4)	3/4 (19.1)	3/16 (4.8)	40 (18.9)	340-380	10 (4.2)

Stainless Steel **DC EN Argon Shield Thoriated Tungsten Electrode**							
1/4 (6.4)	2	1/8 (3.2)	3/8 (9.5)	3/16 (4.8)	18 (8.5)	175-250	10 (4.2)
3/8 (9.5)	2	3 3/16 (4.8)	1/2 (12.7)	3/16 (4.8)	25 (11.8)	250-350	10 (4.2)
1/2 (12.7)	3	3/16 (4.8)	112 (12.7)	1/4 (6.4)	25 (11.8)	250-350	10 (4.2)
Titanium **DCEN Argon Shield Thoriated Tungsten Electrode**							
1/4 (6.4)	2	1/8 (3.2)	5/8 (15.9)	1/8 (3.2)	30 (14.2)	135-200	8 (3.4)
3/8 (9.5)	2	1/8 (3.2)	3/4(19.1)	1/8 (3.2)	35 (16.5)	140-210	6 (2.5)
1/2 (12.7)	3	1/8 (3.2)	3/4(19.1)	3/32 (4.0)	40 (18.9)	160-250	6 (2.5)

Figure 9-90 — Fillet welds.

Table 9-22 — Fillet welds in various types of base metals.

Metal Thickness in (mm)	Number of Passes	Tungsten Size in (mm)	Nozzle Size in (mm)	Filler Size in (mm)	Gas Flow ft.3/hr. (l/min.)	Welding Current Amps	Travel Speed in/min(mm/s)
Aluminum and Aluminum Alloys **AC, Argon Shield, Pure or Zirconium Tungsten Electrode**							
1/16(1.6)	1	3/32 (2.4)	5/16 (7.9)	3/32 (2.4)	15 (7.1)	50-90	9 (3.8)
3/32 (2.4)	1	3/32 (2.4)	5/16 (7.9)	3/32 (2.4)	16 (7.6)	60-115	9 (3.8)
1/8 (3.2)	1	1/8 (3.2)	3/8 (9.5)	1/8 (3.2)	19 (9.0)	70-140	10 (4.2)
3/16 (4.8)	1	5/32 (4.0)	7/16 (11.1)	5/32 (4.0)	25 (11.8)	110-200	10 (4.2)
1/4 (6.4)	1	3/16 (4.8)	1/2 (12.7)	3/16 (4.8)	30 (14.2)	130-250	10 (4.2)
3/8 (9.5)	2	3/16 (4.8)	112 (12.7)	3/16 (4.8)	35 (16.5)	175-310	8 (3.4)
1/2 (12.7)	3	3/16 (4.8)	1/2 (12.7)	3/16 (4.8)	35 (16.5)	250-350	8 (3.4)

Copper and Copper Alloys (Except Silicon Bronze) **DCEN, Argon Shield for Thickness < 3/16” , All others Helium, Thoriated Tungsten Electrode**							
1/16 (1.6)	1	1/16 (1.6)	1/4 (6.4)	1/16 (1.6)	18 (8.5)	90-155	10 (4.2)
1/8 (3.2)	1	3/32 (2.4)	5/16 (7.9)	3/32 (2.4)	18 (8.5)	150-245	8 (3.4)
3/16 (4.8)	1	1/8 (3.2)	3/8 (9.5)	1/8 (3.2)	36 (17.0)	175-255	8 (3.4)
1/4 (6.4)	1	1/8 (3.2)	3/8 (9.5)	1/8 (3.2)	36 (17.0)	200-285	7 (3.0)
3/8 (9.5)	2	3/16 (4.8)	1/2 (12.7)	3/16 (4.8)	36 (17.0)	220-350	6 (2.5)
1/2 (12.7)	3	3/16 (4.8)	5/8 (15.9)	1/4 (6.4)	45 (21.2)	300-500	6 (2.5)
Silicon Bronze **DCEN, Argon Shield, Thoriated Tungsten Electrode**							
1/16 (1.6)	1	1/16(1.6)	1/4 (6.4)	1/16 (1.6)	15 (7.1)	75-120	10 (4.2)
1/8 (3.2)	1	1/16(1.6)	1/4 (6.4)	3/32 (2.4)	15 (7.1)	95-150	10 (4.2)
3/16 (4.8)	1	3/32 (2.4)	5/16 (7.9)	3/32 (2.4)	20 (9.4)	125-220	10 (4.2)
1/4 (6.4)	2	3/32 (2.4)	5/16 (7.9)	1/8 (3.2)	25 (11.8)	140-275	8 (3.4)
3/8 (9.5)	3	1/8 (3.2)	3/8 (9.5)	1/8 (3.2)	25 (11.8)	200-285	8 (3.4)
1/2 (12.7)	7	5/32 (4.0)	3/8 (9.5)	1/8 (3.2)	25 (11.8)	240-300	8 (3.4)
3/4(19.1)	14	5/32 (4.0)	3/8 (9.5)	3/16 (4.8)	25 (11.8)	275-350	8 (3.4)
1 (25.4)	20	3/16 (4.8)	7/16(11.1)	1/4 (6.4)	25 (11.8)	300-365	8 (3.4)
Magnesium Alloys **AC, Argon Shield, Pure or Zirconium Tungsten Electrode**							
20 ga (.9)	1	1/16(1.6)	3/8 (9.5)	3/32 (2.4)	15 (7.1)	25-45	20 (8.5)
16 ga (1.5)	1	1/16 (1.6)	3/8 (9.5)	3/32 (2.4)	15 (7.1)	35-60	20 (8.5)
14 ga (1.9)	1	3/32 (2.4)	3/8 (9.5)	1/8 (3.2)	15 (7.1)	50-80	17 (7.2)
12 ga (2.7)	1	3/32 (2.4)	1/2 (12.7)	1/8 (3.2)	20 (9.4)	75-100	17 (7.2)
11 ga (3.0)	1	3/32 (2.4)	1/2 (12.7)	1/8 (3.2)	20 (9.4)	95-120	17 (7.2)
Nickel and Nickel Alloys **DCEN, Argon Shield, Thoriated Tungsten Electrode**							
24 ga (.6)	1	1/16 (1.6)	3/8 (9.5)	None	15 (7.1)	8-10	8 (3.4)
16 ga (1.5)	1	3/32 (2.4)	1/2 (12.7)	1/16(1.6)	18 (8.5)	25-45	8 (3.4)
1/8 (3.2)	1	1/8 (3.2)	1/2 (12.7)	3/32 (2.4)	25 (11.8)	90-175	11 (4.7)
1/4 (6.4)	2	1/8 (3.2)	1/2 (12.7)	1/8 (3.2)	30 (14.2)	100-175	8 (3.4)
Carbon and Low Alloy Steel **DCEN, Argon Shield, Thoriated Tungsten Electrode**							
24 ga (.6)	1	1/16 (1.6)	1/4 (6.4)	1/16 (1.6)	10 (4.7)	15-20	13 (5.5)
20 ga (.9)	1	1/16 (1.6)	1/4 (6.4)	1/16 (1.6)	10 (4.7)	25-50	15 (6.3)
18 ga (1.2)	1	1/16 (1.6)	1/4 (6.4)	1/16 (1.6)	10 (4.7)	35-70	15 (6.3)
16 ga (1.5)	1	1/16 (1.6)	1/4 (6.4)	1/16 (1.6)	10 (4.7)	50-80	15 (6.3)
14 ga (1.9)	1	1/16(1.6)	1/4 (6.4)	1/16(1.6)	10(4.7)	65-90	15 (6.3)
1/8 (3.2)	1	3/32 (2.4)	5/16 (7.2)	3/32 (2.4)	12(5.7)	75-120	11 (4.7)
3/16 (4.8)	1	1/8 (3.2)	3/8 (9.5)	1/8 (3.2)	15 (7.1)	150-200	10 (4.2)
1/4 (6.4)	2	1/8 (3.2)	3/8 (9.5)	1/8 (3.2)	18 (8.5)	160-250	10 (4.2)

Stainless Steel DCEN, Argon Shield, Thoriated Tungsten Electrode							
1/16 (1.6)	1	1/16(1.6)	1/4 (6.4)	1/16 (1.6)	10 (4.7)	45-75	10 (4.2)
3/32 (2.4)	1	1/16 (1.6)	1/4 (6.4)	3/32 (2.4)	10 (4.7)	65-85	10 (4.2)
1/8 (3.2)	1	1/16 (1.6)	5/16 (7.9)	3/32 (2.4)	10 (4.7)	75-125	10 (4.2)
3/16 (4.8)	1	1/8 (3.2)	3/8 (9.5)	1/8 (3.2)	15 (7.1)	100-175	8 (3.4)
1/4 (6.4)	2	1/8 (3.2)	3/8 (9.5)	3/16 (4.8)	18(8.5)	125-225	10 (4.2)
3/8 (9.5)	2-3	3/16 (4.8)	1/2 (12.7)	3/16 (4.8)	25 (11.8)	175-300	10 (4.2)
1/2 (12.7)	3	3/16 (4.8)	1/2 (12.7)	1/4 (6.4)	25 (11.8)	200-325	10 (4.2)
Titanium DCEN, Argon Shield, Thoriated Tungsten Electrode							
24 ga (.6)	1	1/16(1.6)	3/8 (9.5)	None	18 (8.5)	20-35	6 (2.5)
16 ga (1.5)	1	1/16(1.6)	5/8 (15.9)	None	18 (8.5)	45-85	6 (2.5)
3/32 (2.4)	1	3/32 (2.4)	5/8 (15.9)	1/16 (1.6)	25 (11.8)	60-90	8 (3.4)
1/8 (3/2)	1	3/32 (2.4)	5/8 (15.9)	1/16 (1.6)	25 (11.8)	80-125	8 (3.4)
3/16 (4.8)	2	3/32 (2.4)	5/8 (15.9)	1/8 (3.2)	25 (11.8)	90-140	8 (3.4)
1/4 (6.4)	2	1/8 (3.2)	5/8 (15.9)	1/8 (3.2)	30 (14.2)	125-175	8 (3.4)
3/8 (9.5)	2	1/8 (3.2)	3/4(19.1)	1/8 (3.2)	35 (16.5)	175-225	6 (2.5)
1/2 (12.7)	3	3/32 (2.4)	3/4 (19.1)	5/32 (4.0)	40 (18.9)	225-300	6 (2.5)

Figure 9-91 — Pulsed current parameters.

Table 9-23 — Pulsed current procedures for TIG.

STAINLESS STEEL										
Metal Thickness			**Welding Current Amps**	**% Welding Current**	**High Pulse Time Seconds**	**Low Pulse Time Seconds**	**Argon Gas Flow**		**Travel Speed**	
Gage	**In**	**(mm)**					**ft3/hr**	**(l/min)**	**in/min**	**(mm/s)**
24	.025	(0.6)	35-45	20	0.05	0.3	12	(5.7)	4	(1.69)
18	.050	(1.2)	45-55	20	0.1	0.3	12	(5.7)	4	(1.69)
16	.062	(1.5)	55-70	20	0.2	0.4	12	(5.7)	4	(1.69)
	3/32	(2.4)	65-85	20	0.3	0.6	12	(5.7)	3	(1.27)
	1/8	(3.2)	75-95	20	0.4	0.8	12	(5.7)	3	(1.27)

Figure 9-92 — Pulsed current parameters (cont.).

Table 9-24 — Pulsed current for stainless steel.

STAINLESS STEEL-Unlimited Thickness								
Joint Type	Welding Current Amps	% Welding Current	High Pulse Time Seconds	Low Pulse Time Seconds	Argon Gas Flow		Travel Speed	
					ft^3/hr	(l/min)	in/min	(mm/s)
V/Butt Joint	170-190	20	0.06	0.06	18	(8.5)	3	(1.27)
Consumable Insert	170-190	20	0.06	0.06	18	(8.5)	3	(1.27)
Open Root	170-190	40	0.06	0.06	18	(8.5)	4	(1.27)
Fill Pass	170-190	40	0.06	0.06	25	(11.8)	4	(1.27)

Figure 9-93 — Gas tungsten arc spot welding - Flat and vertical position.

Table 9-25 — Gas Tungsten Arc Spot Welding.

Metal Thickness Top Piece			Welding Condition Amperes		Arc Time Second Note #2	Shielding Gas Argon	
Gage	Inch	(mm)	DCEN	AC		ft^3/hr	(l/min)
Stainless Steel							
24	.025	(0.64)	125	175	1	10	(4.7)
24	.025	(0.64)	110	175	1.25	10	(4.7)
24	.025	(0.64)	100	150	1.5	10	(4.7)
22	.0312	(0.79)	125	175	1.5	10	(4.7)
22	.0312	(0.79)	100	175	1.75	10	(4.7)
18	.05	(1.27)	140	200	1.5	12	(5.7)
16	.05	(1.27)	110	150	2.5	12	(5.7)
16	.062	(1.57)	170	250	3	12	(5.7)
16	.062	(1.57)	140		3.25	12	(5.7)
	.062	(1.57)	115		5.25	12	(5.7)
	.064	(1.62)	160	250	2.25	12	(5.7)
Low Alloy and Mild Steel							
22	.0312	(0.79)	170	250	1.5	8	(3.8)
22	.0312	(0.79)	140	200	2	8	(3.8)
22	.0312	(0.79)	120	175	2.25	8	(3.8)
18	.05	(1.27)	170	250	1.75	10	(4.7)
18	.05	(1.27)	140	200	2	10	(4.7)
18	.05	(1.27)	135	200	2.5	10	(4.7)
16	.062	(1.57)	170	250	3	12	(5.7)
16	.062	(1.57)	155	225	3.5	12	(5.7)
Aluminum							
	.022	(.56)		170	1.1	8	(3.8)
	.32	(.81)		200	1.5	8	(3.8)
	.48	(1.22)		220	1.7	8	(3.8)
	.064	(1.62)		250	2.2	8	(3.8)

11.0.0 PREWELD PREPARATIONS

Several steps must be taken before making a weld with the gas tungsten arc welding process. These include preparing the weld joint, preparing the electrode tip, fixturing the weldment, setting the variables, and in some cases, preheating. The amount of preweld preparation depends upon the size of the weld and weldment, the type of base metal, the ease of fitup, the quality requirements, the governing code or specification, and the welder.

11.1.0 Preparing the Weld Joint

There are different ways of preparing the edge of the joint for welding. For fillet or square-groove welds, the joints are prepared simply by squaring the edges of the members if the as-received edge is not suitable. In TIG welding, a large percentage of the joints are prepared this way because this process is widely used for welding thin materials.

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 are available, with the exception of shearing, the thermal cutting methods such as oxy-fuel cutting, plasma arc cutting, or air carbon arc cutting are faster than the mechanical cutting methods.

Oxy-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, and air carbon arc cutting is used for most steels, including stainless steels. However, do not use air carbon arc on stainless steels involving critical corrosion applications because of the high carbon deposition. The surfaces cut by these thermal methods often have to be ground lightly to remove the 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.

Next to the square edge preparation, the V-groove and single-bevel grooves are used most often, and can be prepared easily by oxy-fuel cutting or plasma arc cutting. These two methods leave a smooth surface if properly done. The edges of U- and J-grooves can be prepared by using special oxy-fuel tips and techniques, air carbon arc cutting, or by machining, which will produce a more uniform groove. These joint preparations are not as common in TIG welding because they are joint preparations for thicker materials.

11.2.0 Cleaning the Work Metal

The welds made by TIG 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 non-ferrous metals. Usually, extremely dirty workpieces, except titanium, are cleaned by using solvent cleaners followed by vapor degreasing, and simple degreasing is used for cleaning metals that have oxide-free surfaces. Generally, acid pickling is used for cleaning metals that have a light oxide coating, while heavier oxide coatings are removed mechanically by grinding and abrasive blasting.

The type of required cleaning operation will vary depending on the metal. Aluminum has a thick, refractory oxide coating which has a high electrical resistance. This coating is removed by deoxidation 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 used for degreasing operations should not be used on titanium because they will cause corrosion cracking. Chemical cleaning can be done by pickling with hydrofluoric acid.

You need to perform several tasks just before welding. One is to file the edges of the joint smooth so no burrs are present; burrs can cause physical pain and be a place to trap contaminants in a weld joint. Another is to wire brush the surfaces of the joint and surrounding area. Use mild steel brushes for cleaning mild and low alloy steel, and use stainless steel wire brushes for stainless steel, aluminum, and other non-ferrous metals. Following this procedure will help you avoid contaminating the stainless steel and non-carbon metals with a mild steel brush. You should do the welding as soon as possible 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 its thickness and makes the metals easier to weld. Wear gloves while cleaning to prevent oil or dirt from your fingers from getting on the joint surfaces, which can also cause contamination.

Contaminates on the workpiece can lead to arc instability and result in welds that contain pores, cracks, or inclusions.

11.3.0 Electrode Tip Preparation

The shape of the tungsten electrode tip is an important process variable in gas tungsten arc welding. The type of electrode tip preparation depends on the type of tungsten electrode; it may have a pointed, hemispherical, or balled profile. A pointed electrode tip is best for welding in restricted areas such as narrow joints, and it permits a high current density to be maintained. Pointed electrode tips are used on thoriated electrodes, while the hemispherical and balled tips are used for zirconium and pure tungsten electrodes.

The pure and zirconium types of electrodes form a hemispherical or balled tip and are used mainly for welding with alternating current. These two types of electrode tip preparations are shown in *Figure 9-94*. You produce a hemispherical electrode tip by starting an arc between the electrode and a piece of scrap metal or copper and maintaining it at a moderate current level until a hemispherical ball is formed on the end of the electrode.

Figure 9-94 — Hemispherical and balled tip.

You produce a balled tip the same way, except you use higher current levels. As you increase the current beyond the point where a hemispherical tip exists, the ball will increase in size proportionately. The diameter of the balled end should not exceed one and one-half times the electrode diameter because the excessive current will consume the electrode too quickly. The surface of the hemispherical and balled tips should always be perfectly clean, shiny, and highly reflective.

The pointed type of tip preparation is used on 1% and 2% thoriated tungsten electrodes, which are generally used for DCEN welding. Unless the thoriated electrodes are used for welding with AC, they are normally ground to a sharp point (*Figure 9-95*). The length of the ground surface of the electrode should be about two or three times the size of the electrode diameter.

To produce optimum arc stability, grind the tungsten electrodes with the axis of the electrode perpendicular to the axis of the grinding wheel or along the length of the electrode and not across the diameter. This will produce a more stable arc. Slightly blunt the tip of the electrode before welding; when higher current levels are used, the tip of the electrode will melt back a bit and give a slightly wider tip. Reserve a grinding wheel for grinding tungsten only to eliminate possible contamination of the tungsten tip, and use exhaust hoods when grinding thoriated electrodes to remove the grinding dust from the work area.

Figure 9-95 — Point tip preparation.

Thoriated and zirconium electrodes will maintain a pointed edge preparation over a wide current range, but pure tungsten electrodes will change their tip profile according to the amount of current they are carrying. The surface of a pointed electrode should be kept clean at all times, but it will not be shiny.

11.4.1 Fixturing, Positioning, and Weld Backing

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

1. Locate parts precisely within the assembly.
2. Maintain alignment during welding.
3. Minimize distortion in the weldment.
4. Control heat buildup.
5. Increase welding efficiency.

When you use a welding fixture, you can assemble and hold the components securely in place while you position the weldment and perform the weld. The need to use these devices depends on the specific application; they are used more often when large numbers of the same parts are produced. When you can use fixtures, your production time for the weldments can be reduced significantly. They are also good for applications where you must hold close tolerances.

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. Sometimes you need a positioner 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 your efficiency because you can use higher welding speeds. This also allows you to use larger diameter wires with globular and high current spray transfer. These modes of metal transfer will produce the highest deposition rates. Flat position welding usually increases the quality of the weld because it makes the welding easier.

Weld backings are commonly used in TIG to provide support for the weld metal and to control the heat input. Copper, stainless steel, and consumable insert rings are the three most common methods. Copper is the most popular method of weld backing because it does not fuse to thin metals. It also provides a fast cooling rate; the high heat conductivity of copper makes this a good method of controlling the heat input. Stainless steel is good backing material for argon shielded TIG welding. Often, consumable inserts are used as weld backing for welding the root pass in pipe welding. They fit into place and are available in plain carbon steel, alloy steel, and stainless steel, as well as in copper and nickel alloys.

11.5.0 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. These factors were discussed in the section on Welding Metallurgy. The specific amount of preheat needed for a given application is often obtained from the welding procedure.

The preheat temperature of the metal should be carefully controlled. There are several good methods of performing this: 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 you use oxy-fuel torches, you need to avoid localized overheating and keep 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 colored crayons, pellets, and hand-held temperature indicators. The crayons and pellets melt at a specific predetermined temperature; the handheld temperature indicators give meter readings, digital readings, or recorder readings, depending on the type of temperature indicator.

Test your Knowledge (Select the Correct Response)

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

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

15. On a pointed tip electrode, what should the length of the ground surface be?

    A. Half the diameter of the electrode
    B. Two to three times the diameter of the electrode
    C. Four to five times the diameter of the electrode
    D. Half the length of the electrode

12.0.0 WELDING DISCONTINUITIES and PROBLEMS

TIG, like the other processes, can have welding procedure problems resulting in weld defects. Some defects are caused by problems with the materials, including the use of improper base metal, filler metal, or shielding gas. Other welding problems may not be foreseeable, such as arc blow and electrode contamination, and may require immediate corrective action. A poor welding technique and an improper choice of welding parameters are other causes of welding defects.

Discontinuities that can occur when using TIG welding are tungsten inclusions, porosity, wormhole porosity, undercutting, incomplete fusion, melt-through, arc strikes, and craters. Problems with the welding technique or procedure weaken the weld and can cause cracking. The base metal and filler metal must be clean to avoid many of these problems. Other problems that can occur and reduce the quality of the weld are arc blow, lack of shielding gas, and drafts or air currents.

TIG welding does not have many problems with slag inclusions because a shielding gas, instead of a slag layer, protects the weld puddle. However, some filler metals, particularly those used for mild steel, will sometimes leave a small amount of slag, which may cause slag inclusions if it is not cleaned properly. However, this is rarely a problem. Welding spatter rarely occurs because the tungsten is a non-consumable electrode and the filler metal is added directly to the weld puddle, not transferred across the arc.

12.1.0 Discontinuities Caused by Welding Technique

12.1.1 Tungsten Inclusions

Tungsten inclusions are chunks or particles from the elctrode which are found in the weld metal (*Figure 9-96*).

These inclusions are the result of problems in the welding procedure such as the following:

1. Exceeding the maximum current for a given electrode size or type.
2. Letting the tip of the electrode make contact with the molten weld puddle.
3. Letting the filler metal come in contact with the hot tip of the electrode.
4. Using an excessive electrode extension.
5. Inadequate gas shielding or excessive wind drafts which result in oxidation.
6. Using improper shielding gases such as argonoxygen or argon-CO_2 mixtures, which are used for gas metal arc welding.

Figure 9-96 — Inclusions.

This problem can be corrected by the following:

1. Reducing the current.
2. Maintaining a distance between the tungsten electrode and weld puddle and the tungsten electrode and filler metal.
3. Reducing the electrode extension.
4. Increasing gas flow or shielding arc from wind drafts.
5. Using inert gas only.

12.1.2 Oxide Inclusions

Oxide inclusions are particles of surface oxides which have not melted and mixed into the weld metal (*Figure 9-97*). These inclusions occur when welding those metals that have surface oxides with very high melting points. This problem is mainly associated with welding aluminum and magnesium, but some problems will also occur when welding stainless steel. Oxide inclusions weaken the weld and can serve as initiation points for cracking. The best method of preventing this problem is to wire brush the joint and weld area and clean the area thoroughly before welding.

Figure 9-97 — Oxide inclusion.

12.1.3 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 9-98*). The voids left in the weld cause it to be weakened. One or more of the following cause porosity:

1. Inadequate shielding gas flow.
2. Excessive welding current.
3. Rust, grease, oil, moisture, or dirt on the surface of the base metal or filler metal, including moisture trapped in aluminum oxide.
4. Impurities in the base metal, such as sulfur and phosphorus.
5. An excessive travel speed, which causes freezing of the weld puddle before gases can escape.
6. Contaminated or wet shielding gas.

Figure 9-98 — Porosity.

Porosity can be prevented or corrected by the following:

1. Increasing the shielding gas flow.
2. Lowering the welding current.
3. Cleaning the surface of the base metal.
4. Changing to a different base metal with a different composition.
5. Lowering the travel speed.
6. Replacing the shielding gas.

12.1.4 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 that becomes trapped in the weld joint (*Figure 9-99*). Wormhole porosity can seriously reduce the strength of the weld. The best methods of preventing this are to clean the surfaces of

Figure **9-99 — Wormhole porosity.**

the joint and preheat to remove moisture. If sulfur in the steel is the problem, a more weldable grade of steel should be selected.

12.1.5 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 9-100*). This is particularly a problem with fillet welds. Undercutting causes a weaker joint at the toe of the weld, which may result in cracking.

It is caused by one or more of the following:

1. Excessive welding current.
2. Arc voltage too high.
3. Excessive travel speed
4. Not enough filler metal added.
5. Excessive weaving speed.

On vertical and horizontal welds, undercutting may also be caused by incorrect electrode angles. This discontinuity can be prevented by the following:

Figure 9-100 — Undercutting.

1. Reducing the welding current.
2. Holding a short arc length.
3. Using a travel speed slow enough so the weld metal can completely fill all of the melted out areas of the base metal.
4. Using more filler metal.
5. Pausing at each side of the weld bead when a weaving technique is used.

12.1.6 Incomplete Fusion

Incomplete fusion occurs when the weld metal is not completely fused to the base metal (*Figure 9-101*). This can occur between the weld metal and the base metal or between passes in a multi-pass weld. Incomplete fusion between the weld metal and the base metal is usually due to inadequate penetration. Causes of this include the following:

Figure 9-101 — Incomplete fusion.

1. Excessive travel speed.
2. Welding current too low.
3. Poor joint preparation.
4. Letting the weld metal get ahead of the arc.

Incomplete fusion can be prevented by the following:

1. Reducing the travel speed.
2. Increasing the welding current.
3. Preparing the joint better.
4. Using proper electrode angles.

12.1.7 Overlapping

Overlapping is the protrusion of the weld metal over the edge or toe of the weld bead (*Figure 9-102*). This defect can cause an area of incomplete fusion, which creates a notch and can lead to crack initiation. Although TIG is primarily for welding thin metals, if this occurs, you can grind off the excess weld metal after welding. Overlapping is produced by one or more of the following:

1. Too slow a travel speed which permits the weld puddle to get ahead of the electrode.
2. Arc welding current that is too low.
3. Addition of too much filler metal.
4. Incorrect electrode angle that allows the force of the arc to push the molten weld metal over unfused sections of the base metal.

Figure 9-102 — Overlapping.

Overlapping can be prevented or corrected by the following:

1. Using a higher travel speed.
2. Using a higher welding current.
3. Reducing the amount of filler metal added
4. Using the correct electrode angles.
5. Grinding off the excess weld metal

12.1.8 Melt-through

Melt-through occurs when the arc melts through the bottom of the weld and creates holes (*Figure 9-103)*. This can be caused by one or more of the following:

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

This can be prevented by:

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

Figure 9-103 — Melt-through.

12.1.9 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.

12.1.10 Craters

Weld craters are depressions on the weld surface at the point where the arc was broken (*Figure 9-104*). 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 can be filled in with a small deposit of filler metal.

For TIG welding, there are two 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 of the weld bead, before breaking the arc. A second method is to use a foot rheostat to control the welding current. 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. For machine and automatic applications, a slope control on the machine will automatically reduce the welding current at the end of the weld, which will also gradually reduce the size of the molten weld puddle.

Figure 9-104 — Weld crater.

12.2.1 Cracking

An improper welding procedure, welder technique, or materials can cause weldment cracking. 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 acting on excessively hard and brittle weld metal. Longitudinal cracks are often caused by high joint restraint and high cooling rates. Although TIG is primarily for thin metals, preheating may be necessary to help 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 it is not repaired. Hot cracking may be prevented or minimized by the following:

1. Preheating to reduce shrinkage stresses in the weld.
2. Using clean or uncontaminated shielding gas.
3. Increasing the cross-sectional area of the weld bead.
4. Changing the contour of the weld bead.
5. Using base metal with very low contents of those elements that tend to cause hot cracking.

Crater cracks are shallow hot cracks that are caused by improperly breaking the arc. Crater cracks may be prevented the same way that 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 9-105*).

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

1. Weld bead that is too small for the thickness of the base metal.
2. Poor fitup.
3. High joint restraint.
4. Extension of a crater crack.

Figure 9-105 — Centerline crack.

The best methods of preventing centerline cracks are the following:

1. Increasing the bead size.
2. Decreasing the width of the root opening.
3. Preheating.
4. 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 (*Figure 9-106*).

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 9-106 — Underbead cracks.

12.3.0 Other Problems

Other problems that can occur with TIG and reduce the quality of the weld are arc blow, loss of shielding gas coverage, and electrode contamination.

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 ends of joints. Arc blow occurs with direct current because the induced magnetic field is in one direction.

Alternating current is rarely subject to arc blow because the magnetic field is building and collapsing continuously due to the reversing current. The problem also occurs when welding complex structures and 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 the weld joint. Backward arc blow occurs toward the grounding connection, into a corner, or toward the end of a welding joint. Several corrective methods that can be used to correct the arc blow problem are the following:

1. Changing to alternating current.
2. Welding toward an existing weld or tack weld.
3. Reducing the welding current and making the arc length as short as possible.
4. Placing the work connection as far as possible from the weld, at the end of the weld, or at the start of the weld, and welding toward the heavy tack weld.
5. Wrapping the work lead cable around the workpiece so that the magnetic field caused by the current in the work cable will neutralize the magnetic field causing the arc blow.

12.3.2 Inadequate Shielding

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

An inadequate gas supply can cause oxidation of both the tungsten electrode and the weld puddle, as well as porosity in the weld bead. This can be detected easily 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:

1. Blockage of gas flow in the torch or hoses.
2. Leak in the gas system.
3. Very high travel speed.
4. Improper flow rate.
5. Wind or drafts.
6. Arc length or stickout too long.

There are several ways this problem can be corrected or prevented. Check the torch and hoses before welding to make sure the shielding gas can flow freely and is not leaking. A very high travel speed may leave the weld puddle, or a portion of it, exposed to the atmosphere. This may be corrected, in some cases, by inclining the torch in the direction of travel, using a nozzle that directs shielding gas back over the heated area, or by increasing the gas flow rate. Increasing the gas flow rate will increase the expense of the welding.

When welding some of the reactive metals, you may have to use an inert atmosphere chamber or trailing nozzles. 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.

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 arc length or stickout will also create a problem in providing adequate shielding because the distance between the end of the nozzle and the molten weld puddle is very long. This can be corrected by shortening the arc length or stickout.

12.3.3 Electrode Contamination

Contamination of the tungsten electrode can cause discontinuities in the weld as well as a hard to control arc and loss of several minutes of welding time to clean the electrode. The electrode can become contaminated by several means, such as contact of the weld puddle with the electrode, contact of the electrode with the filler metal, inadequate shielding gas flow, or post welding gas flow time that is too short. *Figure 9-107* shows the effects of different causes of electrode contamination.

When the electrode becomes contaminated by contact with the filler or weld metal, it produces a wild and unstable arc. When a lack of shielding gas is the cause of the contamination, it greatly reduces the life of the electrode.

Figure 9-107 — Electrode contamination.

There are two major methods of correcting this problem. The first is to break off the contaminated section and then prepare the clean section for welding. This is usually done by using a pair of pliers or by putting the contaminated section over the end of a workbench and breaking it off by striking it with a hammer. The second method is to hold the arc on a section of copper or other metal until the electrode has been cleared of contaminating metal through its vaporization. The first method is more commonly used when the electrode is very contaminated.

13.0.0 POSTWELD PROCEDURE

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

13.1.0 Cleaning

One of the major advantages of gas tungsten arc welding is that it produces a very smooth, clean weld bead with very little or no spatter, so there is no slag to be chipped off the weld bead. Because of this, postweld cleaning may be omitted and only wire brushing or buffing may be required to remove the discoloration around the weld bead.

13.2.0 Inspection and Testing

Inspection and testing the weld to determine the quality of the weld joint is done after cleaning. There are many different methods of inspection and testing which were covered in previous chapters. 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, whereas 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. 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 for 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 you have removed the defects, you can reweld the low areas created by the grinding and gouging using gas metal arc welding or some other welding process. You should then reinspect the welds 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 recrystallization 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, whereas 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 non-ferrous metal when stress buildup is a problem; however, in the case of aluminum alloys, for example, 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 where 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 (Select the Correct Response)

15. Why is spatter rarely a problem when using the TIG process?

    A. Low current is used.
    B. Shielding gases are used.
    C. A non-consumable electrode is used.
    D. The speed of travel is too fast.

16. What is the annealing process used for?

    A. To harden the weldment
    B. To stop discoloration
    C. To dissipates weld heat
    D. To induce softening of the base metal

14.0.0 WELDER TRAINING and QUALIFICATION

Gas tungsten arc welding requires a high degree of welder skill to produce good quality welds. This process requires the use of two hands when filler metal is added. A welder that is skilled in this process will generally have less trouble learning to weld with the other arc welding processes.

The exact content of a training program will vary depending on the specific application of the process. The program should be flexible enough so that it can be adapted to changing needs and applications. The complexity of the parts to be welded, the governing codes and specifications, and the type of metal to be welded all need to be taken into consideration.

A pipe welding course would take more training than a course on welding of plate. A course concerning the welding of stainless steel might cover the use of pulsed current and a different type of tungsten electrode preparation than a course covering the welding of aluminum. The welding characteristics of the metals would also be different.

14.1.1 Basic Gas Tungsten Arc Welding

The basic gas tungsten arc welding training program is used to teach the students the basic skills necessary for using the process to weld plate. Such a course would provide training on how to strike the arc, run weld beads, and make good quality fillet and groove welds. It would also include the welding of mild steel, stainless steel, and aluminum. Because of this, the course shown in the sample outline below has been split into three sections covering each of the three metals. The proper cleaning techniques are also covered for the three metals.

The training obtained by the student should give him or her enough skill to perform a job welding plate material. This course should also provide the background skill and knowledge required to take a course on gas tungsten arc welding of pipe and tubing. The following outline is for a course approximately seventy hours long.

COURSE INTRODUCTION

1. Lecture/Discussion -"Introduction to Gas Tungsten Arc Welding"
2. Lecture/Discussion -"The Safety and Health of Welders"
3. Lecture/Discussion -"Preparation for Welding Starting, Equipment Adjustment, and Shutdown"

14.1.1 Mild Steel

This part of the course covers welding fillet and square groove welds in the flat, horizontal, and vertical positions on mild steel using direct current. This includes techniques used with and without filler metal.

1. Stringer Bead, Flat Position, without and with Filler Metal
2. Fillet Weld, Lap Joint, Horizontal Position, without and with Filler Metal
3. Lecture/Discussion -"Weld Properties and Weld Quality, Mild Steel"
4. Fillet Weld, Outside Corner Joint, Flat Position, without and with Filler Metal
5. Fillet Weld, T-Joint, Horizontal and Vertical Position, with Filler Metal
6. Square-Groove Weld, Butt Joint, Flat Position with Filler Metal
7. Single-V-Groove Weld, Butt Joint, Guided Bend Test
8. Square-Groove Weld, Butt Joint, Overhead Position, with Filler Metal

14.1.2 Stainless Steel

This part of the course covers the welding of stainless steel and the use of pulsed direct current. Groove and fillet welds are made in the flat, horizontal, and vertical positions with and without the use of pulsed current and filler metal.

1. Lecture/Discussion -"Introduction to Gas Tungsten Arc Welding Using Pulsed Current"
2. Square-Groove Weld, Butt Joint, Flat Position, with Filler Metal, without and with Pulsation
3. Fillet Weld, Lap Joint, Horizontal Position, without and with Filler Metal
4. Lecture/Discussion -"Weld Properties and Qualities, Stainless Steel"

5. Filler Weld, Outside Corner Joint, Flat Position, without and with Filler Metal
6. Visual Inspection Test, Stainless Steel
7. Fillet Weld, T-Joint, Horizontal and Vertical Position Up, with Filler Metal
8. Stringer Bead, Flat Position, with Filler Metal

14.1.3 Aluminum

The last part of the course covers welding of fillet and square-groove welds in the flat, horizontal, and vertical positions on aluminum using alternating current.

1. Lecture/Discussion -"Equipment Adjustments and Their Effects on the Welding Arc Electrode, Current Amperage Chart"
2. Square-Groove Weld, Butt Joint, Flat Position, with Filler Metal
3. Lecture/Discussion. "Weld Properties and Qualities, Aluminum"
4. Fillet Weld, Lap Joint, Horizontal Position, with Filler Metal
5. Fillet Weld, Outside Corner Joint, Flat Position, with Filler Metal
6. Fillet Weld, T-Joint, Horizontal and Vertical Position Up, with Filler Metal
7. Visual Inspection Test, Aluminum
8. Square-Groove Weld, Butt Joint, Vertical Position Up, with Filler Metal
9. Square-Groove Weld, Butt Joint, Overhead Position. with Filler Metal

14.2.0 Gas Tungsten Arc Pipe Welding

The training program for gas tungsten arc welding of tubing and pipe is used to teach students basic skills and provides additional training to students who previously learned to weld plate material. This course covers the welding of mild steel, small diameter pipe, tube, and larger diameter pipe. It is divided into two sections.

The first part of the course includes the welding of 3-inch mild steel pipe. All passes are welded using gas tungsten arc welding. Also included in this section of the course is the welding of 4-inch diameter, Schedule 10 tubing, which is welded in one pass.

The second part of the course covers the welding of 8-inch diameter, mild steel pipe. Since gas tungsten arc welding is only used for welding the root and hot passes on the large diameter pipe, the course includes filling out the remainder of the joint with shielded metal arc welding. The student should be skilled in shielded metal arc pipe welding before taking this portion of the training program. The following outline is for a course that is approximately 210 hours in length.

14.2.1 Course Introduction

1. Lecture/Discussion -"Introduction to Gas Tungsten Arc Welding of Pipe"
2. Lecture/Discussion -"Safety and Health of Welders"
3. Lecture/Discussion -"Preparation for Welding"

14.2.2 Small Diameter Piping and Tubing

This part of the course covers the welding of 3-inch diameter, Schedule 40 piping in the 2G and 5G positions, and 4-inch diameter tubing in the 2G, 5G, and 6G positions. This portion of the course is approximately 70 hours in length.

1. Set-up, Tack Welding of Pipe
2. Single-V-Groove Weld, Butt Joint, Vertical Fixed Position (2G), with Filler Metal, 3-inch Pipe
3. Single-V-Groove Weld, Butt Joint, Horizontal Fixed Position (5G) with Filler Metal, 3-inch Pipe

4. Single-V-Groove Weld, Butt Joint, Vertical Fixed Position (2G) and Horizontal Fixed Position (2G) and Horizontal Fixed Position (5 G). Visual and Guided Bend Tests, 3-inch Pipe
5. Single-V-Groove Weld, 45 Degrees Inclined Position (6G)
6. Lecture/Discussion -"Pipe Weld Quality"
7. Square-Groove Weld, Butt Joint, 45 Degrees Inclined Position (6G), 4-inch Tubing

14.2.3 8-Inch Diameter Pipe

This part of the course covers the welding of 8-inch diameter, Schedule 40, mild steel piping in the 2G, 5G, and 6G positions. The root and hot passes are welded using gas tungsten arc welding. A section on the use of pulsed current is also included.

The fill and cover passes are welded using shielded metal arc welding and E7018 electrodes. This part of the course also includes the use of consumable inserts put in the root of the joint, and the welding of stainless steel pipe. This portion of the course is approximately 140 hours in length.

1. Single-V-Groove, Butt Joint, Rolled Flat Position (1G)
2. Single-V-Groove, Butt Joint, Horizontal Fixed Position (5G)
3. Single-V-Groove, Butt Joint, Vertical Fixed Position (2G)
4. Single-V-Groove, Butt Joint, Horizontal Fixed Position (5G) and Vertical Fixed Position (2G) Visual and Guided Bend Tests
5. Single-V-Groove, Butt Joint, 45 Degrees Inclined Position (6G) Visual Test
6. Lecture/Discussion -"Variations of the GTAW Process for Pipe"
7. Single-V-Groove, Butt Weld, 45 Degrees Inclined Position, Using Pulsed Current
8. Lecture/Discussion -"Stainless Steel Pipe Welding"
9. Single-V-Groove Weld, Butt Joint, 45 Degrees Inclined Position (6G) Stainless Steel Pipe
10. Lecture/Discussion -"Joint Designs for Gas Tungsten Arc Welding"
11. Tack Weld, Butt Joint (with consumable insert) Vertical Fixed Position (2G)
12. Single-V-Groove, Butt Joint (with consumable insert) 45 Degrees Inclined Position

14.3.0 Welder Qualification

Before a 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 extremely 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, bridges, public buildings, storage tanks and containers that will hold flammable or explosive materials, cross-country pipelines, aircraft, ordnance material, ships and boats, and nuclear power facilities.

Certification is obtained differently under the various codes. Certification under one code will not necessarily qualify a welder to work under a different code. In most cases, certification for one employer will not allow the welder to work for another employer.

Also, if the welder uses a different process or if 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. An exception is the military aircraft code, which requires requalification every six months.

Responsible manufacturers or contractors may give qualification tests. On pressure vessel work, the welding procedure must also be qualified, and this must be done before the welders can be 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. Test specimens must be made according to standardized sizes and under the observation of a qualified person. In most government specifications, a government inspector must witness the making of weld specimens. Specimens must be properly identified and prepared for testing.

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

Welder qualification is a highly technical subject and cannot be fully covered here. You should obtain and study the actual code prior to taking any tests. Some frequently used codes for welder qualification are the following:

ASME Boiler and Pressure Vessel Code, Section IX

AWS Structural Welding Code D1

Military Specifications and Standards

15.1.1 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 that 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 the following:

1. Electrical shock
2. Arc radiation
3. Air contamination
4. Compressed gases
5. Fire and explosion
6. Weld cleaning and other hazards
7. Other hazards related to other projects

15.1.0 Electrical Shock

Several precautions should be taken to prevent an electrical shock hazard. First, make sure that the arc welding equipment is properly installed, grounded, and in good working condition. Maintain and install the electrical equipment in accordance with the National Electrical Code and any state and local codes that apply. Operate equipment within NEMA Standards' usual operating conditions for proper safety and equipment life. Connect the case or frame of the power supply 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.

Keep the welding area 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

The gas tungsten arc emits invisible ultraviolet and infrared rays. Skin exposed to the arc for a short time can suffer serious ultraviolet and infrared burns that 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. Prolonged and repeated exposure to ultraviolet rays may cause skin cancer in some skin types. You should always wear protective clothing suitable for the welding to be done.

Since there is no spatter in this process, general precautions include wearing long sleeve shirts or cloth lab coats to protect your arms, shoulders, chest, and stomach from the arc radiation. Wear leather gloves, but wear lighter ones than those worn for shielded metal arc welding. Wear cloth gloves for light duty work.

Your eyes must be protected from the radiation emitted by the welding arc. Arc burn can result if your eyes are not protected. Arc burn to the eye is similar to sunburn to 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. Ultraviolet radiation is the only known cause of cataracts at this time. Impaired vision can be the result.

Gas tungsten arc welding produces a brighter arc than shielded metal arc welding because there is no smoke and it is often used on bright and shiny metals such as aluminum and stainless steel. Protect your eyes and face with a head shield that has a window with a filter lens set in it. Helmets with large windows are popular for welding with this process. Head shields are generally made of fiberglass or pressed fiber material and are 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 lens shade used varies for different welders, different metals, and different current levels, but it should be dark enough so that you can view the arc without discomfort but not so dark that you cannot see the arc and puddle clearly. A number 12 filter lens is recommended for use in gas tungsten arc welding because of its brighter arc, but the project's variables may dictate a darker lens. *Table 9-26* shows the different lenses commonly recommended for use in GTAW. 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. Welding should never be done with a broken filter lens or with cracks in the head shield.

Table 9-26 — Recommended filter lens shades used in gas tungsten 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

Welding fumes are generated by the arc. The welding area should be adequately ventilated because the vaporized metals are potentially hazardous for the welder. When welding is done in confined areas, adequate mechanical ventilation or protection for the welder is required. This may be furnished by the use of a gas mask or on a special helmet. A second person should stand just outside the confined area to lend assistance to the welder if necessary.

Another method to use is a mechanical exhaust system to remove the welding fumes. The argon or helium shielding gas may displace the air that the welder needs for breathing. Welding should never be done near degreasing and other similar operations. When they are exposed to an arc, the fumes from chlorinated cleaning solvents form a very toxic gas, called phosgene, so welding should never be done near cleaning chemicals. In addition, a mechanical exhaust should be used when welding metals such as lead, copper, beryllium, cadmium, zinc, brass, bronze, chromium, cobalt, manganese, nickel, and vanadium.

When grinding tungsten electrodes, which are mildly radioactive, it is advisable to use a dust collector on the grinder to prevent inhalation of the dust.

15.4.0 Compressed Gasses

The shielding gases used for TIG, typically argon and helium, are compressed and stored in cylinders. Only use compressed gases for their intended purpose. Cylinders containing oxygen should be stored separately from cylinders containing fuel gases. Cylinders in use or in stores or cargo should be securely fastened to prevent their shifting or falling under any weather conditions. The welder should open the valve of the cylinder slowly and stand away from the face of the regulator when doing this. The welding arc should never be struck on a compressed gas cylinder. When not in use, gas cylinders should be stored with their caps on; caps should also be on when the cylinders 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, do not use oxygen cylinders in welding or cutting operations after the pressure falls below approximately 25 psi.

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 TIG process may produce sparks 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.

Although TIG welding does not produce spatter and long sleeve shirts or cloth lab coats are used sometimes for skin protection, welders should wear leather clothing to protect from burns; 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, use a CO_2 or dry chemical type of fire extinguisher. 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. Do not weld on containers that have held combustibles unless it is absolutely certain that there are no fumes or residue left. Do not welding on sealed containers without providing vents and taking special precautions. Never strike the welding arc on a compressed gas cylinder. When the welding torch 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

Hazards can also be encountered during the weld cleaning process. Precautions must be taken to protect your skin and eyes from hot slag particles. Wear safety glasses, gloves, and heavy clothing during chipping and grinding operations. Set screens up if there are other people in the area to protect them from arc burn.

15.7.1 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 when 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.
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.
16. Follow guidelines and standards set forth by the American Welding Society, the Occupational Safety and Health Administration, the American National Standards Institute, the National Electrical Manufacturers Association, the Compressed Gas Association, and the Material Safety Data Sheets provided by U.S. manufacturers.

Summary

This chapter introduced you to the gas tungsten arc welding (GTAW or TIG) process, from the types of power sources, controls, and welding torches to the types of training and qualifications needed. It described the industries that use the TIG process and its applications. Welding metallurgy, weld and joint design, and welding procedure variables were also discussed. The chapter concluded with a description of possible weld defects and how to identify them, and safety precautions used for the TIG 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.

Review Questions (Select the Correct Response)

1. A tungsten electrode has what type of characteristic?

   A. Non-consumable
   B. Consumable
   C. Self shielding
   D. Flux cored

2. What does Wolfgram mean?

   A. It's the last name of TIG inventor
   B. Tungsten
   C. Inert gas
   D. Electrode

3. The TIG process uses a ______.

   A. constant current power source
   B. constant voltage power source
   C. variable current power source
   D. solar powered

4. In the AWS classification for tungsten electrodes, what is the letter designation for tungsten?

   A. T
   B. Tu
   C. W
   D. La

5. Which is NOT an advantage of TIG?

   A. Ability to weld a variety of different metals
   B. High deposition rates
   C. Pinpoint precision
   D. Very little post-weld cleaning

6. For AC welding with a conventional square wave power source, the High Frequency should be set to what position?

   A. Continuous
   B. Start (Automatic)
   C. Off
   D. Scan

7. Gas tungsten arc welding uses all of these items except which item?

   A. Shielding gas to protect the weld from oxidation
   B. A constant current welding machine
   C. Non-consumable tungsten electrode
   D. A constant voltage welding machine

8. As a general rule, what should the inside diameter of the gas nozzle be?

   A. Three times the electrode diameter.
   B. Five times the electrode diameter.
   C. 3/8 inch.
   D. Two times the electrode diameter.

9. For AC welding with a conventional square wave power source, how should the electrode tip be shaped?

   A. Ground to a point with the sharp tip slightly blunted
   B. Rounded
   C. Similar to a match head
   D. Ground to a point

10. For DCEN welding, how should the electrode tip be shaped?

   A. Ground to a point with the tip slightly blunted
   B. Rounded
   C. Similar to a match head
   D. Ground to a point

11. What condition is caused by filler metal or base metal on the electrode?

   A. Does not interfere with welding.
   B. Increases the arc length.
   C. Results in poor quality welds.
   D. Produces a more stable arc.

12. On conventional sine wave and conventional square wave power sources, why is high frequency added to alternating current?

   A. Help maintain the arc.
   B. Prevent distortion.
   C. Provide cleaning action.
   D. Start the weld puddle.

13. A good rule of thumb for setting post flow time is ______.

   A. 1 second for every 5 amps
   B. 1 second for every 10 amps
   C. 1 second for every 20 amps
   D. 1 second for every 100 amps

14. What parameters are set when the power source is set to DC?

A. HF to start
B. Amperage control to minimum.
C. Adjust the flowmeter to 5 cubic feet per hour.
D. Keep the HF intensity control constant.

15. What type of electrode could you use with ac?

A. Nickel
B. Plain carbon
C. Copper alloy
D. Titanium

16. What does a 60% duty cycle mean with regard to power source operation?

A. 6 minutes out of every 60 minutes at rated output without overheating
B. 6 minutes out of every 10 minutes at rated output without overheating
C. Continuously at 60% of rated output
D. Continuously at 40% of rated output

17. In TIG, what type of current produces the deepest weld penetration?

A. DCEN
B. DCEP
C. AC
D. Pulsed AC

18. In the AWS electrode classification ER4043, the 4043 means _

A. 40,000 psi maximum tensile strength
B. Weight in grams
C. Electrode welding position
D. Chemical composition

19. What should be done with the torch when the torch is not in use?

A. Hang it out of the way.
B. Lay it on the welding table.
C. Lay it across your lap.
D. Point the electrode toward the workpiece.

20. The type of heat treatment where the weldment is held above the transformation temperature and allowed to cool in still air is called _

A. normalizing
B. tempering
C. annealing
D. stress relieving

21. What is the type of heat treatment that reduces warpage?

A. Normalizing
B. Annealing
C. Stress relieving
D. Quenching

22. What is the type of heat treatment that produces the highest ductility in carbon steel?

A. Tempering
B. Annealing
C. Stress relieving
D. Quenching

23. When, if ever, is a transformer welding machine used for TIG welding?

A. Submerged
B. Light industrial
C. Home use
D. Never

24. What power supply was developed to overcome the arc-extinguishing – re-striking problem?

A. Continuous wave dc
B. Pulsed wave dc
C. Square wave ac
D. Fixed ac

25. What is the most common torch head angle for TIG welding?

A. 45°
B. 60°
C. 90°
D. 120°

26. Between 6% and 22% _ by weight is contained in Austenitic stainless steel.

A. nickel
B. tantalum
C. cadmium
D. columbium

27. What is the major alloying element that distinguishes stainless steels from other types of steel?

A. Martensite
B. Chromium
C. Columbium
D. Zinc

28. Between what temperatures does carbide precipitation occur?

    A. 180°F and 395° (82°C and 202°C).
    B. 400°F and 750°F (204°C and 400°C).
    C. 1000°F and 1600°F (539°C and 870°C).
    D. 1700°F and 2100°F (927°C and 1150°C).

29. The best way to prevent carbide precipitation is to use base metals and filler rods with extremely low carbon content; what other elements also prevent carbide precipitation?

    A. Columbium, titanium, or tantalum
    B. Chromium, nickel, or cadmium
    C. Martensite, ferrite, or pearlite
    D. Silicon, oxides, or nitrides.

30. What type of bristle brush should you use when brushing stainless steel?

    A. Plain carbon steel wire brush that has not been used on other metals
    B. Fine-bristled brass brush to prevent scarring the oxide coating
    C. Stainless steel wire brush that has not been used on carbon steel
    D. A new polypropylene brush

31. A stainless steel with a carbon content greater than _ % will often need preheating?

    A. .01
    B. .10
    C. .22
    D. 22

32. What is the maximum preheat temperature used on aluminum?

    A. 150°.
    B. 200°.
    C. 250°
    D. 300°

33. What layer on the surface of aluminum makes it difficult to weld?

    A. Oxide
    B. Zinc Dioxide
    C. Carbon monoxide
    D. Smelting residue

34. What type of current is the pulsed current method of welding commonly used with?

    A. AC
    B. DC
    C. Square wave
    D. Inverter

35. What is the maximum welding current of an air cooled torch?

- A. 100 amps
- B. 200 amps
- C. 300 amps
- D. 500 amps

36. Why is pulsed current useful for welding stainless steel?

- A. It does not overheat the metal as much as continuous current.
- B. It melts the chromium and nickel better than continuous current.
- C. The joint does not require careful cleaning when using pulsed current.
- D. Less amperage is needed to create a fuller weld.

37. How many types of nozzles are available for TIG welding torches?

- A. 2
- B. 3
- C. 4
- D. 5

38. What is the popular type of nozzle used?

- A. Ceramic
- B. Metal
- C. Fused quartz
- D. Dual shielded

39. Where is the gas orifice located on a TIG torch?

- A. Around the nozzle
- B. After the insulator
- C. Behind the nozzle
- D. In the nozzle

40. Orbital welding head torch oscillation speed and width are _______ adjusted?

- A. automatically
- B. intermittently
- C. independently
- D. manually

41. What is the most common type of gas flow control?

- A. Computer
- B. Flowmeter and regulator
- C. Flowmeter only
- D. Regulator only

42. What is the constant outlet pressure from the regulator to the flowmeter?

A. 50 psig
B. 60 psig
C. 70 psig
D. 80 psig

43. A welding cable AWG no. 8 has what maximum amperage rating?

A. 25
B. 50
C. 75
D. 100

44. What group of stainless steels is included in the 200 and 300 series?

A. Austenitic
B. Ferritic
C. Martensitic
D. Duplex

45. What is not a basic group of titanium and titanium alloys?

A. Gamma alloys
B. Beta alloys
C. Alpha alloys
D. Unalloyed titanium

46. What is a refractory metal?

A. Columdium
B. Beryllium
C. Zirconium
D. Titanium

47. What does the number 3 refer to when describing welding positions?

A. Flat
B. Vertical
C. Horizontal
D. Overhead

48. What is the purpose of using helium on thick sections of base metal?

A. Produces a hotter arc with deeper penetration and faster travel speeds.
B. Provides better coverage than argon.
C. Is more cost effective than argon.
D. Is easier to use than argon.

49. Which of the following characteristics help determine welding current?

A. Working cable size
B. Area of the metal
C. Electrode tip size
D. Thickness of the base metal

50. What lens shade number is recommended for 1/16 “ diameter electrodes

A. 10
B. 11
C. 12
D. 14

Trade Terms Introduced in this Chapter

Alloy	A compound of one or more metals or other elements. For example, brass is the alloy of copper and zinc.
American Wire Gauge (AWG)	Standard numbering system for the diameters of round, solid, non-ferrous, electrically conducting wire.
Annular	Having the form of a ring as a carpenter's nail has a series of concentric grooves to improve holding power.
Austenitic	Consisting mainly of austenite, which is a nonmagnetic solid solution of ferric carbide, or carbon in iron used in making corrosion-resistant steel.
Autogenous	In metallurgy, a term meaning self-fused, without the addition of solder or the application of an adhesive.
Ferritic	Consisting of the pure iron constituent of ferrous metals, as distinguished from the iron carbides.
Ferrous	An adjective used to indicate the presence of iron. The word is derived from the Latin word *ferrum* ("iron"). Ferrous metals include steel and pig iron (with a carbon content of a few percent) and alloys of iron with other metals (such as stainless steel).
Inverter	An electrical converter that converts direct current into alternating current.
Malleable	Capable of great deformation without breaking when subject to compressive stress.
Maraging	A blending of two words (martensitic and aging),iron alloys which are known for possessing superior strength and toughness without losing malleability. These steels are a special class of low carbon ultra-high strength steels, which derive their strength not from carbon, but from precipitation of inter-metallic compounds.
Martensitic	Consisting of a solid solution of iron and up to one percent of carbon, the chief constituent of hardened carbon tool steels.
Nodular	Occurring in the form of small rounded or irregular shapes.
Non-ferrous	The term used to indicate metals other than iron and alloys that do not contain an appreciable amount of iron.

Tanalum	A gray, hard, rare, metallic element occurring in columbite and tantalite, and usually associated with niobium; used because of its resistance to corrosion by most acids, for chemical, dental, and surgical instruments and apparatus.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

*Principles of Shielded Metal Arc Weldin*g, Miller Electric Manufacturing Company, Appleton, WI.

Safety in Welding, Cutting, and Allied Processes, ANSI/ASC Z49.1:2005 An American National Standard, American Welding Society, Miami FL, 2005.

Shielded Metal Arc Welding, Hobart Institute of Welding Technology , Troy Ohio,1998.

Welding and Allied Processes, S9086-CH-STM-010/CH-074R4, Commander, Naval Sea Systems Command, Washington Navy Yard, Washington D.C.,1999*.*

Welding Theory and Application, TC 9-237, Department of the Army Technical Manual, Headquarters, Department of the Army, Washington D.C., 1993.

Welding Theory and Application, TM 9-237, Department of the Army Technical Manual, Headquarters, Department of the Army, Washington D.C., 1976.

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Chapter 10

Gas Metal Arc Welding

Topics

To hear audio, click on the box.

Overview

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 chapter 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 extension, 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 chapter is very comprehensive, always refer to the manufacturer's manuals for specific operating and maintenance instructions.

Objectives

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

1. Describe the process of gas metal arc welding.
2. Describe the principles of operation used for gas metal arc welding.
3. Describe the equipment associated with gas metal arc welding.
4. Describe the processes for installation, setup, and maintenance of equipment for gas metal arc welding.
5. State the shielding gas and electrodes for gas metal arc welding.
6. Identify the welding applications for gas metal arc welding.
7. Describe the welding metallurgy of gas metal arc welding.
8. Identify weld and joint designs used for gas metal arc welding.
9. Describe the welding procedure variables associated with gas metal arc welding.
10. Identify welding procedure schedules used for gas metal arc welding.
11. Describe preweld preparations for gas metal arc welding.
12. Identify defects and problems associated with gas metal arc welding.
13. Describe postweld procedures for gas metal arc welding.
14. State the welder training and qualifications associated with gas metal arc welding.
15. Describe the welding safety associated with gas metal arc welding.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	STEELWORKER BASIC
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet-Metal and Fiberglass Duct		
Welding Quality Control		
Flux Core Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

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 10-1*).

Figure 10-1 — 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 Micro-wire 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.

1.2.1 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 the following:

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.

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 10-2*). 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 10-2 — Volt-amp curve.

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 10-3* 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.

Figure 10-3 — Volt-amp slopes.

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 10-4*). 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 10-4 — 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 10-5 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.

Figure 10-5 — Volt-amp curves.

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 10-6*). 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 10-6 — 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 10-7*.

Figure 10-7 — 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 10-8*.

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.

Figure 10-8 — Spray transfer.

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 (Select the Correct Response)

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

3.1.1 EQUIPMENT for WELDING

The basic design of a GMAW system is shown in *Figure 10-9* and includes four principal components:

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

Figure 10-9 — 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 10-10*). 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.

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 10-11*). 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.

Figure 10-10 — Particle flow for DCEP and DCEN.

Figure 10-11 — Pulsed current terminology.

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). ***Inverter*****s** 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 10-12).*

Many of the engine-driven generators used for gas metal arc welding in the field are

Figure 10-12 — Engine-driven power source.

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 10-13)*.

Figure 10-13 — 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 10-14)*.

Figure 10-14 — 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 10-15*). 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 10-15 — 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 10-16* shows several of the most common drive rolls and their uses.

Figure 10-16 — 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 10-17*. 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 10-17 — 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 10-18* uses the standard feeder as the drive motor (push) and the gun as a slave motor (pull).

Figure 10-18 — Standard push-pull wire feeding system.

3.4.0 Welding Guns

A typical GMAW gun is shown in *Figure 10-19.* 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. 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.

Figure 10-19 — Cross-sectional view of a welding gun.

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.

Figure 10-20 — Semi-automatic.

There are three general types of guns available. The one shown in *Figure 10-20* 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 10-21* 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.

Figure 10-21 — Spool gun.

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 10-22* shows a GMAW control panel for a machine welding gun system.

Figure 10-22 — 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 10-23)*.

Figure 10-23 — Regulator and flowmeter.

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.

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 10-1 — 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. *Table 10-1* 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.

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.

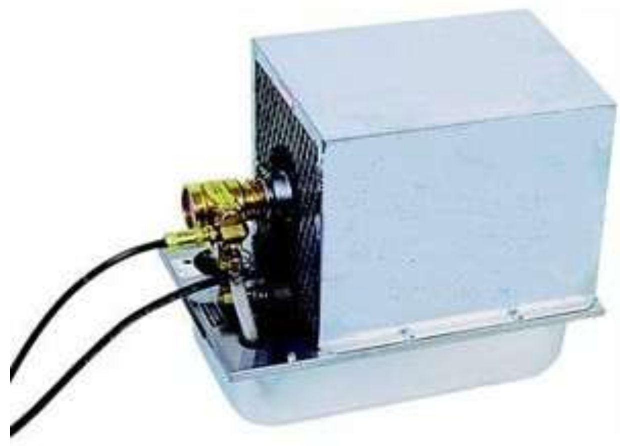

Figure 10-24 — Water circulator.

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 10-24*.

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 (Select the Correct Response)

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

4.1.1 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.

4.2.1 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.

Figure 10-25 — O-ring inspection.

Check the O-rings for damage *(Figure 10-25)*.

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 10-26)*.

Clean spatter from the contact tube with a pair of needle nose pliers.

Figure 10-26 — 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.

- Remove the contact tube and outlet guide.
- Stretch the cable straight.
- 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

Remove the contact tube.

Open the feed roll assembly *(Figure 10-27)*.

Remove the spool retaining ring.

Slide the spool onto the spool hub so the wire feeds from bottom.

Replace the spool retaining ring.

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.

Close the feed roll assembly.

Test tension by pressing the “jog” button until the wire feeds through the gas diffuser.

Replace the contact tube and nozzle.

Figure 10-27 — Wire installation.

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 non-metallic washer inside the regulator connection so the regulator does not frost (*Figure 10-28*). To prevent freezing for flow rates greater than 25 cubic feet per hour (cfh), use a line heater or manifold system.

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.

Figure 10-28 — Installation of pressure regulator.

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 10-29*).

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:

Clip the wire behind the inlet and outlet guides, and remove the tangle of wire.

Remove the gun cable assembly, nozzle, and contact tube.

Extract the wire from the back of the gun cable.

Rethread the wire.

Replace the contact tube and nozzle.

Figure 10-29 — Bird nest.

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.

5.1.1 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:

1. Thermal properties at elevated temperatures
2. Chemical reaction of the gas with the various elements in the base plate and welding wire
3. 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 10-2* 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 10-2 — 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:

1. Type of metal to be welded
2. Arc characteristics and type of metal transfer
3. Speed of welding
4. Tendency to cause undercutting
5. Penetration, width, and shape of the weld bead
6. Availability
7. Cost of the gas
8. 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 10-30* shows a manifold system used for connecting several cylinders together. Excessive flow rates can also result in drawing liquid from the cylinder.

Figure 10-30 — 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:

1. Better joint penetration
2. Higher welding speeds
3. 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.

5.3.1 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:

1. Base plate chemical composition
2. Base plate mechanical properties
3. Shielding gas employed
4. Type of service or applicable specification requirements
5. 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 10-3*).

Table 10-3 — 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.

1. 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.
2. The next two (or three) digits indicate the nominal tensile strength of the filler wire.
3. 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.

4. 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 10-4 — 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
ERll0S-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 10-5 — Tension and impact test of weld metal deposits of carbon steel electrodes.

Tension Test Requirements (As Welded)						
		Tensile Strength (minimum)		Yield Strength (minimum)		
AWS Classification	Shielding Gas	psi	Mpa	psi	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-Ibl but not lower than 15 ft-lbf. The average of the three shall not be less than the 20 ft-Ibf 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 Ibf (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 10-6*, the aluminum classifications shown in *Table 10-7*, the copper classifications shown in *Table 10-8*, the magnesium classifications shown in *Table 10-9*, and the nickel classifications shown in *Table 10-10*.

Table 10-6 — Chemical composition of bare stainless steel welding electrodes and rods (AWS A5.9).

AWS Classification[c,d]	UNS Number[e]	Composition, Wt%[a,b] C	Cr	Ni	Mo	Mn	Si	P	S	N	Cu	Other Elements: 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 max
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 max
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 max
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 max
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 max
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 max
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 max
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 max
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]	0.05
												Ti	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	16.0-21.0
												W	2.0-3.5
												Cb	0.30
												Ta	0.30-1.25
												Al	0.10-0.50
												Zr	0.001-0.10
												La	0.005-0.10
												B	0.02

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 ANSl/ AWS AS.9 in the final revision following publication of the revised ANSl/AWS *AS.2B* document.

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

AWS Classification	UNS Number[c]	Weight Percent[a,b] Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Other Elements Each	Other Elements 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

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 10-8 — 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	CI8980	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 10-9 — Chemical compositions of magnesium alloy bare welding electrodes and rods (AWS A5.19).

AWS Classi-fication	UNS Number'	Weight Percentab											
		Mg	Al	Be	Mn	Zn	Zr	Rare Earth	Cu	Fe	Ni	Si	Other Elements Total
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 10-10 — 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

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.

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 Ibs. (.9-27 kg) and coils normally weigh 60 Ibs. (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.

5.4.1 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:

1. 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.
2. 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.
3. 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.
4. 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), Federal Bureau of Roads, U.S. Coast Guard, and the

Military. 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 (Select the Correct Response)

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

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

6. **(True or False)** One of the most important factors to consider in GMAW welding is the correct filler wire selection.

   A. True
   B. False

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 10-31* 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 10-32*). Submerged arc welding is then employed for making the fill and cover passes.

Figure 10-31 —GMAW pressure vessel welding.

Figure 10-32 —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 10-33* shows a root pass being welded in a 48 in. (1.2 mm) diameter natural gas pipeline.

Figure 10-33 — 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 10-34* 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

Figure 10-34 — GMAW of a nuclear plenum.

as piping fittings, vessels, and liquid metal pumps are also common applications.

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.

Figure 10-35 — GMAW of a structural beam.

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 10-35* 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.

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 non-ferrous 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 non-ferrous metal ships and components.

Figure 10-36 — GMAW vertical weld.

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 10-36* 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.

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 non-ferrous 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 10-37* 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. Gas metal arc welding is the only arc welding process being used to weld aluminum automobile body components, truck cabs, and van bodies. *Figure 10-38* shows the

Figure 10-37 — Automotive welding.

welding of an aluminum truck transmission cross-member.

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.

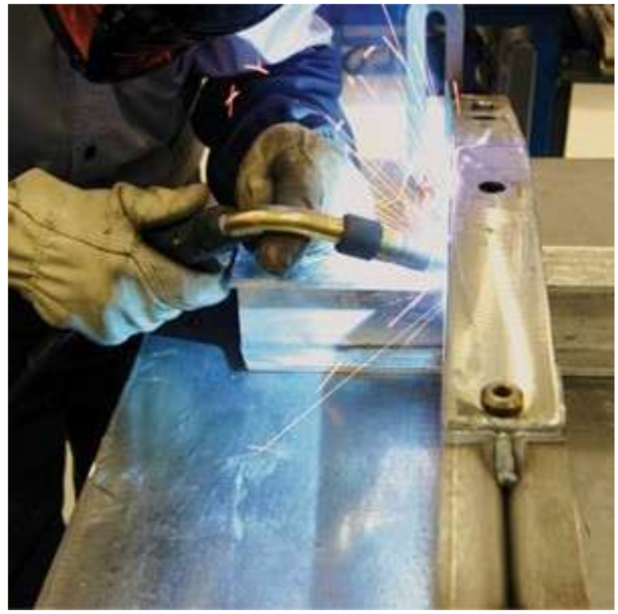

Figure 10-38 — Aluminum welding.

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 10-39* 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 10-39 — 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:

1. The gun is light and portable and can be taken to the weldment.
2. Spot welding can be done in all positions more easily.
3. Spot welds can be made when there is accessibility only to one side of the joint.
4. Spot-weld production is faster for many applications.
5. 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

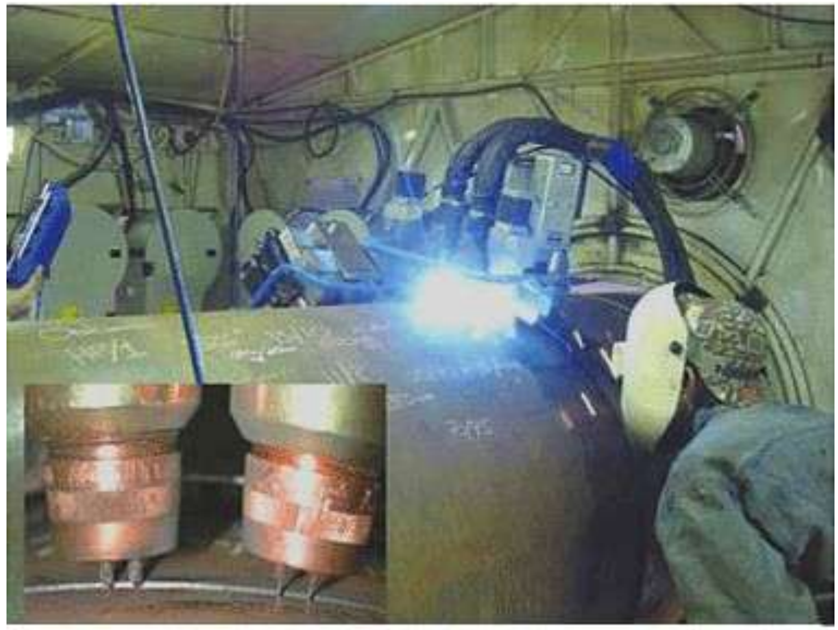

Figure 10-40 — Narrow gap weld.

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 10-40*), but some narrow gap welding has been done on aluminum. 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:

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

Test your Knowledge (Select the Correct Response)

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

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.

7.1.1 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 10-11* 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 10-11 — 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.

Figure 10-41 — Tensile strength testing bars.

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 10-41* 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.

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 10-42* 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 10-42 — 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 10-43* shows a cross section of a weld indicating the different areas.

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

1. Maximum temperature that the weld metal reached
2. Time that the weld spent at that temperature
3. Chemical composition of the base metal

Figure 10-43 — Cross section of a weld.

4. 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 10-44* 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.

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.

Figure 10-44 — Solidification pattern of a weld.

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 10-12* 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 10-12 — 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 10-13* shows a filler metal selection chart based on the specific properties desired. *Table 10-14* 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 10-13 — 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 10-14 — 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									

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, (2) highest weld ductility, and (3) 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 opper 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 10-15* shows the relative ease of welding copper and copper alloys.

Table 10-15 — 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 10-16* 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 10-59*). The type of electrode used is governed by the chemical composition of the base metal.

Table 10-16 — 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 10-17*. 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 10-17 — 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 chrome-moly, nickel-manganese, etc. For discussion purposes in this chapter, 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:

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

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 argon-carbon 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 chapter. 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 10-18* shows filler metal selection for stainless steels.

Table 10-18 — 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 (Select the Correct Response)

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.

8.1.1 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 10-45* shows the five basic joint types. Each of the different joints may be joined by many different types of welds. *Figure 10-45* 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 10-45* lists the nomenclature used for groove and fillet welds.

Several factors influence the joint design to be used:

1. Strength required
2. Welding position
3. Metal thickness
4. Joint accessibility
5. 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.

Figure 10-45 — Weld nomenclature.

Figure 10-46 — Welding test positions.

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 10-46*. 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.

The major effects that the position of a proposed weld will have are on the 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 10-47*. 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 shortcircuiting mode of metal transfer where larger root openings and smaller root faces are required.

Figure 10-47 — 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. Single-V-, 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 10-48* where single V-groove joints are shown with and without a backing strip.

Figure 10-48 — 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 chapter 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 10-19* shows the minimum effective throat thicknesses for partial penetration groove welds. *Figure 10-49* through *10-59* shows the American Welding Society "Standard Welding Symbols," some of which have been used in the weld joint designs.

Table 10-19 — 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.

Figure 10-49 — Welding symbols.

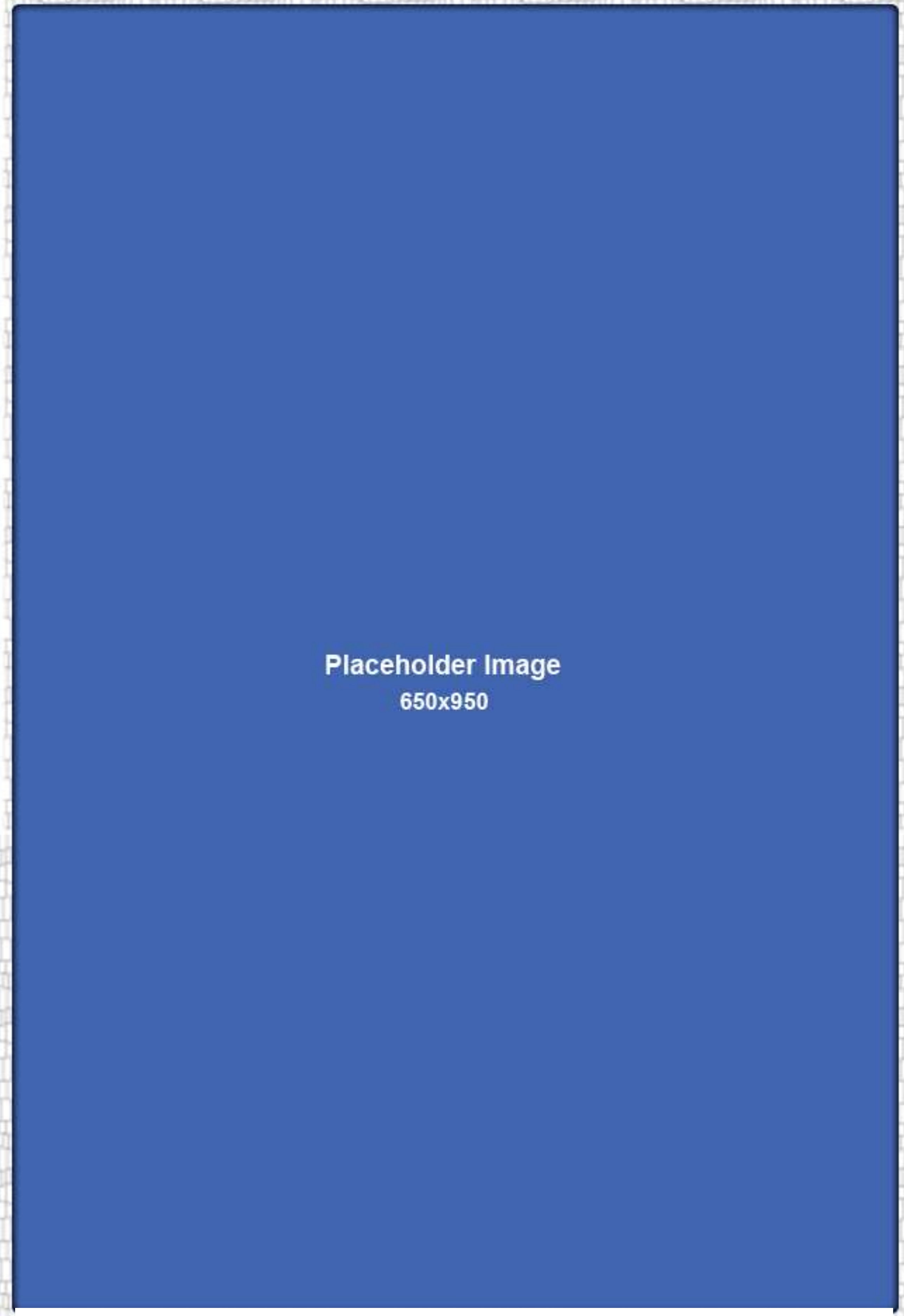

Figure 10-50 — Welding symbols (cont.).

Figure 10-51 — Welding symbols (cont.).

Figure 10-52 — Welding symbols (cont.).

Figure 10-53 — Welding symbols (cont.).

Figure 10-54 — Welding symbols (cont.).

Figure 10-55 — Welding symbols (cont.).

Figure 8-57 — Specification of location and extent of fillet welds.

Figure 10-56 — Welding symbols (cont.).

Figure 10-57 **— Welding symbols (cont.).**

Figure 10-58 — Welding symbols (cont.).

Figure 10-59 — 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 10-60*. 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 10-60 — 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 10-61*).

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.

Figure 10-61 — Pulling and pushing travel angle techniques.

Figure 10-62 — Multi-pass welding.

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 discussed in Chapter 3, Introduction to Welding). 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 10-62*. The numbers refer to the sequences in which you make the passes

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 10-63*.

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.

Figure 10-63 — Butt joints in the flat position.

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

Figure 10-64 — Butt welds with multi-pass beads.

Figure 10-65 — Weave motions.

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 10-64*. Clean each layer of metal before laying additional beads. You may use one of the weaving motions shown in *Figure 10-65*, depending upon the type of joint.

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 10-66*. Excessive welding speed also can cause undercutting and poor fusion at the edges of the weld bead.

Figure 10-66 — 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.

Figure 10-67 — Use of back strips in welding butt joints.

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 10-67.* 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.

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 10-68)*. In a fillet weld, the welding is performed on the upper side of a relatively horizontal surface and against an approximately vertical plane (*Figure 10-69*).

Figure 10-68 — Horizontal groove weld.

Figure 10-69 — 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 10-70*). 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.

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.

Figure 10-70 — Horizontal welding angles.

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 10-71*.

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 10-72*, *View A*). Hold the gun at an angle of 45 degrees to the two plate surfaces (*Figure 10-72*, *View B*) with an incline of approximately 15 degrees in the direction of welding.

Figure 10-71 — Tack weld to hold the tee joint elements in place.

Figure 10-72 — 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 10-73*. 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 10-74.*

Figure 10-73 — Weave motion for multipass fillet weld.

Figure 10-74 — Order of string beads for tee joint on heavy.

Chain-intermittent or staggered-intermittent fillet welds are used on long tee joints (*Figure 10-75*). 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.

Lap joints — When you make a lap joint, two overlapping plates are tack welded in place (*Figure 10-76*), and a fillet weld is deposited along the joint.

Figure 10-75 — Intermittent fillet welds.

Figure 10-76 — Tack welding a lap 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 10-77*. 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 10-77*

Figure 10-77 — Position of electrode on a lap joint.

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 10-78*). Be careful not to overheat or undercut the thinner plate edge.

Figure 10-78 — 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 10-79*). 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.

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 10-80*), 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 10-79 — Horizontal butt joint.

motion and ensure that each bead penetrates the base metal.

Figure 10-80 — 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 10-81*). 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.

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.

Figure 10-81 — Vertical weld plate positions.

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 10-82, View A*). When weaving is necessary, oscillate the gun as shown in *Figure 10-82*, *View B*.

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 10-82*, *View C*). When vertical down welding requires a weave bead, you should oscillate the gun as shown in *Figure 10-82*, *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.

Figure 10-82 — Bead welds in the vertical position.

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 10-83, 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.

When the weld metal overheats, you should quickly shift the gun away from the crater without breaking the arc, as shown in *Figure 10-83, 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 10-83, 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 10-83*, *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.

Figure 10-83 — Fillet welds in the vertical position.

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 10-83, 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

Figure 10-84 — Butt joint welding in the vertical position.

weave motion, as shown in *Figure 10-84*, *View A.*

Welds made on 1/2-in. plate or heavier should be done in several passes, as shown in *Figure 10-84*, *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.

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 10-85*, *View A*). The travel angle should be 10 to 15 degrees in the direction of welding (*Figure 10-85*, *View B*).

Weave beads can be made by using the motion shown in *Figure 10-85*, *View C*. A rather rapid

Figure 10-85 — Position of electrode and weave motion in the overhead position.

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 10-86*, *Views B* and *C*. Make the first pass with the gun held at 90 degrees to the plate, as shown in *Figure 10-86*, *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 10-86 — 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 10-87*, *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.

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 10-87*, *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 10-87*, *View C*, and with a slight circular motion make the second, third, and fourth pass.

Figure 10-87 — Fillet welds in the overhead position.

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

In the following paragraphs, pipe welding positions, pipe welding procedures, definitions, and related information are discussed.

You may recall from *Figure 10-46*, 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.

Figure 10-88 — Butt joints and socket fitting joints.

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 10-88*)

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.

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

Figure 10-89 — Flange connections.

the flange or in combination with a bevel weld (*Figure 10-89*). Fillet welds are also used in welding screw or socket couplings to pipe, using a single fillet weld (*Figure 10-87)*. Sometimes flanges require alignment. *Figure 10-90* shows one type of flange square and its use in vertical and horizontal 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 flame-cut edges; however, it is not necessary to remove the temper color.

Figure 10-90 — Flange alignment.

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 10-91*), while a section of channel or I-beam is more suitable for larger diameter pipe.

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

Figure 10-91 — Angle iron jig.

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 (Select the Correct Response)

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

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.

Figure 10-92 — Bead height, width, and penetration.

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 10-92*. 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.

The welding variables are discussed with particular attention to the three major characteristics of penetration, deposition rate, and bead shape. *Table 10-20* shows the effects of welding variables on the three major characteristics.

Table 10-20 — 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 10-93* 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 10-93 — 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 10-94* 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 10-94* also shows the weld bead profile characteristics of argon, argon-helium mixtures, and helium.

Figure 10-94 — 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 10-95).*

Figure 10-95 — Electrode stick-out.

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 10-96)*. 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.

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 10-97)*.

Figure 10-96 — Arc strike.

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.

Figure 10-97 — Following the arc.

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 10-93*, 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 10-98* 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 10-98 — 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 10-99*. 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 10-102* shows the effects of varying the arc length on the weld profile.

Figure 10-99 — Effect of travel speed, arc volts, and welding current on penetration.

Figure 10-100 — Effect of travel speed, arc volts, and welding current on bead height.

Figure 10-101 — Effect of travel speed, arc volts, and welding current on bead width.

Figure 10-102 — 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 10-99*, the penetration is

Figure 10-103 — Effect of travel speed on bead.

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 10-100*. 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 10-103* shows the effects on the size and shape of the weld bead of different travel speeds.

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 10-104*). 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 10-105*. 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 10-106*). An excessively long electrode extension results in an excess of weld metal being deposited at low heat. This produces a poor weld bead

Figure 10-104 — Electrode. extension.

Figure 10-105 — Effect of electrode extension current.

Figure 10-106 — Effect of electrode extension on penetration.

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 10-107*. 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 stick-out, which reduces the welding current and penetration in this area.

Figure 10-107 — Effect of electrode extension on deposition rate.

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 10-108*.

The effects on the weld bead with respect to travel angle are shown in *Figure 10-109*. 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.

Figure 10-108 — Travel angle and work angle.

Figure 10-109 — Effects of travel angle on penetration and bead shape.

10.0.0 WELDING PROCEDURE SCHEDULES

The welding procedure schedules in this chapter 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 chapter 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 10-110* shows wire feed speeds and their corresponding welding currents for several sizes of steel electrode wire. *Figure 10-111* shows wire feed speeds and their corresponding welding currents for several sizes of non-ferrous metal electrode wire. 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.

Figure 10-110 — Wire-feed speed vs. welding current for steel electrodes.

Figure 10-111 — Wire feed speed vs. welding current for several non-ferrous electrodes.

Table 10-21 — 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)

Table 10-22 — 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)

Table 10-23 — 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)

Table 10-24 — 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)

Table 10-25 — 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)

Table 10-26 — 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 (25.4)	7	1/16 (1.6)	24-26	325-375	(89-110)	45 (21)	(9-11)
	6				100-120		24-28
1 (25.4)	2	3/32 (2.4)	26-29	400-450	(42-51)	45 (21)	(10-12)

Table 10-27 — Welding procedure schedules for GMAW of stainless steel.

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 10-28 — Welding procedure schedules for GMAW of aluminum and alloys.

Fillet size in. (mm)	No. of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min. (mm/s)	Gas Flow Rate ft3/hr. (l/min)	Travel 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)

Table 10-29 — 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)

Table 10-30 — 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)

Table 10-31 — 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)

Table 10-32 — 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)

Table 10-33 — 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)

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 Chapter 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 deoxidation 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.

11.3.1 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:

1. Locate and maintain parts in their positions relative to the assembly.
2. Increase the welding efficiency of the welder.
3. 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 (Select the Correct Response)

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

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 10-112*). 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 10-112 — 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 10-113*). These voids left in the weld cause it to be weakened. Porosity may be internal, on the surface of the weld bead, or both. This discontinuity is caused by one or more of the following:

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

Figure 10-113 — Porosity.

Porosity can be prevented or corrected by the following:

1. Increasing the shielding gas flow rate.
2. Setting up wind shields.
3. Cleaning the nozzle of the welding gun.
4. Replacing the cylinder of shielding gas.
5. Lowering the welding current (reducing the wire feed speed).
6. Decreasing the voltage.
7. Decreasing the electrode extension.
8. Reducing the travel speed.
9. Cleaning the surface of the base metal or filler metal.
10. 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 10-114*). Wormhole porosity can seriously reduce the strength of the weld. The best methods of preventing this are to clean the surfaces of

Figure 10-114 — Wormhole.

the joint and preheat to remove moisture. If sulfur in the steel is the problem, a more weldable grade of steel should be selected.

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 10-115*). This is particularly a problem with fillet welds. Undercutting causes a weaker joint at the toe of the weld, which may result in cracking.

It is caused by one or more of the following:

1. Excessive welding current
2. Arc voltage too high
3. Excessive travel speed which does not allow enough filler metal to be added
4. Erratic feeding of the electrode wire.
5. Excessive weaving speed
6. Incorrect electrode angles, especially on vertical and horizontal welds

Figure 10-115 — Undercutting.

It can be prevented by the following:

1. Reducing the welding current.
2. Reducing the welding voltage.
3. Using a travel speed slow enough so the weld metal can completely fill all of the melted-out areas of the base metal.
4. Cleaning the nozzle inside of the contact tube, or removing the jammed electrode wire.
5. Pausing at each side of the weld bead when a weaving technique is used.
6. 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 10-116*). 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 10-116 — 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:

1. Excessive travel speed which causes an excessively convex weld bead or does not allow adequate penetration
2. Welding current too low
3. Poor joint preparation
4. 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:

1. Reducing the travel speed.
2. Increasing the welding current.
3. Preparing the joint better.
4. Using proper electrode angles or increasing the travel speed.

A special type of incomplete fusion is wagon tracks, shown in *Figure 10-117*.

Figure 10-117 — Wagon tracks.

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.

12.1.6 Overlapping

Overlapping is the protrusion of the weld metal over the edge or toe of the weld bead (*Figure 10-118*). 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. Overlapping is produced by one or more of the following:

Figure 10-118 — Overlapping.

1. Too slow a travel speed, which permits the weld puddle to get ahead of the electrode
2. Arc welding current that is too low.
3. 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:

1. Using a higher travel speed.
2. Using a higher welding current.
3. 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 10-119)*. This can be caused by one or more of the following:

Figure 10-119 — Melt through.

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

This can be prevented by the following:

1. Reducing the welding current.
2. Increasing the travel speed.
3. 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 10-120*). 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.

They can be prevented by the following:

1. Reducing the travel speed.
2. Using a weaving motion.
3. Increasing electrode extension.
4. Reducing electrode current.

Figure 10-120 — Whiskers.

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 10-121*). 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. 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.

Figure 10-121 — Craters.

12.2.1 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:

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

Crater cracks are shallow hot cracks caused by improperly breaking the arc; *Figure 10-122* shows two types. Crater cracks may be

Figure 10-122 — Cracking.

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 10-123*).

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

1. Weld bead too small for the thickness of the base metal
2. Poor fitup
3. High joint restraint
4. Extension of a crater crack

Figure 10-123 — Crater cracks.

The best methods of preventing centerline cracks are the following:

1. Increasing the bead size.
2. Decreasing the gap width.
3. Preheating.
4. 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 10-124*. 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 10-124 — 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 10-125*.

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:

1. Weld toward an existing weld or tack weld.
2. Reduce the welding current and reduce the arc voltage.
3. 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.
4. Change the position of the fixture or demagnetize the base metal or fixture.

Figure 10-125 — Arc blow.

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:

1. Blockage of gas flow in the torch or hoses, or freezing of the regulator with carbon dioxide
2. Leak in the gas system
3. Weld spatter blocking the nozzle of the welding gun
4. Very high travel speed
5. Improper flow rate

6. Wind or drafts
7. 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 ogged 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:

1. Clogged contact tube
2. Clogged conduit in the welding gun assembly
3. Sharp bends or kinks in the wire feed conduit
4. Excessive pressure on the wire feed rolls which can cause breakage of the wire
5. Inadequate pressure on the wire feed rolls
6. Attempting to feed the wire over excessively long distances

7. 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:

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

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 chapters. The uses of these methods wiII 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 recrystallization 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 non-ferrous 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, toughnes, and ductility of the weld.

Test your Knowledge (Select the Correct Response)

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 i s a c ommon n on-stainless steel w ire br ush N OT used o n no n-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.

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 chapter 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)

14.2.1 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:

1. ANSI/API 1104 Standard for Welding Pipelines and Related Facilities

2. ASME Boiler and Pressure Vessel Code, Section IX, Welding and Brazing Qualifications
3. ANSI/AWS 01.1 Structural Welding Code Steel
4. AWS 05.2 Standard for Welded Steel Elevated Tanks, Standpipes, and Reservoirs for Water Storage
5. AWS 010.9 Specification for Qualification of Welding Procedures and Welders for Piping and Tubing
6. ANSI/AWS 014.1 Specification for Welding Industrial and Mill Crane and Other Material Handling Equipment
7. ANSI/AWS 014.2 Specification for Metal Cutting Machine Tool Weldments
8. ANSI/AWS 014.3 Specification for Welding Earthmoving and Construction Equipment
9. ANSI/ASME B96.1 Specification for Welded Aluminum Alloy Storage Tanks
10. 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.

15.1.1 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 the following:

1. Electrical shock
2. Arc radiation
3. Air contamination
4. Compressed gases
5. Fire and explosion
6. 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 10-34* 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 10-34 — 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/in^2.

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.

15.7.1 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.

Summary

This chapter 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 chapter 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.

Review Questions (Select the Correct Response)

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. (1996 Ed.)

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. **(True or False)** 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

Trade Terms Introduced in this Chapter

Alloy	An alloy is a compound of one or more metals or other elements. For example, brass is the alloy of copper and zinc.
American Wire Gauge (AWG)	Standard numbering system for the diameters of round, solid, nonferrous, electrically conducting wire.
Austenitic	Consisting mainly of austenite, which is a nonmagnetic solid solution of ferric carbide, or carbon in iron used in making corrosion-resistant steel.
Ferritic	Consisting of the pure iron constituent of ferrous metals, as distinguished from the iron carbides.
Ferrous	An adjective used to indicate the presence of iron. The word is derived from the Latin word *ferrum* ("iron"). Ferrous metals include steel and pig iron (with a carbon content of a few percent) and alloys of iron with other metals (such as stainless steel).
Inverter	An electrical converter that converts direct current into alternating current.
Martensitic	Consisting of a solid solution of iron and up to one percent of carbon, the chief constituent of hardened carbon tool steels.
Nonferrous	The term used to indicate metals other than iron and alloys that do not contain an appreciable amount of iron.
Tantalum	A gray, hard, rare, metallic element occurring in columbite and tantalite and usually associated with niobium; used because of its resistance to corrosion by most acids, for chemical, dental, and surgical instruments and apparatus.
Ternary	Consisting of three different elements or groups.
Thorium	A grayish-white, lustrous, somewhat ductile and malleable, radioactive metallic element present in monazite; used as a source of nuclear energy, as a coating on sun-lamp and vacuum-tube filament coatings, and in alloys.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

*Principles of Shielded Metal Arc Weldin*g, Miller Electric Manufacturing Company, Appleton, WI.

Safety in Welding, Cutting, and Allied Processes, ANSI/ASC Z49.1:2005 An American National Standard, American Welding Society, Miami FL, 2005.

Shielded Metal Arc Welding, Hobart Institute of Welding Technology , Troy Ohio,1998.

Welding and Allied Processes, S9086-CH-STM-010/CH-074R4, Commander, Naval Sea Systems Command, Washington Navy Yard, Washington D.C.,1999*.*

Welding Theory and Application, TC 9-237, Department of the Army Technical Manual, Headquarters, Department of the Army, Washington D.C., 1993.

Welding Theory and Application, TM 9-237, Department of the Army Technical Manual, Headquarters, Department of the Army, Washington D.C., 1976.

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Chapter 11

Flux Cored Arc Welding

Topics

To hear audio, click on the box.

Overview

Flux cored arc welding, or FCAW, evolved from the gas metal arc welding, or GMAW process to improve arc action, metal transfer, weld metal properties, and weld appearance. The heat is provided by an arc between a continuously fed tubular electrode wire and the workpiece. The major difference is that FCAW utilizes an electrode very different from the solid electrode used in GMAW. In fact, it is closer to the electrodes used in shielded metal arc welding, or SMAW or stick welding, except the flux is on the inside of a flexible electrode instead of on the outside of a very stiff electrode.

The flux-cored electrode is a fabricated electrode and, as the name implies, flux material is deposited into its core. The flux-cored electrode begins as a flat metal strip that is formed first into a "U" shape. Flux and ***alloying*** elements are deposited into the "U" and then the shape is closed into a tubular configuration by a series of forming rolls. Shielding is obtained by the flux contained within the tubular electrode wire, or by the flux and the addition of a shielding gas.

This chapter is designed to give you a basic understanding of the FCAW process and equipment along with the key variables that affect the quality of welds, such as electrode selection, polarity and amperage, arc length, travel speed, and electrode angles. It will also cover core competencies, such as setting up welding equipment, preparing weld materials, fitting up weld materials, welding carbon steel plates, and repairing welds. It will also provide you with an understanding of the safety precautions for FCAW and an awareness of the importance of safety in welding.

Always refer to the manufacturer's manuals for specific operating and maintenance instructions.

Objectives

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

1. Describe the process of flux cored arc welding.
2. Describe the principles of operation used for flux cored arc welding.
3. Describe the equipment associated with flux cored arc welding.
4. Describe the setup, operation and shut down of flux cored arc welding equipment.
5. Identify the classification and selection of flux-cored electrodes flux-cored electrodes used for flux cored arc welding.
6. Identify the welding applications for flux cored arc welding.
7. Describe the welding metallurgy of flux cored arc welding.
8. Identify weld and joint designs used for flux cored arc welding.
9. Describe the welding procedure variables associated with flux cored arc welding.
10. Identify welding procedure schedules used for flux cored arc welding.
11. Describe pre-weld preparations for flux cored arc welding.
12. Identify defects and problems associated with flux cored arc welding.
13. Describe post-weld procedures for flux cored arc welding.
14. State the welder training and qualifications associated with flux cored arc welding.
15. Describe the welding safety associated with flux cored arc welding.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	STEELWORKER BASIC
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet-Metal and Fiberglass Duct		
Welding Quality Control		
Flux Cored Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.1.1 INTRODUCTION to the PROCESS

Flux cored arc welding (FCAW) is an arc welding process in which the heat for welding is produced by an arc between a continuously fed tubular electrode wire and the work. Shielding is obtained by a flux contained within the tubular electrode wire or by the flux and an externally supplied shielding gas (*Figure 11-1*).

Flux cored arc welding is similar to gas metal arc welding in many ways, but the flux-cored wires used for this process give it different characteristics. Flux cored arc welding is widely used for welding ***ferrous*** metals and is particularly good for applications where high deposition rates are desirable. Also, at high welding currents, the arc is smooth and more manageable when compared to using large diameter gas metal arc welding electrodes with carbon dioxide. With FCAW, the arc and weld pool are clearly visible to the welder, and a slag coating is left on the surface of the weld bead, which must be removed. Since the filler metal transfers across the arc, some spatter is created and some smoke produced.

Figure 11-1 — FCAW self shielded and external gas shielded electrodes.

As in GMAW, FCAW depends on a gas shield to protect the weld zone from detrimental atmospheric contamination. However, with FCAW, there are two primary ways this is accomplished:

1. The gas is applied from an external source, in which case the electrode is referred to as a gas shielded flux-cored electrode.
2. The gas is generated from the decomposition of gas-forming ingredients contained in the electrode's core. In this instance, the electrode is known as a self-shielding flux-cored electrode.

In addition to the gas shield, the flux-cored electrode produces a slag covering for further protection of the weld metal as it cools, which must be manually removed with a wire brush or chipping hammer.

The main advantage of the self-shielding method is that its operation is somewhat simplified because of the absence of external shielding equipment. Although self-shielding electrodes have been developed for welding low-alloy and stainless steels, they are most widely used on mild steels. The self-shielding method generally uses a long electrical stickout (distance between the contact tube and the end of the unmelted electrode, commonly from one to four inches). Electrical resistance is increased with the long extension, preheating the electrode before it is fed into the arc. This preheating enables the electrode to burn off at a faster rate and increases deposition. The preheating also decreases the heat available for melting the base metal, resulting in a more shallow penetration than the gas shielded process.

A major drawback of the self-shielded process is the metallurgical quality of the deposited weld metal. In addition to gaining its shielding ability from gas-forming ingredients in the core, the self-shielded electrode contains a high level of deoxidizing and denitrifying alloys, primarily aluminum, in its core. Although the aluminum performs well in neutralizing the effects of oxygen and nitrogen in the arc zone, its presence in the weld metal will reduce ductility and impact strength at low temperatures. For this reason, the self-shielding method is usually restricted to less critical applications.

The self-shielding electrodes are more suitable for welding in drafty locations than the gas-shielded types. Since the molten filler metal is on the outside of the flux, the gases formed by the decomposing flux are not totally relied upon to shield the arc from the atmosphere. To compensate, the deoxidizing and denitrifying elements in the flux further help to neutralize the effects of nitrogen and oxygen present in the weld zone.

The gas-shielded flux-cored electrode has a major advantage over the self-shielded flux-cored electrode, which is, the protective envelope formed by the auxiliary gas shield around the molten puddle. This envelope effectively excludes the atmosphere without the need for core ingredients, such as aluminum. Because of this more thorough shielding, the weld metallurgy is cleaner, which makes this process suitable for welding not only mild steels, but also low-alloy steels in a wide range of strength and impact levels.

The gas-shielded method uses a shorter electrical stickout than the self-shielded process. (Refer to Figure 11-1 again) Extensions from 1/2" to 3/4" are common on all diameters, and 3/4" to 1-1/2" on larger diameters. Higher welding currents are also used with this process, enabling high deposition rates. The auxiliary shielding helps to reduce the arc energy into a columnar pattern. The combination of high currents and the action of the shielding gas contributes to the deep penetration inherent with this process. Both spray and globular transfer are utilized with the gas-shielded process.

1.1.0 Methods of Application

Although flux cored arc welding may be applied semiautomatically, by machine, or automatically, the process is usually applied semiautomatically. In semiautomatic welding, the wire feeder feeds the electrode wire and the power source maintains the arc length. The welder manipulates the welding gun and adjusts the welding parameters. FCAW is also used in machine welding where, in addition to feeding the wire and maintaining the arc length, the machinery also provides the joint travel. The welding operator continuously monitors the welding and makes adjustments in the welding parameters. Automatic welding is used in high production applications. In automatic welding, the welding operator only starts the operation.

1.2.1 Advantages and Limitations

Flux cored arc welding has many advantages for a wide variety of applications. It often competes with shielded metal arc welding, gas metal arc welding, and submerged arc welding (SAW) for many applications. Some of the advantages of this process are:

1. It has a high deposition rate and faster travel speeds.
2. Using small diameter electrode wires, welding can be done in all positions.
3. Some flux-cored wires do not need an external supply of shielding gas, which simplifies the equipment.
4. The electrode wire is fed continuously so there is very little time spent on changing electrodes.
5. Deposits a higher percentage of the filler metal when compared to shielded metal arc welding.
6. Obtains better penetration than shielded metal arc welding.

2.0.0 PRINCIPLES of OPERATION

Flux cored arc welding uses the heat of an electric arc between a consumable, tubular electrode and the part to be welded. Electric current passing through an ionized gas produces an electric arc. 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. The electrons carry about 95% of the heat and the rest is carried by the positive ions. The heat of the arc melts the electrode and the surface of the base metal.

One of two methods shields the molten weld metal, heated weld zone, and electrode. The first method is by the decomposition of the flux core of the electrode. The second method is by a combination of an externally supplied shielding gas and the decomposition of the flux core of the electrode wire. The flux core has essentially the same purpose as the coating on an electrode for shielded metal arc welding. The molten electrode filler metal transfers across the arc and into the molten weld puddle, and a slag forms on top of the weld bead that can be removed after welding.

The arc is struck by starting the wire feed which causes the electrode wire to touch the workpiece and initiate the arc. Arc travel is usually not started until a weld puddle is formed. The welding gun then moves along the weld joint manually or mechanically so that the edges of the weld joint are joined. The weld metal then solidifies behind the arc, completing the welding process. A large amount of flux is contained in the core of a self-shielding wire as compared to a gas-shielded wire. This is needed to provide adequate shielding and because of this, a thicker slag coating is formed. In these wires, deoxidizing and denitrifying elements are needed in the filler metal and flux core because some nitrogen is introduced from the atmosphere.

2.1.0 Arc Systems

The FCAW process may be operated on both constant voltage and constant current power sources. A welding power source can be classified by its volt-ampere characteristics as 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 FCAW applications.

In the constant voltage arc system, the voltage delivered to the arc is maintained at a relatively constant level that gives a flat or nearly flat volt-ampere curve, as shown in *Figure 11-2*. This type of power source is widely used for the processes that require a continuously fed 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 11-2 — Constant voltage system volt-ampere curve.

As *Figure 11-2 shows*, a slight change in the arc length (voltage level) will produce a large change in the welding current.

Most power sources have a fixed slope built in for a certain type of flux cored arc welding. Some constant voltage welding machines are equipped with a slope control used to change the slope of the volt-ampere curve.

Figure 11-3 shows different slopes obtained from one power source. The slope has the effect of limiting the amount of short-circuiting current 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. This is not as important in FCAW as it was in GMAW because short-circuiting metal transfer is not encountered except with alloy cored, low flux content wires.

A slope control is not required, but may be desirable, when welding with small diameter, alloy cored, low flux content electrodes at low current levels. The short-circuit current determines the amount of pinch force available on the electrode. The pinch forces cause the molten electrode droplet to separate from the solid electrode. The flatter the slope of the volt-ampere curve, the higher the short-circuit and the pinch force. The steeper the slope, the lower the short-circuit and pinch force. The pinch force is important with these electrodes because it affects the way the droplet detaches from the tip of the electrode wire. When a high short-circuit and a flat slope cause pinch force, 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 up on the work piece. When the proper amount of short-circuit current is used, it creates very little spatter.

Figure 11-3 — Different slopes from a constant voltage motor generator power source.

The inductance of the power supply also has an effect on the arc stability. When the load on the power supply changes, the current takes time to find its new level. The rate of current change is determined by the inductance of the power supply. Increasing the inductance will reduce the rate of current rise. The rate of the welding current rise increases with the current that is also affected by the inductance in the circuit. 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 arc system provides a nearly constant welding current to the arc, which gives a drooping volt-ampere characteristic, as shown in *Figure 11-4*. This arc system is used with the SMAW and GTAW processes. A dial on the machine sets the welding current 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 flux cored arc welding is done with a constant current system, a special voltage-sensing wire feeder is used to maintain a constant arc length.

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.

Figure 11-4 — Volt-ampere curve for a constant current arc system.

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 type and type of electrode. 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 in order to maintain a fixed voltage across the arc.

With the constant current arc system, the welder changes 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 unable 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 11-5 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 levels are 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 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.

Figure 11-5 — Volt-ampere curves.

2.2.0 Metal Transfer

Metal transfer, from consumable electrodes across an arc, has been classified into three general modes of transfer: spray transfer, globular transfer, and short-circuiting transfer. The metal transfer of most flux-cored electrodes resembles a fine globular transfer. Only the alloy-cored, low flux content wires can produce a short-circuiting metal transfer similar to GMAW.

On flux-cored electrodes, the molten droplets build up around the periphery or outer metal sheath of the electrode. By contrast, the droplets on solid wires tend to form across the entire cross section at the end of the wire. A droplet forms on the cored wire, is transferred, and then a droplet is formed at another location on the metal sheath. The core material appears to transfer independently to the surface of the weld puddle. *Figure 11-6* shows the metal transfer in flux=cored arc welding.

Figure 11-6 — Metal transfer in FCAW.

At low currents, the droplets tend to be larger than at higher current levels. If the welding current using a 3/32 in. (2.4 mm) electrode wire is increased from 350 to 550 amps, the metal transfer characteristics will change. Transfer is much more frequent and the droplets become smaller as the current is increased. At 550 amperes, some of the metal may transfer by the spray mode, although the globular mode prevails. There is no indication that higher currents cause a transition to a spray mode of transfer, unless an argon-oxygen shielding gas mixture is used.

The larger droplets at the lower currents cause a certain amount of "splashing action" when they enter the weld puddle. This action decreases with the smaller droplet size.

This explains why there is less visible spatter. The arc appears smoother to the operator, and the deposition efficiency is higher when a wire is used with a high current density rather than at the low end of its current range.

Test your Knowledge (Select the Correct Response)

1. What does the welding process leave on the surface of the weld bead that must be removed?

   A. Dross
   B. Splatter
   C. Slag
   D. Rust

2. What is “pinch force”?

   A. The amount of pressure applied by the grounding clamp
   B. The grip between the wire feed rollers
   C. It causes the molten electrode droplet to separate from the electrode
   D. It helps the arc transfer from the work piece to the electrode

3.0.0 EQUIPMENT for WELDING

The equipment used for FCAW is very similar to that used for GMAW. The basic arc welding equipment consists of a power source, controls, wire feeder, welding gun, and welding cables. A major difference between the gas-shielded electrodes and self - shielded electrodes is that the gas shielded wires also require a gas shielding system. This may also have an effect on the type of welding gun used. Fume extractors are often used with this process. For machine and automatic welding, several items, such as seam followers and motion devices, are added to the basic equipment. A diagram of the equipment for semiautomatic FCAW is shown in *Figure 11-7*.

Figure 11-7 — Equipment for flux cored arc welding.

3.1.0 Power Sources

The power source (welding machine) provides the electric power of the proper voltage and amperage to maintain a welding arc. Most power sources operate on 230 or 460 volt input power, but machines that operate on 200 or 575 volt input are available as options. Power sources may operate on either single-phase or three-phase input with a frequency of 50 to 60 Hz.

3.1.1 Power Source Duty Cycle

Duty cycle is defined as the ratio of arc time to total time. Most power sources used for FCAW have a duty cycle of 100%, which indicates that they can be used to weld continuously. However, some machines have a duty cycle of 60%. For a welding machine, a 10 minute time period is used. Thus, for a 60% duty cycle machine, the welding load would be applied continuously for 6 minutes and would be off for 4 minutes. Most industrial type, constant current machines are rated at 60% duty cycle. The formula for determining the duty cycle of a welding machine for a given load current is:

% Duty Cycle = $\frac{(Rated\ Current)^2}{(Load\ Current)^2}\ X\ Rated\ Duty\ Cycle$ $\frac{(\text{Rated Current})^2}{(\text{Load Current})^2} \times \text{Rated Duty Cycle}$

For example, if a welding machine is rated at a 60% duty cycle at 300 amperes, the duty cycle of the machine when operated at 350 amperes would be.

% Duty Cycle = $\frac{(300)^2}{(350)^2}\ X\ 60 = 44\%$ $\frac{(300)^2}{(350)^2} \times 60 = 44\%$

In general, these lower duty cycle machines are the constant current type, which are used in plants where the same machines are also used for SMAW and gas tungsten arc welding. Some of the smaller constant voltage welding machines have a 60% duty cycle.

3.1.2 Types of Current

FCAW uses direct current, which can be connected in one of two ways: electrode positive (reverse polarity) or electrode negative (straight polarity). The electrically charged particles flow between the tip of the electrode and the work as shown in *Figure 11-8*.

Flux-cored electrode wires are designed to operate on either DCEP or DCEN. The wires designed for use with an external gas shielding system are generally designed for use with DCEP, while some self-shielding flux-cored wires are used with DCEP and others are used with DCEN. Electrode positive current gives better penetration into the weld joint. Electrode negative current gives lighter penetration, and is used for welding thinner metal or where there is poor fit-up. The weld created by DCEN is wider and shallower than the weld produced by DCEP

Figure 11-8 — Particle flow for DCEP and DCEN.

3.1.3 Types of Power Sources

The power sources generally recommended for flux cored arc welding are direct current constant voltage types. Both rotating (generator) and static (single- or three-phase transformer-rectifiers) are used. Any of these types of machines are available to produce constant current or constant voltage output, or both. The same power sources used with GMAW are used with FCAW, but FCAW generally uses higher welding currents, which sometimes requires a larger power source. It is important to use a power source capable of producing the maximum current level required for an application.

3.1.3.1 Generator and Alternator Welding Machines

Generator welding machines used for this process can be powered by an electric motor for shop use, or an internal combustion engine for field applications. Gasoline or diesel engine-driven welding machines have either liquid or air-cooled engines and many of them provide auxiliary power for emergency lighting, power tools, etc. Many of the engine-driven generators used for FCAW in the field are combination constant current-constant voltage types. These types are popular for applications where both SMAW and FCAW can be accomplished using the same power source. *Figure 11-9* shows an engine-driven generator machine used for flux cored arc welding. The motor-driven generator welding machines are gradually being replaced by transformer-rectifier welding machines. Motor-driven generators produce a very stable arc, but they are noisier, more expensive, consume more power and require more maintenance than transformer-rectifier machines. They can, however, function without being sourced by an electrical power supply and, in fact, can produce the auxiliary electricity during power outages.

Figure 11-9 — Gas powered welder/generator.

An alternator welding machine is an electric generator made to produce AC power. This power source has a rotating assembly. These machines are also called rotating or revolving field machines.

3.1.3.2 Transformer Welding Machines

Transformer-rectifiers are the most widely used welding machines for FCAW. . Adding a rectifier to a basic transformer circuit is a method of supplying direct current to the arc without using a rotating generator.. A rectifier is an electrical device which changes alternating current into direct current. These machines are more efficient electrically than motor-generator welding machines 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.

The single-phase transformer-rectifier machines provide DC current to the arc and a constant current volt-ampere characteristic, but are not as popular as three-phase transformer-rectifier welding machines for FCAW. When using a constant current power source, a special variable speed or voltage-sensing wire feeder must be used to maintain a uniform current level. 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. These machines normally have a duty cycle of 60%.

The most widely used type of power source for this process is the three-phase transformer-rectifier. These machines produce DC current for the arc, and for FCAW, most have a constant voltage volt-ampere characteristic. When using these constant voltage machines, a constant-speed wire feeder is used. 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.

Figure 11-10 — Three-phase, 650 amp solid state power source.

Many of these machines also use solid state controls for the welding. A 650 amp solid state controlled power source is shown in *Figure 11-10*. This machine will produce the flattest volt-ampere curve of the different constant voltage power sources. Most three-phase transformer-rectifier power sources are rated at a 100% duty cycle.

3.2.0 Controls

Figure 11-11 — Programmable control unit.

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 include an on-off switch, a voltage control, and often a switch to select the polarity of direct current. The voltage control can be a single knob, or it can have a tap switch for setting the voltage range and a fine-voltage control knob.

Other controls are sometimes present, such as a switch for selecting constant current (CC) or constant voltage (CV) output on combination machines, or a switch for a remote control. On 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 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, or close by, the wire feeder assembly. 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. A control box for semiautomatic or automatic welding is shown in *Figure 11-11*. There may also be switches to turn the control on and off on the wire feeder control box, and gradually feed the wire up and down.

Other controls for this process are used for special applications, especially when a programmable power source is used. An example is a timer for spot welding. Controls that produce a digital readout are popular because it is easier for concise control.

3.3.0 Wire Feeders

The wire feed motor provides the power for driving the electrode through the cable and gun to the work. There are several different wire feeding systems available. The selection of the best type of system depends on the application. Most FCAW wire feed systems are the constant speed type, which are used with constant voltage power sources. This means the wire feed speed is set before welding. The wire feed speed controls the amount of welding current. Variable speed or voltage-sensing wire feeders are used with constant current power sources. With a variable speed wire feeder, a voltage-sensing circuit maintains the desired arc length by varying the wire feed speed. Variations in the arc length increase or decrease the wire feed speed.

A wire feeder consists of an electrical motor connected to a gear box containing drive rolls. The gear box and wire feed motor shown in *Figure 11-12* have four feed rolls in the gear box. While many systems have only two, in a four-roll system, the lower two rolls drive the wire.

Because of their structure, flux-cored wires can be easily flattened. The type of drive roll used is based on the size of the tubular wire being fed. The three basic types of drive rolls are the “U” groove, “V” knurled, and “U” cogged, as shown in *Figure 11-13*. “U” groove drive rolls are only used on small diameter wires. These can be used because small diameter tubular wires are less easily flattened. “V” knurled drive rolls are most commonly used for wire sizes 1/16 in. (1.6 mm) and greater. These drive rolls are lightly knurled to prevent slipping of the wire. The “U” cogged drive rolls are used for large diameter flux-cored wires. A groove is cut into both rolls. Different gear ratios are used, depending on the wire feed speed required. *Table 11-1* shows the wire feed speeds that can be obtained from different gear ratios.

Figure 11-12 — Wire feed assembly.

Figure 11-13 — Drive roll types and applications.

Table 11-1 — Wire feed speeds obtained from different gear ratios.

	Wire Feed Speed	
Gear Ratio	In/min	(mm/s)
15:1	500-2000	212-846
37.5:1	60-1000	25-423
46:1	50-825	21-349
75:1	30-500	13-212
90:1	25-400	11-169
150:1	15-250	6-106
300:1	8-125	3-53
600:1	4-63	2-27
1200:1	2-30	1-13

Wire feed systems may be the pull, push, or push-pull type, depending on the method of application and the distance between the welding gun and the coil or spool of wire. Pull type wire feeders have the drive rolls attached to the welding gun. Most machine and automatic welding stations use this type of system, but pull type wire feeders are rarely used in semiautomatic welding. Pull wire feeders have the advantage for welding small diameter aluminum and soft non-ferrous metals with GMAW because it reduces wire feeding problems, but, since most flux-cored wires are steel, this is not an advantage for FCAW.

Figure 11-14 — Semi-automatic, solid state control wire feeder.

The push type system with the drive rolls mounted near the coil or spool of wire is the most commonly used wire feed method for semiautomatic welding (*Figure 11-14*). The wire is pulled from the coil or spool and then pushed into a flexible conduit and through the gun. The relatively large diameter wires used in FCAW are well suited to this type of system. The length of the conduit can be up to about 12 feet (3.7 m). Another advantage of this push type system is that the wire feed mechanism is not attached to the gun, which reduces the weight and makes the gun easier to handle.

Some wire feed systems contain a two-gun, two wire feeder arrangement connected to a single control box, which is connected to a single power source. Both wire feeders may be set up, and there is a switch on the control to automatically select which of the two systems will be used.

One advantage to this system is that the second wire feeder and gun can provide backup in case of breakdown, gun maintenance, or electrode change. Another advantage is that two different electrodes for different applications can be set up. For example, a GMAW electrode and gun can be set up on one schedule for welding a root pass, and a second schedule can be set up with a flux-cored wire to weld the rest of the joint with FCAW's faster deposition. This eliminates the need for two power sources or the need to change the electrode wire and gun. The liner is made of flexible metal and is available in sizes compatible with the electrode size. The liner guides the electrode wire from the wire feeder drive rolls through the cable assembly and prevents interruptions in the travel.

Heavy-duty welding guns are normally used because of the large size electrode wires typically used and the corresponding high welding current levels required. Because of the intense heat created by this process, heat shields are attached to the gun in front of the trigger to protect the welder's hand.

Both air-cooled and water-cooled guns are used for FCAW. Air-cooled guns are cooled primarily by the surrounding air, but when a shielding gas is used, this will have an additional cooling effect.

A water-cooled gun is similar to an air-cooled gun, except that ducts to permit the water to circulate around the contact tube and nozzle have been added. Water-cooled guns permit more efficient cooling of the gun. *Figure 11-15* shows a 500-ampere water-cooled gun. Water-cooled guns are preferred for many applications using 500 amperes and recommended for use with welding currents greater than 600 amperes. Welding guns are rated at the maximum current capacity for continuous operation.

Figure 11-15 — Water-cooled gun.

Air-cooled guns are lighter and easier to manipulate. *Figure 11-16* shows a 350 ampere air-cooled welding gun.

Figure 11-16 — Air-cooled gun.

Some self-shielded electrode wires require a specific minimum electrode extension to develop proper shielding, so welding guns for these electrodes have guide tubes with an insulated extension guide. This guide supports the electrode and insures a minimum electrode extension, as shown in *Figure 11-17.*

3.3.1 Machine Welding Guns

Machine and automatic welding guns use the same basic design principles and features as the semiautomatic welding guns. These guns often have very high current-carrying capacities and may also be air cooled or water-cooled. Large diameter wires up to 1/8 in. (3.2 mm) are commonly used with high amperages. Machine welding guns must be heavy duty because of the high amperages and duty cycles required, and the welding gun is mounted directly below the wire feeder. *Figure 11-18* shows a machine welding head for FCAW.

Figure 11-17 — Insulated extension guide.

If a gas-shielded wire is to be used, the gas can be supplied by a nozzle that is concentric around the electrode or by a side delivery tube, as is shown in *Figure 11-18*. The side shielding permits the welding gun to be used in deep, narrow grooves and reduces spatter buildup problems in the nozzle. Side shielding is only recommended for welding using carbon dioxide. A concentric nozzle is preferred when using argon-carbon dioxide and argon-oxygen mixtures, and a concentric nozzle provides better shielding and is sometimes recommended for CO_2 at high current levels when a large weld puddle exists.

3.4.0 Fume Extractors

Fume extractors are often used to help reduce the smoke levels produced by flux-cored electrodes. This reduces air pollution and gives better visibility. Welding guns can be equipped with a fume extractor that consists of an exhaust nozzle that encircles the gun nozzle, as shown in *Figure 11-19*. The nozzle is connected to a filter and an exhaust pump. The fume extraction nozzle should be located at a distance far enough from the arc to draw in the rising fumes without disturbing the shielding gas flow.

The major advantage of this fume extraction system is that it is always close to the point of welding. A portable fume exhaust fan cannot be positioned as close to the arc, and requires repositioning for every change in welding position.

Figure 11-18 — Automatic welding head.

The major disadvantage of the fume extractor is that it makes the gun bulkier and more difficult to manipulate. Fume extractors are generally not necessary in a welding booth that is well ventilated.

3.5.0 Shielding Gas Equipment

The shielding gas equipment used for gas-shielded flux-cored wires consists of a gas supply hose, a gas regulator, control valves, and supply hose 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 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

Figure 11-19 — Fume extractor nozzle.

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.

The purpose of a gas flow regulator is to reduce the pressure from the gas supply source and maintain a constant delivery pressure. The gas flowmeter is then used to control the flow of gas from the regulator to the welding gun. A valve at the flowmeter outlet adjusts the gas flow rate. The flowmeter is often attached to the regulator, as shown in *Figure 11-20*. Regulators and flowmeters are designated for use with specific shielding gases and should only be used with the gas for which they were designed.

Figure 11-20 — Flowmeter and regulator for carbon dioxide.

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, and is usually part of the welding gun assembly.

3.6.0 Welding Cables

The welding cables and connectors connect the power source to the welding gun and to the work. These cables are normally made of copper or aluminum with copper being the most common. The cable consists of hundreds of wires enclosed in an insulated casing of natural or synthetic rubber. The cable connecting 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 the electrode wire feeds through. For machine or automatic welding, the electrode lead is normally separate.

The cable connecting the work to the power source is called the work lead. Work leads are usually connected to the work by pincher clamps or a bolt. The size of the welding cables used depends on the output capacity of the welding machine, the duty cycle of the machine, and the distance between the welding machine and the work. Cable sizes range from the smallest at American Wire Gauge (AWG) No.8 to AWG No. 4/0 with amperage ratings of 75 amperes on up. *Table 11-2* shows recommended cable sizes for use with different welding currents and cable lengths; too small a cable may become too hot during welding.

Table 11-2 — Recommended cable sizes for different welding currents and cable lengths.

Weld Type	Weld Current	Length of Cable Circuit in Feet-Cable Size A.W.G.					
		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	4/0				
	1200	4/0	4/0				

3.7.0 Other Equipment

For machine and automatic welding, several items, such as seam followers, water circulators, and motion devices, are added to the basic equipment

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 gun through hoses that may or may not go through a valve in the welding machine. A typical water circulator is shown in *Figure 11-21*.

Figure 11-21 — Water circulator.

3.7.2 otion 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 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 are supported on the vertical face of a flat track and can be used for straight line welding. Multiple electrode welding heads can be used to obtain higher deposition rates.

Welding head manipulators may be used for longitudinal welds and, in conjunction with a rotary weld positioner, for circumferential welds. Available in many boom sizes, they 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. Oscillators can either be mechanical or electromagnetic devices.

3.7.3 Accessories

Accessory equipment for FCAW consists of items for cleaning the weld bead and cutting the electrode wire. Because of the slag coating formed, chipping hammers and wire brushes are usually required to remove the slag. A grinder is often used for final cleaning and for removing spatter. A pair of wire cutters or pliers is used to cut the end of the electrode wire between stops and starts.

4.0.0 EQUIPMENT SETUP, OPERATION, and SHUT DOWN

It is necessary for a welder to be able to set up, weld, and secure the equipment that will be used. The following is a brief overview on what materials you will need and what to look for when you are welding, followed by a short description on how to secure the welding machine.

4.1.0 Protective Clothing and Tools

The FCAW process could be a dangerous process if you do not protect yourself from the heat, radiation, and spatter. You must wear a leather coat, gloves, safety glasses, and a welding helmet.

Normally, a number 11 or 12 filter lens is required to protect your eyes from the intense arc created by this welding process.

You should also be equipped with a wire brush, wire cutters, pliers, and chipping hammer.

4.2.0 Obtaining Materials

You will need to select the proper electrode according to the base metal you will be welding. You can obtain the proper electrode type and diameter using the AWS classifications.

You may also be using a shielding gas, depending on which electrode wire you are using. Welding-grade carbon dioxide or a mixture of carbon dioxide and argon are normally used.

4.3.0 Set Up Equipment

Now that you have your electrode wire, you need to know how to install it on the welding machine.

Small diameter flux-cored electrode wires are generally spooled in the manner as solid wires used for GMAW, and can be loaded in the same manner.

Large-diameter electrode wires are usually much stiffer. Rather than being stored on spools, the large-diameter flux-cored electrode wires are rolled into coils. These wires have a surprising amount of tension and can cause serious injury if they are allowed to unwind suddenly or uncontrollably.

When removing the wire, four equally spaced bands should be used in order to completely secure the wire and prevent the coil from distorting in shape while handling.

Cut the wire between the coil and the wire feeder, and then loosen the hold down brackets, to remove the secured coil.

The wire feed rollers should then be removed from the wire feeder before mounting the new coil.

With the coil removed, advance the wire feeder until the cutoff end of the wire is released from the drive rollers. Remove the wire with a pair of pliers.

Every time a coil or spool is used or changed, the liner should be cleaned or replaced if damaged. To clean the liner, first remove the two set screws, then remove the gun from the wire feeder and pull the liner from the cable. Use a compressed air supply to purge any contaminants from the liner. Replace in the same manner.

Before adding a new coil, the contact tube and nozzle should be removed from the welding gun and examined for evidence of excessive wear damage. Replace these parts if necessary.

With the coil in place on the feeder, slip the end of the electrode through the wire feeder guides. Manually advance the wire through the wire feed guides, replace the fee rolls, then clip the bands as the wire is advanced through the system.

Some self-shielded electrode wires require a higher preheat to help decompose the flux and provide shielding gas. The welding gun for these wires was designed to maintain as much as 2 1/2 inches of stickout. The contact tube is recessed as much as 1 1/2 inches, and an insert, which acts as an insulator, is placed in the nozzle to protect the preheated wire. The length of the insert controls the amount that the contact tube is recessed into the nozzle.

Gas-shielded wires require a gas nozzle. The electrode stickout is generally between three-fourths and 1 1/2 inches.

Welding guns may be cooled by either air or water, depending on the application. When welding currents over 500 amps are used, water-cooled guns are necessary.

Due to the large amounts of smoke given off by the flux-cored process, a smoke exhaust system can be fitted to the gun, or even manufactured as part of the gun.

High current densities and production welding may require that a heat shield be attached to the gun to protect the hand from the intense heat.

Welding gun maintenance is not complicated. Periodically, the gun should be cleaned to remove spatter and dirt from inside the nozzle.

The flux-cored electrode wire is easily flattened during feeding. To prevent this from happening, the feed rollers must match the size of the wire being used.

Of the types of feed rolls available, the knurled V-groove is generally used with large-diameter electrodes, from one sixteenth to one eighth in diameter.

Medium diameter electrodes should be used with groove geared drive rolls. Normally, groove gear rolls can handle either solid or tubular wire from .045-to 7/64-inch in diameter.

Small-diameter electrodes require a concave roller with a smooth face to prevent the wire from flattening.

In most cases, the drive rollers are mounted in pairs, with two pair being a typical feeding system. The electrode wire is pushed from the wire feeder to the gun.

4.4.0 Adjust Equipment

The voltage is adjusted by turning the voltage control knob to the desired range.

To adjust the gas flow rate, stand to one side as a safety measure, open the cylinder valve of the shielding gas, and check the regulator dial to assure there is sufficient pressure. Press the button on the wire feeder, and at the same time, adjust the flowmeter.

If the wire feeder is not equipped with a purge button, set the wire feed control to zero, press the gun trigger, and then set the flowmeter for the desired gas flow rate.

Select the correct current and polarity. Direct current electrode positive is usually used for gas-shielded wires. Direct current electrode positive or negative may be used for self-shielded wires as appropriate to the work material.

To adjust the amperage setting when using a constant voltage power source, it will be necessary to start the arc by pressing the gun trigger, and then tune the wire feed speed control until the current is within the desired range. Since the current will register on the ammeter only during welding, it may be necessary to ask someone to watch the meter while you maintain the arc.

4.5.0 Perform the Weld

Flux-cored wires are sensitive to changes in voltage; it is important that the electrode stickout remain in the recommended range (Figure 11-22).

Allowing the stickout to increase reduces the amperage, while reducing the stickout will cause the amperage to increase. Since penetration is greatly influenced by welding current, you can use stickout to a limited degree to control penetration without interrupting the arc to adjust the welding machine.

The flux core of the electrode will cover the weld with a glass-like slag, which must be chipped and brushed from the weld before inspecting. Always wear eye protection when performing any welding operation.

Figure 11-22 — Different effects of voltage and current on a weld.

4.6.0 Shut Down Equipment

Shut down the welding equipment. Close the shielding gas cylinder valve. Purge the shielding gas cylinder lines. Some welding machines are equipped with a purge button. On other equipment, it may be necessary to set the wire feed to zero and press the gun trigger. Adjust the flowmeter to zero.

Turn off the power source.

Cleanup your work area

5.0.0 SHIELDING GAS and ELECTRODES

FCAW electrodes provide the filler metal to the weld puddle and shielding for the arc, but a shielding gas is required for some electrode types. The purpose of the shielding gas is to provide protection to the arc and molten weld puddle from the atmosphere. The chemical composition of the electrode wire and flux core in combination with the shielding gas will determine the weld metal composition and mechanical properties of the weld.

5.1.1 Shielding Gas

The primary purpose of a shielding gas in FCAW, as in any gas-shielded arc welding process, is to protect the arc and weld puddle from the contaminating effects of the atmosphere. If allowed to be exposed to the molten weld metal, the nitrogen and oxygen of the atmosphere can cause porosity and brittleness.

In SMAW, protection is accomplished by placing an outer coating on the electrode, which produces a gaseous shield as the coating disintegrates in the welding arc. In FCAW, the same effect is accomplished by decomposition of the electrode core, or by a combination of this and surrounding the arc area with a shielding gas supplied from an external source.

A shielding gas displaces air in the arc area. Welding is then accomplished under a blanket of shielding gas, and since the molten weld metal is exposed only to the shielding gas, the atmosphere does not contaminate it.

Oxygen, which makes up 21% of air, is a highly reactive element that, at high temperatures, combines readily with other elements in metals, and specifically in steels, to form undesirable oxides and gases. Oxygen combines with the iron in steels to form compounds that can lead to inclusions in the weld metal and lower its mechanical properties. On heating, free oxygen in the molten metal combines with the carbon of the steel to form carbon monoxide. If gas is trapped in the weld metal as it cools, it collects in pockets and causes pores in the weld deposit.

Nitrogen, which makes up 78% of air, causes the most serious problems when welding steel. When steel is molten, it can take a relatively large amount of nitrogen into solution. At room temperature, the solubility of nitrogen in steel is very low. Therefore, in cooling, nitrogen precipitates or comes out of the steel as nitrites. These nitrites cause high yield strength, tensile strength, hardness, and a pronounced decrease in the ductility and impact resistance of the steel. The loss of ductility due to the presence of iron nitrites often leads to cracking of the weld metal. Excessive amounts of nitrogen can also lead to extensive porosity in the weld deposit.

Hydrogen may come from water in the atmosphere or from moisture on surfaces welded and is harmful to welds. Hydrogen is also present in oils, paints, and some protective coverings. Even very small amounts of hydrogen in the atmosphere can produce an erratic arc. Of more importance is the effect that hydrogen has on the properties of the weld deposit. As in the case of nitrogen, steel can hold a relatively large amount of hydrogen when it is molten but, upon cooling, it has a low solubility for hydrogen. As the metal starts to solidify, it rejects the hydrogen. The hydrogen entrapped in the solidifying metal collects at small discontinuities and causes pressure stresses to occur. This pressure can lead to minute cracks in the weld metal, which can later develop into larger cracks. Hydrogen also causes defects known as "fish eyes" and underbead cracks. Underbead cracking is caused by excessive hydrogen that collects in the heat-affected zone.

Inert and active gases may be used for FCAW. Active gases, such as carbon dioxide, argon-oxygen mixtures, and argon-carbon dioxide mixtures are used for almost all applications, with carbon dioxide being the most common. Active gases are not chemically inert and can form compounds with the metals. Since almost all flux cored arc welding is done on ferrous metals, this is not a problem.

The choice of the proper shielding gas for a specific application is based on:

1. Type of metal to be welded
2. Arc characteristics and metal transfer
3. Availability
4. Cost of the gas
5. Mechanical property requirements
6. Penetration and weld bead shape

5.1.1 Carbon Dioxide

Carbon dioxide is manufactured from fuel gases that are given off by the burning of natural gas, fuel oil, or coke. It is also obtained as a by-product of calcining operation in limekilns, from the manufacturing of ammonia, and from the fermentation of alcohol. The carbon dioxide given off by the manufacturing of ammonia and the fermentation of 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 gun. The bulk system is normally only used 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, as shown in *Figure 11-23*. By weight, this is approximately 90% of the content of the cylinder. Above the liquid, it exists as a vapor gas. As carbon dioxide is drawn from the cylinder, it is replaced with carbon dioxide that vaporizes from the liquid in the cylinder; therefore, the overall pressure will be indicated by the pressure gauge. When the pressure in the cylinder has dropped to 200 psi (1.4 MPa) the cylinder

Figure 11-23 — Carbon dioxide gas cylinder.

should be replaced. 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 about 10 to 50 cubic feet per hour (4.7 to 24 liters per minute). However, a maximum discharge rate of 25 cfh (12 L/min.) is recommended when welding using a single cylinder. As the vapor pressure drops from cylinder pressure to discharge pressure through the 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 CO_2 regulator and flow meter, which interrupts the shielding gas flow. 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 cylinder and gas regulator, pressure regulator, and flow meter. *Figure 11-24* shows a manifold system used for connecting several cylinders together. Excessive flow rates can also result in drawing liquid from the cylinder.

Carbon dioxide is the most widely used shielding gas for FCAW. Most active gases cannot be used for shielding, but carbon dioxide provides several advantages for use in welding steel, such as deep penetration, low cost, and it promotes a globular transfer.

Figure 11-24 — Manifold system for CO_2.

The carbon dioxide shielding gas breaks down into components, such as carbon monoxide and oxygen. Because carbon dioxide is an oxidizing gas, deoxidizing elements are added to the core of the electrode wire to remove oxygen. The oxides formed by the deoxidizing elements float to the surface of the weld and become part of the slag covering. Some of the carbon dioxide gas will break down to carbon and oxygen. If the carbon content of the weld pool is below about .05%, carbon dioxide shielding will tend to increase the carbon content of the weld metal. Carbon, which can reduce the corrosion resistance of some stainless steels, is a problem for critical corrosion applications. Extra carbon can also reduce the toughness and ductility of some low-alloy steels. If the carbon content in the weld metal is greater than about .10%, carbon dioxide shielding will tend to reduce the carbon content. This loss of carbon can be attributed to the formation of carbon monoxide, which can be trapped in the weld as porosity deoxidizing elements in the flux core, reducing the effects of carbon monoxide formation.

5.1.2 Argon-Carbon Dioxide Mixtures

Argon and carbon dioxide are sometimes mixed for use with FCAW. A high percentage of argon gas in the mixture tends to promote a higher deposition efficiency due to creating less spatter. This mixture also creates less oxidation and lower fumes. The most commonly used argon-carbon dioxide mixture contains 75% argon and 25% carbon dioxide. This gas mixture produces a fine globular metal transfer that approaches a spray. It also reduces the amount of oxidation that occurs, compared to pure carbon dioxide. The weld deposited in an argon-carbon dioxide shield generally has higher tensile and yield strengths. Argon-carbon dioxide mixtures are often used for out-of-position welding, achieving better arc characteristics and welder appeal. This mixture also improves arc transfer on smaller diameters. Argon/CO_2 is often used on low-alloy steels and stainless steels.

Electrodes designed for use with CO_2 may cause an excessive build-up of manganese, silicon, and other deoxidizing elements if they are used with shielding gas mixtures containing a high percentage of argon, and this will have an effect on the mechanical properties of the weld.

5.1.3 Argon-oxygen mixture

Argon-oxygen mixtures containing 1 or 2% oxygen are used for some applications. Argon-oxygen mixtures tend to promote a spray transfer that reduces the amount of spatter. A major application of these mixtures is in welding stainless steels where carbon dioxide can cause corrosion problems.

5.2.0 Electrodes

The electrodes for FCAW consist of a metal sheath surrounding a core of fluxing and/or alloying compounds, as shown in *Figure 11-25.* The core of carbon steel and low-alloy electrodes contains primarily fluxing compounds. Some of the low-alloy steel electrode cores contain high amounts of alloying compounds with a low flux content. Most low-alloy steel electrodes require gas shielding.

The sheath comprises approximately 75 to 90% of the weight of the electrode. Self-shielded electrodes contain more fluxing compounds than gas shielded electrodes. The compounds contained in the electrode perform essentially the same functions as the coating of a covered electrode used in shielded metal arc welding. These functions are:

1. To form a slag coating that floats on the surface of the weld metal and protects it during solidification
2. To provide deoxidizer and scavengers which help purify and produce solid weld metal
3. To provide arc stabilizers which produce a smooth welding arc and keep spatter to a minimum
4. To add alloying elements to the weld metal which will increase the strength and improve other properties in the weld metal
5. To provide shielding gas, as gas-shielded wires require an external supply of shielding gas to supplement

Figure 11-25 — Cross section of a flux-cored wire.

Figure 11-26 — Making a flux-cored wire.

that produced by the core of the electrode

The manufacture of a flux-cored electrode is an extremely technical and precise operation requiring specially designed machinery. *Figure 11-26* shows a simplified version of the apparatus for producing tubular type cored electrodes on continuous production. A thin, narrow, flat, low-carbon steel strip passes through forming rolls, which form the strip into a U-shaped cross-section. This U-shaped steel passes through a special filling device where a measured amount of the specially formulated granular core material is added. The flux-filled U-shaped strip then flows through special closing rolls which form it into a tube and tightly compress the core materials. This tube is then pulled through draw dies to reduce its diameter and further compress the core materials. Drawing tightly seals the sheath and additionally secures the core materials inside the tube under compression, thus avoiding discontinuities in the flux. The electrode may or may not be baked during, or between, drawing operations. This depends on the type of electrode and the type of elements and compounds enclosed in the sheath.

Additional drawing operations are performed on the wire to produce various electrode diameters. Flux-cored electrode wires are commonly available in sizes ranging from .035- to 5/32-inch.

The finished electrode is wound into a continuous coil, spool, reel, or drum. These are available as 10 lb., 15 lb., or 50 lb. spools, 60 lb. (27 kg) coils, 250 or 500 lb. (113-225 kg) reels, or a 600 lb. drum. Electrode wires are generally wrapped in plastic to prevent moisture pick-up.

5.2.1 Classification

The American Welding Society (AWS) devised the classification system used for tubular wire electrodes throughout industry in the United States. There are several different specifications covering flux cored arc welding electrodes for steels as shown in *Table 11-3*.

Table 11-3 — Specifications covering flux-cored electrodes.

AWS Specification	Metal
A5.20	Carbon Steel
A5.22	Stainless Steel
A5.29	Low-alloy Steel

Table 11-4 — As-welded mechanical property requirements of carbon steel flux-cored electrodes (AWS A.5.20).

AWS Classification	Shielding Gas	Tensile Strength ksi (Mpa)	Yield Strength ksi (Mpa)	% Elongation Min in 1" (50mm)	Min Impact Strength ft-lbs @OF(J @0C)
E6XT-13	None	60(415)	48 (330)	22	Not Specified
E6XT-G	Not Specified	60 (415)	48 (330)	22	Not Specified
E6XT-GS	Not Specified	60 (415)	48 (330)	Not Specified	Not Specified
E7XT-1	CO_2	70 (480)	58 (400)	22	20 @ -20 (27 @ -18)
E7XT-1M	75-80%Ar/bal CO2	70 (480)	58 (400)	22	20 @ -20 (27 @ -18)
E7XT-2	CO_2	70 (480)	58 (400)	Not Specified	Not Specified
E7XT-2M	75-80%Ar/bal CO2	70 (480)	58 (400)	Not Specified	Not Specified
E7XT-3	None	70 (480)	58 (400)	22	Not Specified
E7XT-4	None	70 (480)	58 (400)	22	Not Specified
E7XT-5	CO_2	70 (480)	58 (400)	22	20 @ -20 (27 @ -29)
E7XT-5M	75-80%Ar/bal CO2	70 (480)	58 (400)	22	20 @ -20 (27 @ -29)
E7XT-6	None	70 (480)	58 (400)	22	20 @ -20 (27 @ -29)
E7XT-7	None	70 (480)	58 (400)	22	Not Specified
E7XT-8	None	70 (480)	58 (400)	22	20 @ -20 (27 @ -29)
E7XT-9	CO_2	70 (480)	58 (400)	22	20 @ -20 (27 @ -29)
E7XT-9M	75-80%Ar/bal CO_2	70 (480)	58 (400)	22	20 @ -20 (27 @ -29)
E7XT-10	None	70 (480)	58 (400)	Not Specified	Not Specified
E7XT-11	None	70 (480)	58 (400)	20	Not Specified
E7XT-12	CO_2	70 (480)	58 (400)	22	20 @ -20 (27 @ -29)
E7XT-12M	75-80%Ar/bal CO_2	70 (480)	58 (400)	22	20 @ -20 (27 @ -29)
E7XT-13	None	70 (480)	58 (400)	Not Specified	Not Specified
E7XT-14	None	70 (480)	58 (400)	Not Specified	Not Specified
E7XT-G	Not Specified	70 (480)	Not Specified	22	Not Specified
E7XT-GS	Not Specified	70 (480)	Not Specified	Not Specified	Not Specified

Carbon and low-alloy steels are classified on the basis of the following items:

1. Mechanical properties of the weld metal
2. Position of welding
3. Chemical composition of the weld metal
4. Type of welding current
5. Whether or not CO_2 shielding gas is used

An example of a carbon-steel electrode classification is E70T-4 where:

1. The "E" indicates an electrode.
2. The second digit indicates the minimum tensile strength in units of 10,000 psi (69 Mpa). *Table 11-4* shows the mechanical property requirements for carbon steel electrodes.
3. The third digit indicates the welding position. A "0" indicates flat and horizontal positions only, and a "1" indicates all positions.
4. The "T" stands for a tubular (flux-cored) wire classification.
5. The suffix "4" gives the performance and usability capabilities as shown in *Table 11-5*.

When a "G" classification is used, no specific performance requirements are indicated. This classification is intended for electrodes not covered by another classification. The chemical composition requirements of the deposited weld metal for carbon steel electrodes are shown in *Table 11-6.*

Table 11-7 shows the mechanical properties requirements of low-alloy flux-cored electrodes. Single-pass electrodes do not have chemical composition requirements because checking the chemistry of undiluted weld metal does not give the true results of normal single-pass weld chemistry.

Table 11-5 —Performance and usability characteristics of carbon steel flux-cored electrodes (AWS A5.20).

AWS Classification	Welding Current	Shielding Gas	Single or Multiple Pass
EXXT-1	DCEP	CO_2	Multiple
EXXT-2	DCEP	CO_2	Single
EXXT-3	DCEP	None	Single
EXXT-4	DCEP	None	Multiple
EXXT-5 EXXT-	DCEP	CO_2	Multiple
6	DCEP	None	Multiple
EXXT-7	DCEN	None	Multiple
EXXT-8	DCEN	None	Multiple
EXXT-9	DCEN	None	Multiple
EXXT-10	DCEN	None	Single
EXXT-11	DCEN	None	Multiple
EXXT-12	DCEN	None	Multiple
EXXT-13	DCEN	CO_2	Single
EXXT-14	DCEN	None	Single
EXXT-G	Not Specified	Not Specified	Multiple
EXXT-GS	Not Specified	Not Specified	Single

Table 11-6 — Chemical composition requirements of carbon-steel flux-cored electrodes (AWS A5.20).

AWS Classification	UNS Number	Chemical Composition (%max.) C	Mn	Si	S	P	Cr	Ni	Mo	V	Al	Cu
E7XT-1 E7XT-1M	W07601											
E7XT-5 E7XT-5M	W07605	0.18	1.75	0.90	0.03	0.03	0.20	0.50	0.30	0.08		0.35
E7XT-9 E7XT-9M	W07609											
E7XT-4	W07604											
E7XT-6	W07606											
E7XT-7	W07607	(b)	1.75	0.60	0.03	0.03	0.20	0.50	0.30	0.08	1.8	0.35
E7XT-8	W07608											
E7XT-11	W07611											
EXXT-G		(b)	1.75	0.90	0.03	0.03	0.20	0.50	0.30	0.08	1.8	0.35
E7XT-12 E7XT-12M	W07612	0.15	1.75	0.90	0.03	0.03	0.20	0.50	0.30	0.08	1.8	0.35
E6XT-13	W06613											
E7XT-2 E7XT-2M	W07602											
EXXT-3	W07603											
EXXT-10	W07610	Not Specified[c]										
E7XT-13	W07613											
E7XT-14	W07614											
EXXT-GS												

a. Chemical compositions are based on the analysis of the deposited weld metal.
b. No requirement, but the amount of carbon shall be determined and reported.
c. Since these are single-pass welds, the analysis of the undiluted weld metal is not meaningful.

Table 11-7 — Mechanical property requirements of low-alloy flux-cored electrodes (AWS A5.29).

AWS	Tensile Strength Range		Yield Strength @0.2 Offset Min		Percent Elongation in 2 in (51 mm)
Classification	ksi	MPa	ksi	MPa	Min
E6XTX-X	60-80	410-550	50	340	22
E7XTX-X	70-90	490-620	58	400	20
E8XTX-X	80-100	550-690	68	470	19
E9XTX-X	90-110	620-760	78	540	17
E10XTX-X	100-120	690-830	88	610	16
E10XTX-K9 -K9M	(b)	(b)	82-97	560-670	18
E11XTX-X	110-130	760-900	98	680	15
E12XTX-X	120-140	830-970	108	750	14
EXXXTX-Ga EXXTG-Xa EXXTG-Ga	Properties as agreed between supplier and purchaser				

a. Placement of a "G" in this designation indicates those properties as agreed upon between the supplier and purchaser.
Other properties are dictated by the digit(s) or suffix replacing the X. Variations used in this specification include the following:
(1) EXXTX-G-Alloy requirements are as agreed upon. The mechanical properties and slag system are as indicated by the digits used.
(2) EXXTG-X-The slag system and shielding gas are as agreed upon. Mechanical properties and alloy requirements conform to those indicated by the digits.
(3) EXXTG-G-The slag system, shielding gas, and alloy requirements are as agreed upon. Mechanical properties conform to those indicated by the digits.

b. For this classification, E10XTX-K9, K9M, the "10" approximates the tensile strength, not a requirement.

The classification of low-alloy steel electrodes is similar to the classification of carbon-steel electrodes. An example of a low-alloy steel classification is ES1T1-Ni2 where:

1. The "E" indicates an electrode.
2. The second digit indicates the minimum tensile strength in units of 10,000 psi (69 Mpa). The mechanical property requirements for low-alloy steel electrodes are shown in *Table 11-8*.
3. The third digit indicates the welding position capabilities of the electrode. A "0" indicates flat and horizontal positions only, and a "1" indicates all positions.
4. The "T" stands for a tubular (flux-cored) wire classification.
5. The fifth digit describes the usability and performance characteristics of the electrode. These digits are the same as used in carbon steel electrode classification but only EXXT1-X, EXXT4-X, EXXT5-X and EXXTS-X are used with low-alloy steel flux-cored electrode classifications.
6. The suffix tells the chemical composition of the deposited weld metal as shown in *Table 11-9*.

The classification system for stainless steel electrodes is based on the chemical composition of the weld metal and the type of shielding to be used during welding. An example of a stainless steel electrode classification is E30ST-1 where:

1. The "E" indicates an electrode.
2. The digits between the "E" and the "T" indicate the chemical composition of the weld as shown in *Table 11-10*.
3. The 'T' stands for a tubular (flux-cored) wire classification.
4. The suffix indicates the type of shielding to be used as shown in *Table 11-11*.

Table 11-8 — Impact requirements for low-alloy flux-cored electrodes (AWS A5.29)

Classifications	Condition [(a)]	Minimum Impact Strength
EBXT1-A 1 ,-Ai M	PWHT	Not Required
E7XT5-A 1, -A 1 M	PWHT	20 ft·lbf @ -20°F (27 J @ -29°C)
EBXT1-B1, -B1M	PWHT	Not Required
EBXT1-B1L, -B1LM	PWHT	Not Required
EBXT1-B2, -B2M	PWHT	Not Required
EBXT5-B2, -B2M	PWHT	Not Required
EBXT1-B2H, -B2HM	PWHT	Not Required
EBXT1-B2L, -B2LM	PWHT	Not Required
EBXT5-B2L, -B2LM	PWHT	Not Required
EBXT5-B6, -B6M	PWHT	Not Required
EBXT5-B6L, -B6LM	PWHT	Not Required
EBXT5-BB, -BBM	PWHT	Not Required
EBXT5-BBL, -BBLM	PWHT	Not Required
E9XT1-B3, -B3M	PWHT	Not Required
E9XT5-B3, -B3M	PWHT	Not Required
E10XT1-B3, -B3M	PWHT	Not Required
E9XT1-B3L, -B3LM	PWHT	Not Required
E9XT1-B3H, -B3HM	PWHT	Not Required
E6XT1-Ni1, -Ni1M	AW	20 ft·lbf @ -20°F (27 J @ -29°C)
E7XT6-Ni1	AW	20 ft·lbf @ -20°F (27 J @ -29°C)
E7XTB-Ni1	AW	20 ft·lbf @ -20°F (27 J @ -29°C)
EBXT1-Ni1, -Ni1 M E9XTS-	AW	20 ft·lbf @ -20°F (27 J @ -29°C)
N11, -Ni1 M E7XTB-Ni2	PWHT	20 ft·lbf @ -60°F (27 J @ -51°C)
EBXTB-Ni2 EBXT1-	AW	20 ft·lbf @ -20°F (27 J @ -29°C)
Ni2, -Ni2M	AW	20 ft·lbf @ -20°F (27 J @ -29°C)
EBXT5-Ni2([b]), -Ni2M([b] E9XT1-	AW	20 ft·lbf @ -40F (27 J @ -40°C)
Ni2, -Ni2M	PWHT	20 ft·lbf @ -75°F (27 J @ -60°C)
EBXT5-Ni3([b)], -Ni3M([b])	AW	20 ft·lbf @ -40°F (27 J @ -40°C)
EBXT11-Ni3	PWHT	20 ft·lbf @ -100°F (27 J @ -73°C)
E9XT5-Ni3([b]), -Ni3M([b])	AW	20 ft·lbf @ 0°F (27 J @ -18°C)
E9XT1-D1, -D1M	PWHT	20 ft·lbf @ -100°F (27 J @ -73°C)
E9XT5-D2, -D2M	AW	20 ft·lbf @ -40°F (27 J @ -40°C)
E10XT5-D2, -D2M	PWHT	20 ft·lbf @ -60°F (27 J @ -51°C)
E9XT1-D3, -D3M	PWHT	20 ft·lbf @ -40°F (27 J @ -40°C)
EBXTS-K1, -K1M	AW	20 ft·lbf @ -20°F (27 J @ -29°C)
E7XT7-K2	AW	20 ft·lbf @ -40°F (27 J @ -40C)
E7XT4-K2 E7XTB-	AW	20 ft·lbf @ -20°F (27 J @ -29°C)
K2 EBXT1-K2, -	AW	20 ft·lbf @ 0°F (27 J @ -18°C)
K2M E9XT1-K2, -	AW	20 ft·lbf @ -20°F (27 J @ -29°C)
K2M EBXT5-K2, -	AW	20 ft·lbf @ -20°F (27 J @ -29°C)
K2M E7XT11-K2	AW	20 ft·lbf @ 0°F (27 J @ -18°C)
E9XT5-K2, -K2M	AW	20 ft·lbf @ -20°F (27 J @ -29°C)
E10XT1-K3, -K3M	AW	20 ft·lbf @ +32°F (27 J @ 0°C)
E11 XT1-K3, -K3M	AW	20 ft·lbf @ -60°F (27 J @ -51°C)
E10XT5-K3, -K3M	AW	20 ft·lbf @ 0°F (27 J @ -18°C)
E11 XT5-K3, -K3M	AW	20 ft·lbf @ 0°F (27 J @ -18°C)
E 11 XT1-K4, -K4M	AW	20 ft·lbf @ -60°F (27 J @ -51°C)
E11XT5-K4, -K4M	AW	20 ft·lbf @ -60°F (27 J @ -51°C)
E12XT5-K4, -K4M	AW	20 ft lbf @ 0°F (27 J @ -18°C)
E12XT1-K5, -K5M	AW	20 ft·lbf @ -60°F (27 J @ -51°C)
E7XT5-K6, -K6M	AW	20 ft·lbf @ -60°F (27 J @ -51°C)
E6XTB-K6	AW	Not Required
E7XTB-K6 E10XT1-	AW	20 ft·lbf @ -75°F (27 J @ -60°C)
K7, -K7M E9XTB-KB	AW	20 ft·lbf @ -20°F (27 J @ -29°C)
E10XT1-K9, -K9M	AW	20 ft·lbf @ -20°F (27 J @ -29°C)
EBXT1-W2, -W2M	AW	20 ft·lbf@ -60°F (27 J @ -51°C)
EXXXTX-G EXXXTG-	AW	20 ft·lbf @ -20°F (27 J @ -29°C)
G EXXXTG-X	AW	35 ft·lbf @ -60°F (47 J @ -51°C)
	AW	20 ft·lbf @ -20°F (27 J @ -29°C)
	Not Specified[(c)]	Not Specified[c]

a. AW= As welded
PWHT = Postweld heat treated in accordance with AWS 5.29 Specification.
b. PWHT temperatures in excess 1150°F (620°C) will decrease the impact value.
c. See Table 11-7, Note a

Table 11-9 — Chemical composition requirements for low-alloy flux-cored electrodes (AWS A5.29).

AWS Classification	UNS Number	C	Mn	P	S	Si	Ni	Cr	Mo	V	A1[b]	Cu
						Chemical Composition Weight-Percent[a]						
						Carbon-Molybdenum Steel Electrodes						
E7XT5-A1-A1M	W17035	0.12	1.25	0.03	0.03	0.80			0.40-0.65			
ESXT1-A1-A1M	W17031											
						Chromium-Molybdenum Steel Electrodes						
ESXT1-B1-B1M	W51031	0.05-0.12	1.25	0.03	0.03	0.80		0.40-0.65	0.40-0.65			
ESXT1-B1L-B1LM	W51131	0.05	1.25	0.03	0.03	0.80		0.40-0.65	0.40-0.65			
ESXT1-B2-B2M	W52031	0.05-0.12	1.25	0.03	0.03	0.80		1.00-1.50	0.40-0.65			
ESXT5-B2-B2M	W52035											
ESXT1-B2L-B2LM	W52131	0.05	1.25	0.03	0.03	0.80		1.00-1.50	0.40-0.65			
ESXT5-B2L-B2LM	W52135											
ESXT1-B2H-B2HM	W52231	0.10-0.15	1.25	0.03	0.03	0.80		1.00-1.50	0.40-0.65			
E9XT1-B3-B3M	W53031											
E9XT5-B3-B3M	W53035	0.05-0.12	1.25	0.03	0.03	0.80		2.00-2.50	0.90-1.20			
E10XT1-B3-B3M	W53031											
E9XT1-B3L-B3LM	W53131	0.05	1.25	0.03	0.03	0.80		2.00-2.50	0.90-1.20			
E9XT1-B3H-B3HM	W53231	0.10-0.15	1.25	0.03	0.03	0.80		2.00-2.50	0.90-1.20			
ESXT5-B6-B6M	W50231	0.05-0.12	1.25	0.04	0.03	1.0	0.40	4.0-6.0	0.45-0.65			0.50
ESXT5-B6L-B6LM	W50230	0.05	1.25	0.04	0.03	1.0	0.40	4.0-6.0	0.45-0.65			0.50
ESXT5-BS-BSM	W50431	0.05-0.12	1.25	0.04	0.03	1.0	0.40	8.0-10.5	0.85-1.20			0.50
ESXT5-BSL-BSLM	W50430	0.05	1.25	0.03	0.03	1.0	0.40	8.0-10.5	0.85-1.20			0.50
						Nickel-Steel Electrodes						
E7XTS-Ni1 E7XT6- Ni1 E6XT1-Ni1-Ni1M	W21038 W21038 W21031	0.12	1.50	0.03	0.03	0.80	0.80-1.10	0.15	0.35	0.05	1.8	
ESXT1-Ni1-Ni1M	W21031	0.12	1.50	0.03	0.03	0.80	0.80-1.10	0.15	0.35	0.05		
ESXT5-Ni1 -Ni1M	W21035											
ESXT1-Ni2 -Ni2M	W22031											
ESXT5-Ni2 -Ni2M	W22035	0.12	1.50	0.03	0.03	0.80	1.75-2.75					
E9XT1-Ni2 -Ni2M	W22031											
E7XTS-Ni2	W22038	0.12	1.50	0.03	0.03	0.80	1.75-2.75				1.8	
ESXTS-Ni2	W22038											
ESXT5-Ni3 -Ni3M	W23035	0.12	1.50	0.03	0.03	0.80	2.75-3.75					
E9XT5-Ni3 -Ni3M	W23035	0.12	1.50	0.03	0.03	0.80	2.75-3.75					
ESXT11-Ni3	W23039	0.12	1.50	0.03	0.03	0.80	2.75-3.75				1.8	
						Manganese-Molybdenum Steel Electrodes						
E9XT1-01 -01M	W19131	0.12	1.25-2.00	0.03	0.03	0.80			0.25-0.65			
E9XT5-02 -02M	W19235	0.15	1.65-2.25	0.03	0.03	0.80			0.25-0.55			
E10XT5-02 -02M	W19235											
E9XT1-03 -03M	W19331	0.12	1.00-1.75	0.03	0.03	0.80			0.40-0.65			
						All Other Low-Alloy Steel Electrodes						
ESXT5-K1, K1M	W21135	0.15	0.80-1.40	0.03	0.03	0.80	0.80-1.10	0.15	0.20-0.65	0.05		
E7XT4-K2	W21234											
E7XT7-K2	W21237	0.15	0.50-1.75	0.03	0.03	0.80	1.00-2.00	0.15	0.35	0.05	1.8	
E71TS-K2	W2123S											
E7XT11-K2	W21239											
ESXT1-K2 -K2M	W21231											
E9XT1-K2 -K2M	W21231	0.15	0.50-1.75	0.03	0.03	0.80	1.00-2.00	0.15	0.35	0.05		
ESXT5-K2 -K2M	W21235											
E9XT5-K2 -K2M	W21235											
E10XT1-K3 -K3M	W21331											
E11XT1-K3 -K3M	W21331	0.15	0.75-2.25	0.03	0.03	0.80	1.25-2.80	0.15	0.25-0.65	0.05		
E10XT5-K3 -K3M	W21335											
E11XT5-K3 -K3M	W21335											
E11XT1-K4 -K4M	W22231											
E11XT5-K4 -K4M	W22235	0.15	1.20-2.25	0.03	0.03	0.80	1.75-2.60	0.20-0.60	0.20-0.65	0.03		
E12XT5-K4 -K4M	W22235											
E12XT1-K5 -K5M	W21531	0.010-0.25	0.60-1.60	0.03	0.03	0.80	0.75-2.00	0.20-0.70	0.15-0.55	0.05		
E6XTS-K6	W21048	0.15	0.50-1.50	0.03	0.03	0.80	0.40-1.00	0.20	0.15	0.05	1.8	
E7XTS-K6	W21048											
E7XT5-K6 -K6M	W21045	0.15	0.50-1.50	0.03	0.03	0.80	0.40-1.00	0.20	0.15	0.05		
E10XT1-K7 -K7M	W22051	0.15	1.00-1.75	0.03	0.03	0.80	2.00-2.75					
E9XTS-KS	W21438	0.15	1.00-2.00	0.03	0.03	0.40	0.50-1.50	0.20	0.20	0.05	1.8	
E10XT1-K9 -K9M	W23230	0.07	0.50-1.50	0.15	0.15	0.80	1.30-3.75	0.20	0.50	0.05		0.06
ESXT1-W2 -W2M	W21031	0.12	0.50-1.30	0.03	0.03	0.35-0.80	0.40-0.80	0.45-0.70				0.30-0.75
EXXTX-G			1.75[c]	0.03	0.03	0.80[c]	0.50[c]	0.30[c]	0.20[c]	0.10[c]	0.8[c]	

a. Single values are maximum unless otherwise noted.
b. For self-shielded electrodes only.
c. In order to meet the alloy requirements of the G group, the undiluted weld metal shall have the minimum of at least one of the elements listed in this table. Shielding gas, slag system, and mechanical properties are dictated by the digit(s) replacing XIs).

Table 11-10 — Undiluted weld metal composition requirements for stainless steel electrodes (AWS A5.22).

		Chemical Composition Weight-Percent[a]										
AWS Classification[b]	**UNS Number[c]**	**C**	**Cr**	**Ni**	**Mo**	**Cb(Nb) +Ta**	**Mn**	**Si**	**P**	**S**	**N**	**Cu**
E307TX-X	W30731	013	18.0-20.5	9.0-10.5	0.5-1.5		3.30-4.75	1.0	0.04	0.03		0.5
E308TX-X	W30831	0.08	18.0-21.0	9.0-11.0	0.5		0.5-2.5	1.0	0.04	0.03		0.5
E308LTX-X	W30835	0.04	18.0-21.0	9.0-11.0	0.5		0.5-2.5	1.0	0.04	0.03		0.5
E308HTX-X	W30831	0.04-0.08	18.0-21.0	9.0-11.0	0.5		0.5-2.5	1.0	0.04	0.03		0.5
E308MoTX-X	W30832	0.08	18.0-21.0	9.0-11.0	2.0-3.0		0.5-2.5	1.0	0.04	0.03		0.5
E308LMoTX-X	W30838	0.04	18.0-21.0	9.0-12.0	2.0-3.0		0.5-2.5	1.0	0.04	0.03		0.5
E309TX-X	W30931	0.10	22.0-25.0	12.0-14.0	0.5		0.5-2.5	1.0	0.04	0.03		0.5
E309LCbTX-X	W30932	0.04	22.0-25.0	12.0-14.0	0.5	0.70-1.00	0.5-2.5	1.0	0.04	0.03		0.5
E309LTX-X	W30935	0.04	22.0-25.0	12.0-14.0	0.5		0.5-2.5	1.0	0.04	0.03		0.5
E309MoTX-X	W30939	0.12	21.0-25.0	12.0-16.0	2.0-3.0		0.5-2.5	1.0	0.04	0.03		0.5
E309LMoTX-X	W30938	0.04	21.0-25.0	12.0-16.0	2.0-3.0		0.5-2.5	1.0	0.04	0.03		0.5
E309LNiMoTX-X	W30936	0.04	20.5-23.5	15.0-17.0	2.5-3.5		0.5-2.5	1.0	0.04	0.03		0.5
E310TX-X	W31031	0.20	25.0-28.0	20.0-22.5	0.5		1.0-2.5	1.0	0.03	0.03		0.5
E312TX-X	W31331	0.15	28.0-32.0	8.0-10.5	0.5		0.5-2.5	1.0	0.04	0.03		0.5
E316TX-X	W31631	0.08	17.0-20.0	11.0-14.0	2.0-3.0		0.5-2.5	1.0	0.04	0.03		0.5
E316LTX-X	W31635	0.04	17.0-20.0	11.0-14.0	2.0-3.0		0.5-2.5	1.0	0.04	0.03		0.5
E317LTX-X	W31735	0.04	18.0-21.0	12.0-14.0	3.0-4.0		0.5-2.5	1.0	0.04	0.03		0.5
E347TX-X	W34731	0.08	18.0-21.0	9.0-11.0	0.5	8 x C min. 1.0 max.	0.5-2.5	1.0	0.04	0.03		0.5
E409TX-X[d]	W40931	0.10	10.5-13.5	0.60	0.5		0.80	1.0	0.04	0.03		0.5
E410TX-X	W41031	0.12	11.0-13.5	0.60	0.5		1.2	1.0	0.04	0.03		0.5
E410NiMoTX-X	W41036	0.06	11.0-12.5	4.0-5.0	0.40-0.70		1.0	1.0	0.04	0.03		0.5
E410NiTiTX-X[d]	W41038	0.04	11.0-12.0	3.6-4.5	0.5		0.70	0.50	0.03	0.03		0.5
E430TX-X	W43031	0.10	15.0-18.0	0.60	0.5		1.2	1.0	0.04	0.03		0.5
E502TX-X	W50231	0.10	4.0-6.0	0.40	0.45-0.65		1.2	1.0	0.04	0.03		0.5
E505TX-X	W50431	0.10	8.0-10.5	0.40	0.85-1.20		1.2	1.0	0.04	0.03		0.5
E307T0-3	W30733	0.13	19.5-22.0	9.0-10.5	0.5-1.5		3.30-4.75	1.0	0.04	0.03		0.5
E308T0-3	W30833	0.08	19.5-22.0	9.0-11.0	0.5		0.5-2.5	1.0	0.04	0.03		0.5
E308LT0-3	W30837	0.03	19.5-22.0	9.0-11.0	0.5		0.5-2.5	1.0	0.04	0.03		0.5
E308HT0-3	W30833	0.04-0.08	19.5-22.0	9.0-11.0	0.5		0.5-2.5	1.0	0.04	0.03		0.5
E308MoT0-3	W30839	0.08	18.0-21.0	9.0-11.0	2.0-3.0		0.5-2.5	1.0	0.04	0.03		0.5
E308LMoT0-3	W30838	0.03	18.0-21.0	9.0-12.0	2.0-3.0		0.5-2.5	1.0	0.04	0.03		0.5
E308HMoT0-3	W30830	0.07-0.12	19.0-21.5	9.0-10.7	1.8-2.4		1.25-2.25	0.25-0.80	0.04	0.03		0.5
E309T0-3	W30933	0.10	23.0-25.5	12.0-14.0	0.5		0.5-2.5	1.0	0.04	0.03		0.5
E309LT0-3	W30937	0.03	23.0-25.5	12.0-14.0	0.5		0.5-2.5	1.0	0.04	0.03		0.5
E309LCbT0-3	W30934	0.03	23.0-25.5	12.0-14.0	0.5	0.70-1.00	0.5-2.5	1.0	0.04	0.03		0.5
E309MoT0-3	W30939	0.12	21.0-25.0	12.0-16.0	2.0-3.0		0.5-2.5	1.0	0.04	0.03		0.5
E309LMoT0-3	W30938	0.04	21.0-25.0	12.0-16.0	2.0-3.0		0.5-2.5	1.0	0.04	0.03		0.5
E310T0-3	W31031	0.20	25.0-28.0	20.0-22.5	0.5		1.0-2.5	1.0	0.03	0.03		0.5
E312T0-3	W31231	0.15	28.0-32.0	8.0-10.5	0.5		0.5-2.5	1.0	0.04	0.03		0.5
E316T0-3	W31633	0.08	18.0-20.5	11.0-14.0	2.0-3.0		0.5-2.5	1.0	0.04	0.03		0.5
E316LT0-3	W31637	0.03	18.0-20.5	11.0-14.0	2.0-3.0		0.5-2.5	1.0	0.04	0.03		0.5
E316LKT0-3[e]	W31630	0.04	17.0-20.0	11.0-14.0	2.0-3.0		0.5-2.5	1.0	0.04	0.03		0.5
E317LT0-3	W31737	0.03	18.5-21.0	13.0-15.0	3.0-4.0		0.5-2.5	1.0	0.04	0.03		0.5
E347T0-3	W34733	0.08	19.0-21.5	9.0-11.0	0.5	8 x C min. 1.0 max.	0.5-2.5	1.0	0.04	0.03		0.5
E409T0-3[d]	W40931	0.10	10.5-13.5	0.60	0.5		0.80	1.0	0.04	0.03		0.5
E410T0-3	W41031	0.12	11.0-13.5	0.60	0.5		1.0	1.0	0.04	0.03		0.5
E410NiMoT0-3	W41036	0.06	11.0-12.5	4.0-5.0	0.40-0.70		1.0	1.0	0.04	0.03		0.5
E410NiTiT0-3[d]	W41038	0.04	11.0-12.0	3.6-4.5	0.5		0.70	0.50	0.03	0.03		0.5
E430T0-3	W43031	0.10	15.0-18.0	0.60	0.5		1.0	1.0	0.04	0.03		0.5
E2209T0-X	W39239	0.04	21.0-24.0	7.5-10.0	2.5-4.0		0.5-2.0	1.0	0.04	0.03	0.80-2.0	0.5
E2553T0-X	W39553	0.04	24.0-27.0	8.5-10.5	2.9-3.9		0.5-1.5	0.75	0.04	0.03	0.10-0.20	1.5-2.5
EXXXTX-G			Not Specified									

a. Single values shown are maximum.
b. In this table, the "X" following the "T" refers to the position of welding (1 for all-position operation or 0 for flat or horizontal operation) and the "X" following the dash refers to the shielding medium (-1 or -4).
c. ASTM/SAE Unified Number System for Metals and Alloys.

d. Titanium - 10 x C min., 1.5% max.
e. This alloy is designed for cryogenic applications.

Table 11-11 — Performance and usability characteristics for stainless steel flux-cored electrodes.

AWS Classification	External Shielding Gas	Welding Polarity
EXXXT-1	CO_2	DCEP
EXXXT-3	None (Self-shielded)	DCEP
EXXXT-4	75-80% Argon/remainder CO_2	DCEP
EXXXT-G	Not Specified	Not Specified

5.2.2 Electrode Selection

The selection of the proper electrode for an application is based on the type of metal to be welded and the specific chemical and mechanical properties required of the joint. Identification of the base metal is required to select an electrode. If the type of metal is not known, tests must be made based on visual, magnetic, chisel, flame, fracture, spark, or chemistry tests.

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

1. Base Metal Strength Properties — This is done by choosing an electrode wire to match the tensile or yield strength of a metal. This is usually one of the most important criteria for selecting a filler metal to be used on low-carbon and many low-alloy steels.
2. Base Metal Composition — The chemical composition of the metal to be welded should be known. Closely matching the filler and base metal com positions is important when corrosion resistance and creep resistance are needed. The filler metals for welding stainless steels and alloy steels are usually chosen based on matching chemical compositions.
3. Welding Position — Flux-cored electrodes are designed to be used in specific positions. Wire diameter is the major factor limiting the position in which an electrode can be used. All-position electrodes are available only in the smaller sizes. Flat and horizontal-position-only electrodes may have very similar compositions but are available in all sizes or the larger sizes that cannot be easily used for vertical and overhead welding. Electrodes should be selected to match the welding position.
4. Welding Current — Flux-cored electrodes are designed to operate on either direct current electrode negative or direct current electrode positive. Electrodes operating on DCEN generally give lighter penetration and higher deposition rates. Electrodes operating on DCEP generally provide deeper penetration.
5. Joint Design and Fit-up — Electrodes should be chosen according to their penetration characteristics. Gas-shielded flux-cored wires produce deeper penetration than self-shielding wires. This can have an effect on the joint design used.

6. Thickness and Shape of Base Metal — Weldments may include thick sections or complex shapes that may require maximum ductility to avoid weld cracking. Electrodes that give the best ductility should be used for these applications.
7. Service Conditions and/or Specifications — For weldments subject to severe conditions, such as low temperature, high temperature, or shock loading, an electrode that matches the ductility and impact strength of the steel should be selected.
8. Production Efficiency and Job Conditions — Large-diameter electrodes should be used, if possible, to give higher deposition rates.

Flux-cored electrodes for carbon and low-alloy steels are each designed for specific applications based on the composition of the flux core of the wire. Each suffix used indicates a general grouping of electrodes that have similar flux components and usability characteristics.

T-I electrodes are single- or multiple-pass electrodes. They operate on DCEP and require gas shielding. They produce a flat to slightly convex weld bead with a moderate slag coating. T-I electrodes produce a fine globular transfer and low spatter levels. Welds produced with T-1 electrodes have good mechanical properties.

T-2 electrodes operate on DCEP and also require gas shielding. These electrodes are similar to T-I types, but are designed to weld over rust and scale. They are for singlepass welding only because of their high silicon and manganese contents.

T-3 electrodes are self-shielding wires using DCEP for single-pass welding operations. These electrodes produce a fine globular transfer, and are designed for welding sheet metal at high welding speeds.

T-4 electrodes are self-shielding wires using DCEP for single- or multiple-pass operation. These electrodes produce a globular metal transfer and light penetration for joints with poor fit-up. Desulfurizing elements are contained in the flux core to help prevent weld cracking.

T-5 electrodes can be used to weld higher carbon steels, or for joining low-alloy steels to carbon steels because of cleaner welds and lower hydrogen levels.

T-6 electrodes are self-shielded electrodes for single- or multiple-pass welding using DCEP. A fine globular transfer and deep penetration characterize these electrodes. The slag coating has good deep-groove removal characteristics and produces good low temperature impact properties.

T-7 electrodes are self-shielded electrodes that operate on DCEN for single- or multiple-pass welding. The larger sizes of this type of electrode are designed to produce high deposition rates. The smaller sizes are used for all-position welding. The slag coating desulfurizes the weld metal to a very low level that helps prevent cracking.

T-8 electrodes are self-shielding electrodes for single- or multiple- pass welding that operate on DCEN. The slag system is designed to allow all-position welding. The slag also desulfurizes the weld metal and produces good low temperature impact properties.

T-10 electrodes are self-shielded, single-pass electrodes that operate on DCEN. These electrodes are used for making welds in the flat and horizontal positions at high travel speeds.

T-11 electrodes are self-shielded electrodes that operate on DCEN for single- and multiple-pass welding. These are general-purpose electrodes for all-position welding at moderate travel speeds. They produce a fine globular transfer.

T-G electrodes are for multiple-pass welding not covered by another classification.

T-GS electrodes are single-pass electrodes not covered by another classification. The operating conditions and characteristics are not defined for the T-G and the T-GS electrodes.

5.2.3 Conformance and Approvals

Flux cored arc welding electrodes must conform to specifications, or be approved by code-making organizations for many FCAW applications. Some of the code-making organizations that issue specifications or approvals are the American Welding Society (AWS), the American Bureau of Shipping (ABS), and other state and federal highway and military organizations.

The American Welding Society provides specifications for flux-cored wire electrodes. Electrodes must meet specific requirements in order to conform to a particular 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 covered by that code. These organizations send inspectors to witness the welding and testing, as well as to approve the classification of the flux-cored electrodes.

To conform to the AWS specifications for carbon- and low-alloy steel filler metals, the electrodes must produce a weld deposit that meets the specific mechanical and chemical requirements. For 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 electrodes.

Test your Knowledge (Select the Correct Response)

3. For what wire size is the knurled V-groove drive rolls most commonly used?

    A. 1/32 and smaller
    B. 1/16 and smaller
    C. 1/32 and larger
    D. 1/16 and larger

4. **(True or False)** Electrodes are designed to be used in specific positions.

    A. True
    B. False

6.0.0 WELDING APPLICATIONS

Flux cored arc welding has gained popularity for a wide variety of applications. FCAW has replaced SMAW for some applications. One of the major advantages of the process is the high deposition rates obtained when compared to the manual arc welding processes. FCAW deposition rates are also generally higher than those obtained from gas metal arc welding. Because FCAW is a semiautomatic process, higher productivity can be obtained compared to SMAW. This process also lends itself easily to machine and automatic welding. Because of the versatility of FCAW, it has obtained wide application in shop fabrication, maintenance, and field erection work.

Each of the two variations of FCAW has their advantages, but the areas of application of the two variations often overlap. The method of welding used depends on the joint design, fit-up, availability of electrodes, and mechanical property requirements of the welded joints.

The self-shielding electrode wire variation can often be used for applications that can be done by SMAW. This is especially true when welding in locations where compressed gas cylinders are difficult to handle.

Gas-shielded flux-cored wires are used for many applications that compete with GMAW. There are many different applications possible but the most common ones are discussed below.

6.1.0 Industries

FCAW is the welding process of choice in a number of civilian industries because it is versatile, has high deposition rates, and is user friendly.

6.1.1 Structures

One of the most important applications of FCAW is in the structural fabrication industry. This industry uses a wide variety of low-carbon and low-alloy steels in many different thicknesses. Welding is done in the shop and in the field, and FCAW is readily adaptable to both types of wires. The major advantages of this process in the structural industry are the high deposition rates, high production rates, deep penetrating characteristics, and the adaptability of the process for field erection welding. Because a large percentage of the welds made in structural work are fillets, FCAW is widely used for making large single-pass fillet welds. Many of these welds would require multiple passes using GMAW and SMAW.

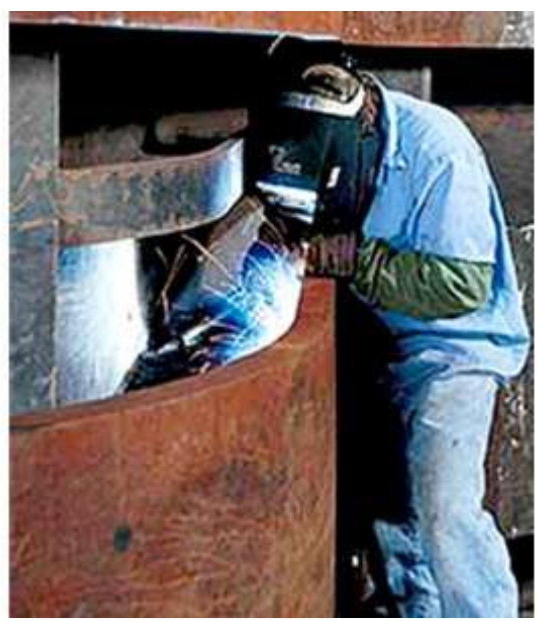

Figure 11-27 — Flux cored arc welding of structures.

Gas-shielded flux-cored wires have replaced SMAW and GMAW for many shop applications. FCAW is widely used for welding the thicker structural members where the higher deposition rates provide more advantage. *Figure 11-27* shows welding a bridge girder using a gas-shielded flux-cored wire in the flat position. Out-of-position welding is done using the smaller diameter wires.

For field welding, the self-shielding flux-cored wires are commonly used. These flux-cored wires are preferred over the gas-shielded types because a supply of shielding gas is not required, which makes the equipment more portable.

Another advantage of the self-shielding electrodes for field construction is that they can be used in windier conditions. This is because the decomposition of the flux core that provides the shielding is less sensitive to wind than an external gas shielding supply.

Figure 11-28 shows FCAW being used. Note the welder's hand shield in place to protect from the higher heat created by the FCAW process.

Another application of self-shielding electrodes is for welding galvanized steel roof decking. Single-pass electrodes using DCEN are preferred for most applications because of the lighter penetration produced, which reduces the chances of burning through the decking.

Figure 11-28 — Self-shielded flux cored welding.

6.1.2 Ships

FCAW is used in the shipbuilding industry because of the wide variety of low-carbon and low-alloy steels and metal thicknesses being welded. Because this process can be used in the vertical and overhead positions, it is used in places where submerged arc welding (SAW) cannot be used. The process is also useful for vertical welding on metal thicknesses too thin for electroslag welding to be economical. Most FCAW is done semiautomatically but some automatic welding applications are used. *Figure 11-29* shows an automatic welding system welding a cargo hoist control unit.

Figure 11-29 — Automatic welding system.

6.1.3 Industrial Piping

FCAW is used to some extent in the industrial piping industry. This process is used for welding pipe in both the shop and the field for steam generating plants, refineries, distilleries, and chemical processing plants. FCAW competes with submerged arc welding, SMAW, and GMAW.

This process may be used to deposit all passes or it may be used to deposit the fill and cover passes over a root pass welded by another process. Flat roll welding (I G position) is often used for both semiautomatic and automatic welding applications. This allows higher welding currents with larger diameter wires and requires fewer weld passes. Roll welding is often used, especially on large-diameter piping. Copper backing strips are sometimes used to allow higher current levels and insure full penetration to the root of the joint. When welding fixed position pipe, smaller diameter electrodes are used. These electrodes operate at lower current levels and require more passes. In these positions, the root pass is often welded using GMAW and sometimes GTAW. In horizontal fixed (5 G position) welding, the root pass by FCAW is done using a downhill technique. The remaining passes are then welded using an uphill technique.

FCAW is used for welding both carbon-steel and alloy-steel pipe. A major application of the process is for welding chromium-molybdenum steel pipe. This is the major type of alloy steel used for pipe. Flux-cored electrodes are preferred over the solid wire when matching chemical compositions. This is because porosity is hard to avoid. In addition, with the solid wire electrodes the operating characteristics of solid wires are not as good, which makes them more difficult to use. Most of the electrodes used for FCAW pipe are gas-shielded because of the better penetration and the generally better mechanical properties produced.

6.1.4 Railroads

FCAW is used extensively in the railroad industry. Other processes, such as SMAW, GMAW and SAW, are also widely used, so the choice of the welding process is based on the weld size, joint accessibility, joint length and welding position. The longest welds on the heavier metal thicknesses in the flat position are generally welded using SAW. FCAW is usually used on the heavier metal thicknesses where SAW is not practical. Examples would be for joints in other positions, shorter joints, and where accessibility is more limited. FCAW is preferred over SMAW and GMAW for many uses because of the higher deposition rates obtained. Many different components on the engines and the rail cars are commonly welded. *Figure 11-30* shows FCAW of a seam on a rail car.

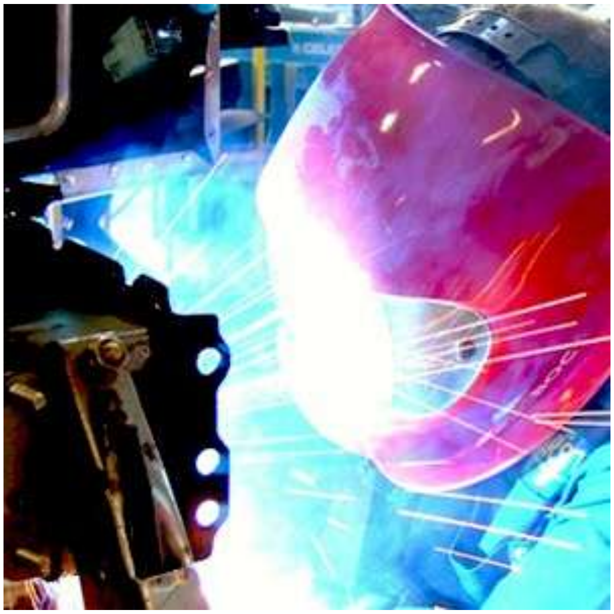

Figure 11-30 — FCAW of a railroad car.

6.1.5 Automotive Products

FCAW has gained popularity for use in the automobile and truck manufacturing industries. This process is used because of the high production rates that can be obtained. Both the self-shielding and the gas-shielded electrode wires have been used. The gas-shielded wires are generally used when deeper penetration is required. FCAW is also popular because it can be easily automated. Components such as frames, truck wheels, trailers, and axle housings are common applications. FCAW is more popular for trucks because of the larger thicknesses of metal generally used.

Figure 11-31 — FCAW of a truck frame.

An example of FCAW is shown in *Figure 11-31* where a truck trailer chassis is being welded. This part had previously been a casting that was made into a weldment. Because of the relatively thick plate being welded, FCAW is more economical on this application than GMAW. Another advantage of this application is that the depth of some bevels has been reduced and some bevels have been eliminated because of the deep penetrating characteristics of the process. The use of FCAW has increased over GMAW for many frame welding applications because joint fit-up is less important, better appearing weld beads can be produced, and FCAW has better welder appeal. Many flux-cored electrodes have been developed for welding over some rust and scale, which reduces the metal preparation time.

A special application of FCAW is for welding catalytic converters. These are made of type 409 stainless steel that is welded with an equivalent filler metal using gas shielding.

6.1.6 Heavy Equipment

The heavy equipment manufacturing industry includes mining, agricultural, and earth moving equipment, as well as other items such as forklift trucks and armored vehicles. FCAW is popular in these industries because of the high deposition rates obtained. Fillet welds are often encountered in these industries, and large single-pass fillet welds can often be welded by FCAW, which eliminates interpass cleaning time and increases productivity.

The mining equipment manufacturing industry also is a major user of FCAW for welding a wide variety of low-carbon and low-alloy steels.

6.1.7 Maintenance and Repair

The FCAW process is very useful for maintenance and surfacing operations. Maintenance operations range from repairing and modifying plant and building facilities to repairing pipe, production equipment, and castings. Surfacing and salvaging operations include the repair of mismachined parts, foundry defects, accommodating engineering changes, rebuilding worn parts (especially shafting and rollers), and overlaying parts with special materials. Reclamation includes the disassembly and rewelding of defective items manufactured in the factory and in the field. It has been used for maintaining and repairing items too expensive to repair with oxyacetylene welding and other arc welding processes. Self-shielding flux-cored electrodes are popular for field repairs and maintenance because the equipment is more portable.

A metal overlay can be used to extend the usable life of new parts that lack some of the wear-resistant qualities required for certain applications. Overlays are used mostly to replace metal that has been worn away by abrasion, corrosion, and impacts. An overlay provides toughness and resistance to corrosion, abrasion, and wear at the exact location on the part where it is needed most. The primary reason for weld overlaying parts is to prepare them for certain applications and to extend their service life. FCAW is widely used because of its characteristic high deposition rate and good weld bead appearance.

6.2.1 Flux Cored Arc Spot Welding

Flux cored arc spot welding (FCASW) is a variation of the process where a fusion weld is made through one sheet into an adjacent sheet of a lap joint while the welding gun is held stationary. The equipment used for arc spot welding is the same as for normal welding, except that it requires a timer and a special gun nozzle. FCASW is used on low-carbon and low-alloy steels and is generally preferred for welding thicker sheet metal and thin plate sections. This is because of the greater penetrating capability of the process as compared to gas tungsten (GTASW) or gas metal arc spot welding (GMASW). The FCASW process also provides a wider penetration spot weld at the interface between the plates to be joined. This produces a larger diameter spot weld with greater strength. FCASW is identical to GMASW except that a flux-cored electrode wire is used. Carbon dioxide shielding is generally used but argon-CO_2 mixtures are sometimes used to reduce the amount of penetration. When welding thinner metals, a backup bar is used under the sheet metal.

The advantages of FCASW over resistance spot welding are:

1. Access is only required from the top of the joint.
2. Spot welding can be done in all positions more easily.
3. The gun is light and portable and can be taken to the weldment.
4. Weld joint fit-up is not as critical.
5. Faster production rates can be obtained, particularly on thicker metal.

The main disadvantage of arc spot welding is the consistency of weld size and strength is not as good.

Either the gas-shielded or self-shielding flux-cored electrodes may be used. The weld is made by depressing the trigger that starts the shielding gas, if used, and, after a preflow interval, starts the arc and the wire feed. The arc melts through the top sheet of the lap joint and fuses into the bottom sheet. When the preset weld time is finished, the arc and wire feed are stopped, followed by the gas flow, if used. FCASW is shown in *Figure 11-32*. This process is used for making welds in metal ranging from 16 gauge (1.5 mm) to 1/4-in. (6.4 mm) in thickness. Metals of the same or different thicknesses can be made. If dissimilar thicknesses are being welded, the thinner member should always be placed on top. The length of the spot weld cycle affects the penetration and the amount of reinforcement on the surface of the weld bead. FCASW generally produces larger, stronger weld nuggets on the same metal thicknesses as compared to GMASW. The rest of the welding variables affect the weld in the same way as normal weld.

Figure 11-32 — FCASW.

7.0.0 WELDING METALLURGY

Welding metallurgy concerns the chemical, physical, and atomic properties and structures of metals, and the principles by which metals are combined to form alloys.

7.1.0 Properties of the Weld

The properties of a weld include the chemical composition, mechanical strength, ductility, toughness, and the microstructure. These items will relate to the weldability of the metal. The weldability of a metal is the quality obtained and the ease of welding for the intended service conditions. The types of materials used affect the chemical, physical, and mechanical properties of the weld. The mechanical properties and microstructure are determined by the heat input as well as the chemical composition and physical properties of the weld.

7.2.0 Chemical Properties

The chemical composition of the base and filler metal has a great influence on the weldability of a metal, and this property has an influence on the preheating and postheating used, as well as the welding parameters.

For welding stainless steels, the chemical composition of the weld is often the most important property. The chemical composition of the weld must match the composition of the base metal when corrosion resistance, thermal and electrical conductivity, and appearance are major considerations. The chemical composition can also affect the high and low temperature strength, as well as the microstructure and mechanical properties of the weld. Preheating reduces the cooling rate of the weld after welding 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.

Steels with higher carbon contents need higher preheat than steels with lower carbon equivalents. *Table 11-12* shows typical preheat values for different metals welded by FCAW.

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. Thick metal draws the heat away from the welding zone more quickly because there is a large mass of metal to absorb the heat. This would cause a quicker cooling of the weld if the same preheat temperature was used, as on thinner base metals.

The third major factor for determining the amount of preheat 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. Higher preheat temperatures are needed as the amount of joint restraint increases. Slower cooling rates reduce the amount of internal stresses that are building up as the weld cools.

Table 11-12 —Preheats for various metals.

Type of Steel	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' (6.4 mm) thick -More than ¼' (6.4 mm) thick	 Room Temperature 500°F (260°C)
Low-alloy Nickel-Chrome Steel -Carbon content below .20% -Carbon content .20% to .35% -Carbon content above .35%	 200-300°F (93-150°C) 600-800°F (315-425°C) 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 .150% Carbon content above .15%	 Room Temperature 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	300-350°F (150-260°C)
Martensitic Stainless Steel	400-600°F (205-315°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.

7.3.0 Mechanical Properties

The mechanical properties that are most important in the weld are the tensile strength, yield strength, elongation, reduction of area, and 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 FCAW steels designed to give maximum strength, ductility, and toughness.

FCAW can produce good properties in the weld- and heat-affected zone. The slag coating in FCAW slows the cooling rate of the weld metal, which reduces the tendency to become brittle.

FCAW produces a higher heat input, which will also tend to produce a slower cooling rate. A disadvantage of the higher heat input is that distortion is more of a problem than with GMAW. The mechanical properties of the weld will vary, depending on whether a self-shielded or gas-shielded flux-cored wire is used. Some self-shielded electrodes contain high amounts of deoxidizers, which may produce weld metal with relatively low impact toughness. Most of the gas-shielded flux-cored wires produce welds that have better impact toughness.

The yield strength, ultimate tensile strength, elongation, and reduction of area are all measured from a .505 in. (12.8 mm) diameter machined tensile testing bar. The metal is tested by pulling it in a tensile testing machine. *Figure 11-33* 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 ultimate tensile strength is the maximum stress or load that can be carried by the metal without breaking. 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 of elongation, is measured.

Figure 11-33 — Tensile strength testing bars.

Reduction of area is another method of measuring ductility. The original diameter of the testing bar is .20 sq in (128 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 11-34* shows some typical Charpy V-notch test bars. Bars with V-notches 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, also called newton-meters).

Figure 11-34 — Charpy V-notch bars.

7.4.1 Microstructure

Figure 11-35 shows a cross section of a weld bead showing the weld metal zone, the heat-affected zone, and the base metal zone- the three basic microstructural areas within a weldment. The weld metal zone is where the metal was molten during welding. The heat-affected zone is the area where the heat from welding has an effect on the microstructure of the base metal. The base metal zone is the area that was not affected by the welding. The extent of change of the microstructure is dependent on four factors:

1. Maximum temperature exposure
2. Temperature exposure time
3. The chemical composition of the base metal
4. The cooling rate of the weld

Figure 11-35 — Cross section of weld bead showing in the three areas.

The weld metal zone, which is the area heated above about 2800°F (1540°C) and melted, generally has the coarsest grain structure of the three areas. Generally, a fairly fine grain size is produced on cooling in most metals. Large grain size is undesirable because it gives poor weld toughness and cracking resistance. The filler metal starts to solidify at the edges of the weld puddle. The grains that form at the edge are called dendrites and they grow toward the center of the weld into the area that is still molten (*Figure 11-36*).

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. 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 temperature, the larger the grain size. A faster 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.

Figure 11-36 — Solidification pattern of the weld.

The heat-affected zone is an area of change in the microstructure of the base metal. The area that is closest to the weld metal usually undergoes grain growth. Other parts of the heat-affected zone will go through grain refinement. Other areas may be annealed and considerably softened. Because of the changes due to the heat input and cooling rate, 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. This is often not desirable, so the welding parameters used can help influence the size of the heat-affected zone.

7.5.0 Metals Weldable

FCAW is commonly used to weld most steels and stainless steels. This process also welds some nickel alloys. Most ***nonferrous*** metals are not welded by this process because of the high heat input and because suitable electrode wires have not been developed.

7.5.1 Steels

FCAW is widely used for welding steels. In general, steel is classified according to the carbon content, such as low-carbon, mild, medium-carbon, and high-carbon steels. In addition, steel is also classified according to the alloys used. For the purpose of discussion in this chapter, the different steels will be grouped according to their welding characteristics.

When welding steel, the carbon and other alloy content influences the hardness and hardenability of the weld metal, which in turn influences the amount of preheat needed. The two terms, hardness and hardenability, are not the same. The maximum hardness of a 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. The hardenability wiIl 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 used. There are several different formulas used. One of the most popular is as follows:

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

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. When welding some of the steels, it is more important to match the mechanical properties than the chemical composition 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.

7.5.1.1 Low-carbon and Mild Steels

Low-carbon and mild steels are those that have low carbon contents and are the most readily weldable. This group of steels is the most widely used in industrial fabrication. This group also includes the high strength structural steels.

Low-carbon steels have carbon contents up to .14%. Mild steel has carbon contents ranging from .15 to .29%. For many applications, preheating is not required except on thick sections, highly restrained joints, or where codes require preheating. 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. When welding these steels, electrodes of the E70-T class are used with carbon dioxide. Self-shielding wires are also widely used. The filler metal should be chosen so that it matches the tensile strength of the base metal. When welding rimmed steels, which have silicon contents less than .05%, filler metal with sufficient amounts of deoxidizers must be chosen to prevent porosity. 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 (310 MPa) and 70,000 psi (485 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.

Some low-carbon and mild steel electrodes are designed for welding over some rust and mill scale. The flux core helps to reduce the bad effects of rust and mill scale but some reduction in weld quality may occur. These FCAW electrodes are preferred for many applications because cleaning of the base metal is less important. For applications where the maximum mechanical properties are not as important as higher deposition rates and travel speeds, high welding currents can be used.

7.5.1.2 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 that is the principal complication in welding. Low-alloy steels have good weldability but are not as good as the mild steels. This higher hardenability permits martensite to form at lower cooling rates. As the alloy content and the carbon content increases, the hardenability also increases.

In general, the weldability of the steel decreases as the hardenability increases. 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. Generally, the higher the carbon equivalent, the more difficult the steel is to weld.

The selection of electrodes for welding steels is usually based on the strength and mechanical properties desired of the weld, rather than matching chemical compositions. Low-alloy steels are often welded using the gas-shielded EXXT-1 and EXXT-5 electrodes. These wires produce good, low temperature toughness and are preferred for most applications. EXXT-4 and EXXT-8 self-shielded wires often contain nickel for good strength and aluminum as a deoxidizer to help give good mechanical properties. In other cases, such as for welding low nickel steels, the electrode wires are chosen to match the chemical composition of the base metal.

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 up to .25%. Some common examples of these types of steel are the ASTM designations A533 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. Preheat is generally not used on thinner sections, but it is used on thicker or highly restrained sections. Postweld heat treatment is usually not used because the flux cored arc welds made in these have a 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 electrodes that have the same general chemical compositions as the base metal. Preheating is required with highly restrained joints. Most self-shielding wires for low-alloy steels have been developed for welding the low nickel steels.

7.5.1.3 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 quenched and tempered steels after welding, normalized or annealed steels, and medium- and high-carbon steels. These steels are more difficult to weld than other types of steels already mentioned in this chapter. The most important factor for selecting the type of 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 a 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 reduce the cracking tendency. This can be done by using a procedure that requires a lower carbon content in the filler metal, and by slowing the cooling rate. The procedure includes 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 E70T-E90T classifications. High-carbon steels should be welded with the E80T-E120T, using the electrode of the proper tensile strength to match the tensile strength of the base metal. Generally, very high-carbon steels are not used in welded production work. These steels are usually only welded 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 reduce the brittle structure.

The quenched and tempered steels, 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. The weldability of these steels 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. FCAW is often used for welding these steels. Filler metal of the same chemical composition as the base metal is required to obtain the maximum strength. The composition of the weld metal is usually similar to that of the base metal.

7.5.1.4 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 high oxidation 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 welding 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.

FCAW is one of the most common methods of welding the chromium-molybdenum steels. The steels with less than 6% chromium are welded with a carbon dioxide or argon-carbon dioxide mixture. For the steels with 6% chromium or more, argon with small additions of carbon dioxide is often used. The filler metal is chosen to match the chemical composition of the base metal as closely as possible to give good corrosion resistance.

7.5.1.5 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, selenium, or phosphorous, these steels have chemical compositions similar to mild, low-alloy, and stainless steels. The addition of these elements makes these steels difficult to weld. The reason for this is that the elements- lead, phosphorous, selenium and sulfur- have melting points that are much lower than the melting point of the steel. As the weld solidifies, these elements retain liquid much longer than the steel so that they coat the grain boundaries, which cause 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.

7.5.1.6 Stainless Steels

FCAW can weld most types of stainless steels. 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 element that 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 them 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 has high manganese contents to replace some of the nickel, is 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 only occurs 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 resistance to corrosion. There are several methods for preventing this problem:

1. A 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. The use of extra low-carbon base and filler metal (.03% C max.). Examples are 304L and 316L.
3. The use of a stabilized base and filler metal alloy containing columbium, tantalum, or titanium. Examples are 347 and 321.
4. The use of a solution heat treatment to resolve 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, (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 steels 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. Preheating is usually done in the range of from 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.

The FCAW process can produce stainless steel weld deposits with a quality similar to those produced by GMAW. 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.

Carbon dioxide, argon-carbon dioxide, and argon-oxygen mixtures are used. Carbon dioxide causes a loss of silicon and manganese and an increase in carbon in the low-carbon stainless steels. The use of carbon dioxide or EXXT-1 electrodes is restricted for welding many of the stainless steels, especially austenitic grades, because the corrosion resistance may be reduced due to carbon added to the weld by gas. When good corrosion resistance is required, argon-carbon dioxide or argon-oxygen mixtures are used. The argon-oxygen mixtures containing 1 or 2% oxygen are used to improve the arc stability and weld puddle wetting, as well as to eliminate carbon pickup from the shielding gas. When the self-shielding EXXXT-3 electrodes are used, there is greater pickup of nitrogen from the atmosphere into the weld metal. Nitrogen is an austenite stabilizer and when the weld absorbs excessive nitrogen, there is a greater chance for micro-cracking to occur. The welding position and arc length have a large influence on this problem. An excessive arc length will usually cause excessive nitrogen pickup in the weld. For this reason, procedures for out-of-position welding with self-shielding wires should be carefully controlled to produce a sound weld deposit.

The filler metal used for welding stainless steel is generally chosen to match the chemical composition of the base metal. In the 200-series austenitic stainless steels, 300-series austenitic filler metal is usually used due to a lack of availability of 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. The 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 used for 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 11-13* shows filler metal selection for stainless steels.

Table 11-13 — Filler metal selection for welding stainless steel.

AISI 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 3.00-4.00	317
321	0.08 max	2.00	1.00	17.00-19.00	9.00-12.00	Ti 5 x C min	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 10 x C 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	—	Al 0.10-0.30	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	—	N0 .25 max	309, 310

Test your Knowledge (Select the Correct Response)

5. What primary property determines the maximum hardness of steel?

   A. The amount of heat used to make the steel
   B. The amount of carbon in the steel
   C. The amount of alloy in the steel
   D. The thickness of the steel

6. What type of stainless steel is generally the easiest to weld?

   A. Annealed
   B. Ferritic
   C. Modular
   D. Austenitic

8.1.1 WELD and JOINT DESIGN

Like other welding processes, the weld joint designs used in FCAW are determined by the design of the weldment, metallurgical considerations, and codes or specifications. Another factor to consider is the method of FCAW to be used. A properly selected joint design should allow the highest quality weld to be made at the lowest possible cost. A weld joint consists of a specific weld being made in a specific joint. A joint is defined as the junction of members which are to be, or have been, joined. *Figure 11-37* shows the five basic joint classifications.

Figure 11-37 — Types of joints.

Each of the different types of joints can be joined by many different types of welds. *Figure 11-38* shows the most common types of welds made.

Figure 11-38 — Types of welds.

The type of weld made is governed by the joint configuration. Each of the different types of welds has its own specific advantages. The nomenclature used for the various parts of groove and fillet welds is given in *Figure 11-39*. There are several factors that influence the joint design to be used:

1. Process Method
2. Strength Required
3. Welding Position
4. Joint Accessibility
5. Metal Thickness
6. Type of Metal

Figure 11-39 — Weld nomenclature.

The edge and joint preparation are important because they affect both the quality and cost of welding. The cost items to be considered are the amount of filler metal required, the method of joint preparation, the amount of labor required, and the quality level required. Joints that are more difficult to weld will often have more repair work necessary than those that are easier to weld. This can lead to significant increases in cost, since repair welding sometimes requires more time and expense than the original weld. All of the five basic joint types are applicable to FCAW, although the butt and T-joints are the most widely used. Lap joints have the advantage of not requiring much preparation other than squaring off the edges and making sure the members are in close contact. Edge joints are widely used on thin metal. Corner joints generally use similar edge preparations to those used on T-joints.

Many of the joint designs used for FCAW are similar to those used in GMAW or SMAW. FCAW has some characteristics that may affect the joint design. The joint should be designed so the welder has good access to the joint and is properly able to manipulate the electrode. Joints must be located so an adequate distance between the joint and nozzle of the welding gun is created. The proper distance will vary depending on the type of flux-cored electrode being used.

8.1.0 Process Method

The joint design as well as the welding procedure will vary, depending on whether the welding is done using gas-shielded or self-shielded electrodes. Both methods of FCAW achieve deeper penetration than SMAW. This permits the use of narrower grooves with smaller groove angles, larger root faces, and narrower root openings. Differences also exist between the two FCAW methods because of the deeper penetration that is produced by the gas-shielded electrode wires. *Figure 11-40* shows a comparison of a flat position, V-groove weld on a backing strip for each of the two methods.

Figure 11-40 — Comparison between gas-shielded and self-shielded wire joint designs for the flat position.

The joint design for the self-shielding wire requires a larger root opening to allow better access to the root of the joint. The joint design for the gas-shielded wire does not need such a wide root opening because complete penetration is easier to obtain. This weld would be less expensive to make using the gas-shielded electrode because less filler metal is required. This difference in joint design usually only applies when a backing strip is used. For joints not requiring a backing strip, gas-shielded and self-shielded wires use the same joint designs.

8.2.0 Type of Metal

The FCAW process is used to weld steel, some stainless steels, and some nickels. The influence of the type of metal on the joint design is based primarily on the physical properties of the metal to be welded and whether or not the metal has an oxide coating. For example, stainless steels have a lower thermal conductivity than carbon steels. This causes the heat from welding to remain in the weld zone longer, which enables slightly greater thicknesses of stainless steels to be welded using a square groove joint design. Stainless steels also have an oxide coating that tends to reduce the depth of fusion of the weld. Consequently, stainless steels normally use larger groove angles and root openings than carbon steels. This allows the welder to direct the arc on the base metal surfaces to obtain complete fusion.

8.3.0 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 where weld metal only extends partially through the joint thickness. Welds that are subject to cyclic, impact, or dynamic loading require complete penetration. 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. This type of joint is easier to prepare and requires less filler metal than full penetration joints. Fillet welds of the same leg size made by this process are stronger than those made by SMAW. This is because of the deeper penetration obtained from FCAW, as shown in *Figure 11-41*. For some applications, the size of the weld can be reduced which decreases the amount of filler metal required. This can reduce the total cost also.

Figure 11-41 — Comparison between the penetrating characteristics of SMAW and FCAW.

The root opening and root face used will affect the amount of penetration obtained. 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 more for partial penetration welds than for complete penetration welds because less penetration is required. Because of the deep penetrating characteristics of the FCAW process, larger root faces are used compared to SMAW and GMAW, which use short circuiting metal transfer. This is to prevent burning through the back of the joint being welded, which can be a problem in FCAW because of the high welding currents used. When compared to SMAW, smaller groove angles are used because the flux-cored wire is smaller than a covered electrode and operates with a higher current density. Because of the smaller electrode, access to the root of the joint is better.

8.4.0 Position

FCAW may be used in all welding positions based on the size and type of electrode wire used. A diagram of the welding position capabilities is shown in *Figure 11-42.*

Figure 11-42 — Welding test positions.

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. A G designation indicates a groove weld and an F designation indicates a fillet weld. The 5G and 6G positions are used in pipe welding. The large diameter wires, which are over 1/16 in. (1.6 mm) in diameter, are limited to the flat and horizontal positions only because the weld puddle becomes too large to control. The smaller diameter electrodes, which are 1/16 in. (1.6 mm) and less, can generally be used easily in all positions.

The joint configuration will vary depending on the position of welding. One example of this is wider groove angles needed for vertical position welding. This is done to provide enough room to manipulate the electrode wire in the joint. Weaving of the electrode is usually required in vertical position welding to prevent excessive reinforcement or dropping the weld metal out of the puddle. Joint designs for overhead welding are generally the same as for flat position welding. Joints that are welded in

Figure 11-43 — V-groove joint in the horizontal position.

the horizontal position often have an unsymmetrical joint configuration. This usually consists of a groove angle that has a horizontal lower groove face, as shown in *Figure 11-43*. The upper groove face is raised accordingly to provide a groove angle large enough to provide good access. The horizontal lower groove face is used as a shelf to support the molten weld metal. This joint configuration is less expensive to prepare because the bevel is only made in one plate.

8.5.0 Thickness

The thickness of the base metal has a large influence on the joint preparation required to produce the best quality weld joint. FCAW is used to weld thicknesses down to 18 gauge (1.2 mm), but the process is also suitable for welding thick metal. Because of this, wide varieties of joint designs are used. 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 used 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) thick 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 SMAW or GTAW because of the hotter arc and deeper penetration 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 insure adequate penetration.

V-grooves for butt joints and bevel-grooves for tee joints are commonly used for thicker metal up to about 3/4-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° with smaller groove angles, such as 45° or 60°, being more commonly used. The smaller groove angles become even more economical as the thickness of the metal increases. 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 used for SMAW and GTAW. 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, the savings become very substantial.

8.6.0 Accessibility

The accessibility of the weld joint is another important factor in determining the weld joint design. Welds can be made from one or both sides of the weld joint. Single V-, 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 weld 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. This tends to make double-groove welds more economical on metal 1-in. (25 mm) thick or greater.

The third advantage is that complete penetration can be more easily insured. 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. The amount of savings in the filler metal needed for a double-groove weld may more than compensate for the extra joint preparation costs; 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.

8.6.1 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, which are fusible or nonfusible. 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. Nonfusible 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 strip is more expensive because of the cost of a backing strip and the larger amount of filler metal required. However, 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 11-44,* where single V-groove joints are shown with and without a backing strip.

As discussed earlier in this chapter, the use of a backing strip will have an effect on the joint designs used for gas-shielded and self-shielded electrodes. The deeper penetrating characteristics of the gas-shielded electrode allow the joint designs to be adjusted to take advantage of this.

Figure 11-44 — Single V-groove joints with and without backing strip in the same thickness metal.

8.7.1 Weld Joint Designs

The details of a joint, which include both the geometry and the required dimensions, are called the joint design**.** Just what type of joint design is best suited for a particular job depends on many factors. Although welded joints are designed primarily to meet strength and safety requirements, there are other factors that must be considered. A few of these factors are as follows:

1. Whether the load will be in tension or compression and whether bending, fatigue, or impact stresses will be applied

2. How a load will be applied; that is, whether the load will be steady, sudden, or variable

3. The direction of the load as applied to the joint

4. The cost of preparing the joint

Another consideration that must be made is the ratio of the strength of the joint compared to the strength of the base metal. This ratio is called joint efficiency**.** An efficient joint is one that is just as strong as the base metal.

Normally, the joint design is determined by a designer or engineer and is included in the project plans and specifications. Even so, understanding the joint design for a weld enables you to produce better welds.

Earlier in this chapter, we discussed the five basic types of welded joints—butt, corner, tee, lap, and edge.

Just keep in mind that there are many different variations of the basic joint welds. If you want more information refer to Chapter 3, Introduction to Welding. The weld joint designs shown in *Figures 11-45 through 11-56* are those typically used for FCAW. All of the partial penetration weld joint designs covered may be welded using either the self-shielded or gas-shielded electrode wires. The joint dimensions will vary for full penetration welds using backing strips, depending on which method of FCAW is being used. The joint designs that should be used only by the gas-shielded method are indicated on these joints. All other full penetration welds may be made by either of the two methods.

Ranges are given on many of the joint dimensions to account for varying fit-up and types of electrode wires. The thickness ranges given are those typically recommended for use with the joint designs. Minimum effective throat thicknesses are commonly used for partial penetration welds. Recommended minimum effective throat sizes are given in *Table 11-14*.

Table 11-14 — 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)
Over1/4 to 1/2	(6.4 to 12.7)	Inclusive	3/16	(5)
Over1/2 to 3/4	(12.7 to 19.0)	Inclusive	1/4	(6)
Over3/4 to 1 1/2	(19.0 to 38.1)	Inclusive	5/16	(8)
Over1 1/2 to 2 1/4	(38.1 to 57.1)	Inclusive	3/8	(10)
Over2 1/4 to 6	(57.1 to 152)		1/2	(13)
Over 6	(152)		5/8	(16)

Figure 11-45 — Welding symbols.

Figure 11-46 — Welding symbols (cont.).

Figure 11-47 — Application of arrow and other side convention.

Figure 11-48 — Applications of break in arrow of welding symbol.

Figure 11-49 — Combinations of weld symbols.

Figure 11-50 — Combinations of weld symbols (cont.).

Figure 11-51 — Specification of location and extent of fillet welds.

Figure 11-52 — Specification of location and extent of fillet welds (cont.).

Figure 11-53 — Specification of extent of welding.

Figure 11-54 — Specification of extent of welding (cont.).

Figure 11-55 — Specification of extent of welding (cont.).

Figure 11-56 — Applications of melt-through symbol.

8.8.0 Arc Welding Positions

The types of welds, joints, and welding positions used in FCAW are very similar to those used in GMAW, with the exception of overhead welding. Manual overhead welding is rarely used in FCAW because the filler metal is so fluid due to the powdered core.

8.8.1 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 on 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 11-57*.

Plates up to 1/8-inch thick can be welded in one pass with no special edge preparation. Plates from 1/8- to 3/16 -inch 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 electrode motion is the same as that used in making a bead weld.

Figure 11-57 — Butt joints in the flat position.

In welding 1/4-inch 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, as shown in *Figure 11-58,* the second, third, and fourth layers of weld metal are made with a weaving motion of the electrode. Clean each layer of metal before laying additional beads. You may use one of the weaving motions shown in *Figure 11-59*, depending upon the type of joint and size of electrode.

Figure 11-58 — Butt welds with multipass beads.

In the weaving motion, oscillate or move the electrode uniformly from side to side, with a slight hesitation at the end of each oscillation. Incline the electrode 5 to 15 degrees in the direction of welding as in bead welding. When the weaving motion is not done properly, undercutting could occur at the joint, as shown in *Figure 11-60*. Excessive welding speed also can cause undercutting and poor fusion at the edges of the weld bead.

Figure 11-59 — Weave motions used in FCAW.

Butt joints with backing strips — Welding 3/16-inch 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-inch thick, the backing strips should be approximately 1-inch wide and 3/16-inch thick. For plates more than 1/2-inch thick, the backing strips should be 1 1/2 inches wide and 1/4-inch thick. Tack-weld the backing strip to the base of the joint, as shown in *Figure 11-61.* 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.

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.

Figure 11-60 — Undercutting in butt joint welds.

Figure 11-61 — Use of back strips in welding butt joints.

8.8.2 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 11-62)*. In a fillet weld, the welding is performed on the upper side of a relatively horizontal surface and against an approximately vertical plane (*Figure 11-63*).

Figure 11-62 — Horizontal groove weld.

Figure 11-63 — Horizontal fillet weld.

Inexperienced welders usually find the horizontal position of arc welding difficult, at least until they have developed 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.

8.8.2.1 Electrode Movement

In horizontal welding, position the electrode so that it points upward at a 5- to 10-degree angle in conjunction with a 20-degree travel angle (*Figure 11-64*). 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 electrode holder a little to increase the upward angle.

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.

Figure 11-64 — Horizontal welding angles.

8.8.2.2 Joint Type

Horizontal-position welding can be used on most types of joints. The most common types of joints it is used on are tee joints, lap joints, 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 11-65*.

Figure 11-65 — Tack-weld to hold the tee joint elements in place.

Figure 11-66 — Position of electrode on a fillet weld.

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 11-66*, *View A*). Hold the electrode at an angle of 45 degrees to the two plate surfaces (*Figure 11-66*, *View B*) with an incline of approximately 15 degrees in the direction of welding.

When practical, weld light plates with a fillet weld in one pass with little or no weaving of the electrode. 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 11-67.* To ensure good fusion and the prevention of undercutting, you should make a slight pause at the end of each weave or oscillation.

For fillet-welded tee joints on 1/2-inch plate or heavier, deposit stringer beads in the sequence shown in *Figure 11-68.*

Figure 11-67 — Weave motion for multipass fillet weld.

Chain-intermittent or staggered-intermittent fillet welds, as shown in *Figure 11-69*, are used on long tee joints. 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.

Figure 11-68 — Order of string beads for tee joint on heavy plate.

Figure 11-69 — Intermittent fillet welds.

Lap joints — When you make a lap joint, two overlapping plates are tack-welded in place (*Figure 11-70*), 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 electrode 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 electrode in relation to the plates is shown in *Figure 11-71*. 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 undercut. Lap joints on 1/2-inch plate or heavier are made by depositing a sequence of stringer beads, as shown in *Figure 11-71*.

Figure 11-70 — Tack welding a lap joint.

Figure 11-71 — Position of electrode on a lap joint.

In making lap joints on plates of different thickness, you should hold the electrode so that it forms an angle of between 20 and 30 degrees from the vertical (*Figure 11-72*). Be careful not to overheat or undercut the thinner plate edge.

Figure 11-72 — Lap joints on plates of different thickness.

Figure 11-73 — Horizontal butt joint.

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 that it does not run out of the joint (*Figure 11-73*). Often, 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.

The number of passes required for a joint depends on the diameter of the electrode and the thickness of the metal. When multiple passes are required (*Figure 11-74*), place the first bead deep in the root of the joint. The electrode holder 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 electrode holder held about 10 degrees upward. For the third pass, hold the electrode holder 10 to 15 degrees downward from the horizontal. Use a slight weaving motion and ensure that each bead penetrates the base metal.

Figure 11-74 — Multiple passes.

8.8.3 Vertical-Position Welding

A “vertical weld” is defined as a weld that is applied to a vertical surface or one that is inclined 45 degrees or less (*Figure 11-75*). 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. To counteract this force, you should use fast-freeze or fill-freeze electrodes.

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.

Figure 11-75 — Vertical weld plate positions.

8.8.3.1 Current Settings and Electrode Movement

In vertical arc welding, the current settings should be less than those used for the same electrode 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 electrode and the base metal. In welding upward, you should hold the electrode at 90 degrees to the vertical, as shown in *Figure 11-76, View A*. When weaving is necessary, oscillate the electrode, as shown in Figure *11-76, View B*. In vertical down welding, incline the outer end of the electrode downward about 15 degrees from the horizontal while keeping the arc pointing upward toward the deposited molten metal (*Figure 11-76, View C*). When vertical down welding requires a weave bead, you should oscillate the electrode, as shown in *Figure 11-76*, *View D*.

Figure 11-76 — Bead welding in vertical position.

8.8.3.2 Joint Type

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 electrode 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 electrode in a triangular weaving motion, as shown in *Figure 11-77, 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.

When the weld metal overheats, you should quickly shift the electrode away from the crater without breaking the arc, as shown in *Figure 11-77, View B*. This permits the molten metal to solidify without running downward. Return the electrode 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 11-77, 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 electrode in a triangular weaving motion, as shown in *Figure 11-77*, *View E*. Use the same procedure as outlined above for the tee joint, except direct the electrode 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.

Figure 11-77 — Fillet welds in the vertical position.

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 11-77, 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 the motion of the arc should be carefully controlled.

Butt joints on beveled plates 1/4-inch thick can be welded in one pass by using a triangular weave motion, as shown in *Figure 11-78*, *View A*.

Welds made on 1/2-inch plate or heavier should be done in several passes, as shown in *Figure 11-78*, *View B*. Deposit the last pass with a semicircular weaving motion and a slight "whip-up" and pause of the electrode 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 11-78 — Butt joint welding in the vertical position.

8.8.4 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.

8.8.4.1 Current Settings and Electrode 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 electrode to the base metal becomes increasingly difficult and the chances of large globules of molten metal dropping from the electrode increase. When you routinely shorten and lengthen the arc, the dropping of 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.

8.8.4.2 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 electrode is 90 degrees to the base metal (*Figure 11-79, View A*). The travel angle should be 10 to 15 degrees in the direction of welding (*Figure 11-79*, *View B*).

Weave beads can be made by using the motion shown in *Figure 11-79*, *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.

Figure 11-79 — Position of electrode and weave motion in the overhead position.

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 extreme care is taken by the operator.

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 electrode position and the order of deposition of the weld beads when welding on 1/4- or 1/2-inch plate are shown in *Figure 11-80*, views B and C. Make the first pass with the electrode held at 90 degrees to the plate, as shown in *Figure 11-80*, *View A*. When you use an electrode that is too large, you cannot hold a short arc in the root area. This results in insufficient root penetration and inferior joints.

Figure 11-80 — Multipass 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 of the electrode. Hold the electrode at approximately 30 degrees to the vertical plate and move it uniformly in the direction of welding, as shown in *Figure 11-80*, *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 electrode quickly away from the crater and ahead of the weld to lengthen the arc and allow the metal to solidify. Immediately return the electrode to the crater and continue welding.

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 11-81*, *View A*. The root pass is a string bead made with no weaving motion of the electrode. Tilt the electrode about 15 degrees in the direction of welding, as shown in *Figure 11-81*, *View C*, and with a slight circular motion make the second, third, and fourth pass. This motion of the electrode 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.

Figure 11-81 – Fillet welding in the overhead position.

8.8.5 Pipe welding

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 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 (TIG, MIG & FCAW) 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.

In the following paragraphs, pipe welding positions, pipe welding procedures, definitions, and related information are discussed.

8.8.5.1 Pipe welding positions

You may recall that there are four positions used in pipe welding. They are known as the horizontal rolled position (1G), the horizontal fixed position (5G), pipe inclined fixed (6G), and the vertical position (2G). Remember: these terms refer to the position of the pipe and not to the weld.

8.8.5.2 Pipe welding procedures

Welds that 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.

Figure 11-82 — Butt joints and socket fitting joints.

Butt joints are commonly used between pipes and between pipes and welded fittings. They are also used for butt welding of flanges and welding stubs. In making a butt joint, place two pieces of pipe end to end, align them, and then weld them. (See *Figure 11-82*).

When the wall thickness of the pipe is 3/4-inch or less, you can use either the single V or single U type of butt joint; however, when the wall thickness is more than

Figure 11-83 — Flange connections.

3/4-inch, only the single U type should be used.

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 11-83*). Single-fillet welds are also used in welding screw or socket couplings to pipe (*Figure 11-83)*. Sometimes flanges require alignment. *Figure 11-84* shows one type of flange square and its use in vertical and horizontal 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.

8.8.5.3 Joint preparation and fit-up

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 flame-cut edges; however, it is not necessary to remove the temper color.

Figure 11-84 — Flange alignment.

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 percent 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 11-85*), while a section of channel or I-beam is more suitable for larger diameter pipe.

Figure 11-85 — Angle iron jig.

8.8.6 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-inch 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.

8.8.7 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.

8.8.8 Electrode selection

Select the electrode that is best suited for the position and type of welding to be done. For the root pass of a multilayer weld, you need an electrode large enough, yet not exceeding 3/16-inch, that ensures complete fusion and penetration without undercutting and slag inclusions.

Make certain the welding current is within the range recommended by the manufacturers of the welding machines and electrodes.

8.8.9 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, unless using self-shielded electrodes

At temperatures between 0°F and 32°F, within 3 inches of the joint, heat the weld area with a torch to a temperature warm to the hand before beginning to weld.

Test your Knowledge (Select the Correct Response)

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

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

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

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

9.0.0 WELDING PROCEDURE VARIABLES

The welding procedure variables are those that control the welding process and the quality of the welds that are produced. When all of the variables are in proper balance, the result will be a smooth running arc and a quality weld deposit. You need to understand the effect of each variable on the different properties or characteristics of the weld to increase the probability of producing the required weld properties. You should recognize that some welding variables are more easily applied as controls of a welding process. There are three major types of welding variables used for welding. These are the fixed or preselected, primary adjustable, and the secondary adjustable variables.

The preselected or fixed variables are those that can only be changed in large steps or intervals and are therefore unfavorable as controls. For the FCAW process, these variables are set according to the type of material being welded, the thickness of the material, welding position, deposition rate required, and mechanical properties required. These variables cannot be changed once the welding starts.

The primary adjustable variables are the major variables used to control the welding process once the fixed variables have been selected. The primary variables control the formation of the weld bead by affecting the bead width, bead height, penetration, arc stability, and weld soundness. The primary welding variables are welding current, arc voltage, and travel speed. These can be easily adjusted and measured so they can be used effectively to control the welding process. Specific values can be assigned to the primary adjustable variables and these values can be accurately reset time after time.

The secondary adjustable variables can also be changed continuously over a wide range of values. However, they are sometimes difficult to measure accurately. It is not easy to use them as controls since, for the most part, they cannot be assigned exact values. This is especially true in semiautomatic welding operations. Although difficult to measure, these variables should be controlled within the range for proper operation. Secondary adjustable variables are such things as electrode extension or stickout, work and travel angles.

Figure 11-86 — Bead height, bead width, and penetration.

The different variables affect the characteristics of the weld, such as the penetration of the weld, bead height, bead width, and the deposition rate. The penetration of the weld is defined as the greatest depth below the surface of the base metal that the weld metal reaches. The bead height or reinforcement is the height of the weld metal above the surface of the base metal. The deposition rate is the weight of the metal that is deposited per unit of time. The definitions of bead height, bead width, and penetration are shown in *Figure 11-86*.

The welding variables are discussed with particular attention to the three major characteristics of penetration, deposition rate, and bead shape. *Table 11-15* is a chart showing the effects of welding variables on the three major characteristics.

Table 11-15 — Recommended welding variable adjustment for FCAW.

Change Required \ Welding Variable		Arc Voltage	Welding Current (See footnote)	Travel Speed	Nozzle Angle	Stickout or Tip to Work Distance	Wire Size	Gas Type
Deeper Penetration			1 Increase		3 Trailing Max. 25°	2 Decrease	5 (a) Smaller	4 CO_2
Shallower Penetration			1 Decrease		3 Leading	2 Increase	5 (a) Larger	4 (C) Ar+CO_2
Bead Height and Bead Width	Larger Bead		1 Increase	2 Decrease		3 (a) Increase		
	Smaller Bead		1 Decrease	2 Increase		3 (a) Decrease		
	Higher Narrower Bead	1 Decrease			2 Trailing	3 Increase		
	Flatter Wider Bead	1 Increase			2 90° or Leading	3 Decrease		
Faster Deposition Rate			1 Increase			2 (a) Increase	3 (b) Smaller	
Slower Disposition Rate			1 Decrease			2 (a) Decrease	3 (b) Larger	

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 the welding current remains constant.
b. See deposition rate section of welding variables section.
c. This change is especially helpful on materials 20 gauge and smaller in thickness.

9.1.0 Fixed Variables

Fixed variables include electrode size and type, welding current type, and polarity.

9.1.1 Electrode Type

The type of electrode wire will have an effect on the welding characteristics of this process. The flux cores of the electrodes contain different components that affect bead shape, penetration, deposition rate, and the operating characteristics. Because of this, a wide variety of operating characteristics exist, which are similar to those found with the various covered electrodes used in SMAW. Some self-shielded flux-cored electrodes have been developed to operate on DCEN. These electrodes produce relatively light penetration, and are used for many sheet metal welding and weld surfacing operations. Self-shielded electrodes that operate on DCEP produce deeper penetration. Gas-shielded electrode wires operate on DCEP and provide the deepest penetration due to the gas shielding addition to the flux core.

Many FCAW electrodes are designed to produce a stable arc and high deposition rates at the higher current levels. *Figures 11-87 and 11-88* show some deposition rate comparisons between several types of flux-cored electrodes.

9.1.2 Electrode Size

Each electrode wire diameter of a given type has a usable welding current range. Larger diameter electrode wires use higher welding currents to produce higher deposition rates and deeper penetration. The rate at which the electrode melts is based on the welding current density and the components in the flux. If two electrode wires of the same type, but different diameters, are operated at the same current level, the smaller electrode will give a higher deposition rate because the current density is higher. *Figures 11-87 and 11-88* also show the deposition rates produced by different electrode diameters. The amount of penetration is also based on the current density. A smaller electrode will produce deeper penetration than a larger electrode at the same current setting, but the weld bead will be wider when using the larger electrode wire. The choice of the optimum electrode size to be used is based on the thickness of the metal to be welded, the amount of penetration required, the position of welding, the deposition rate desired, the bead profile desired, and the cost of the electrode wires. A smaller diameter electrode is more costly on a weight basis, although for out-of-position welding, the smaller diameter electrodes are the only ones that can be used. For each application, an optimum electrode size can be used to produce minimum welding costs.

Figure 11-87 — Deposition rate vs. current for externally shielded FCAW electrode wire.

Figure 11-88 — Deposition rate vs. current for self-shielded FCAW electrode wire.

9.2.0 Primary Variables

Primary variables include welding current, travel speed, and welding voltage.

9.2.1 Welding Current

The amount of welding current has the greatest effect on the deposition rate, weld bead size and shape, and the weld penetration. Welding current is proportional to the wire feed speed for a given electrode type, shielding gas type and pressure, and amount of electrode extension. In a constant voltage system, the welding current is controlled by the knob on the wire feeder control, which sets the wire feed speed. The welding current increases with the wire feed speed.

As shown in *Figures 11-87 and 11-88*, 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 variables are held constant, increasing the welding current will increase the electrode deposition rate, increase penetration, and increase the size of the weld bead. *Figure 11-89* shows the effect of welding current.

Figure 11-89 — Effect of welding current on bead formation.

An excessive welding current level will create a large, deep-penetrating weld bead that causes excessive convexity and can burn through the bottom of the joint. Insufficient welding current produces large globular transfer and excessive spatter in addition to poor penetration and excessive piling up of the weld metal. With self-shielding electrodes, insufficient current can cause porosity and pickup too much nitrogen from the atmosphere. The nitrogen causes a harder weld that has poorer ductility. *Figures 11-90, 11-91, and 11-92* show the effects of welding current on the penetration, bead height, and bead width.

Figure 11-90 — Effect of travel speed, arc volts, and welding current on penetration.

Figure 11-91 — Effect of travel speed, arc volts, and welding current on bead height.

Figure 11-92 — Effect of travel speed, arc volts, and welding current on bead width.

9.2.2 Welding Voltage (Arc Length)

The welding voltage is determined by the distance between the tip of the electrode and the work. In a constant voltage system, a voltage control knob on the front of the power source adjusts the welding voltage. The power source maintains a given voltage that maintains a certain arc length. In a constant current system, the voltage-sensing wire feeder controls the voltage. The voltage-sensing wire feeder regulates the wire feed speed to maintain the arc length that produces the preselected arc voltage. For a given welding current, a certain voltage will provide the smoothest welding arc. 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. When the other welding variables are held constant and the welding voltage is increased, the weld bead becomes wider and flatter. The effect of varying the arc voltage on a gas-shielded electrode is shown in *Figure 11-93*. The penetration will increase up to an optimum voltage level and then begin to decrease, as shown in *Figure 11-90.* A higher voltage is often used to bridge a gap because of the decreased penetration obtained. An excessive voltage or arc length will result in excessive amounts of spatter and irregularly shaped weld beads. When using self-shielded electrodes, an excessive arc length can also cause nitrogen pickup, which causes porosity in low-carbon steel weld metal. With the self-shielded stainless steel electrodes, nitrogen absorption can cause cracking. With all types of electrodes, undercutting can also be produced. A decrease in the arc length results in a narrower weld bead with a greater convexity and deeper penetration. An arc voltage that is too low will cause a narrow convex weld bead with excessive spatter and reduced penetration. *Figures 11-91 and 11-92* show the effects of the welding voltage on bead height and bead width.

Figure 11-93 — Effects of arc voltage on the weld bead.

9.2.3 Travel Speed

The travel speed influences the weld penetration and the shape of the weld deposit. In semiautomatic welding, this is controlled by the welder and will vary somewhat, depending on the welder. In machine and automatic welding, as shown in *Figure 11-90*, the penetration is at a maximum with 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 of length increases, which creates a large, shallow weld puddle. Weld metal tends to get slightly ahead of the arc, which reduces the penetration and produces a wide weld bead. Reducing the travel speed will increase the bead height, as is shown in *Figure 11-91,* and the bead width, as shown in *Figure 11-92*. Travel speeds that are too slow can result in overheating the weld metal because of the excessive heat input, which creates a very large heat affected zone. It can also cause excessive piling up of the weld metal, which has a rough appearance and may trap slag. As the travel speed is increased, the heat input into the base metal is reduced, which decreases the melting of the base metal, limits penetration, and the bead height and the bead width are also reduced. An excessive travel speed will result in an irregular, ropy weld bead that may have undercutting along the edges. *Figure 11-94* shows the effects of travel speed on the shape of the weld bead.

Figure 11-94 — Effects of travel speed on the weld bead.

The effects of the primary welding variables are summarized in *Figure 11-95* for gas-shielded flux-cored electrodes and in *Figure 11-96* for self-shielded flux-cored electrodes.

Figure 11-95 — Externally shielded flux cored arc good and bad welds.

Figure 11-96 — Self-shielded flux cored arc good and bad welds.

9.3.0 Secondary Variables

Secondary variables include work and travel angles of the electrode.

9.3.1 Electrode Extension

The electrode extension, sometimes referred to as the stickout, is the distance between the tip of the contact tube and the tip of the electrode as shown in *Figure 11-97.*

The length of electrode that extends beyond the contact tube is resistance heated in proportion to its length. The amount of resistance heating that occurs affects the electrode deposition rate and the amount of penetration, as well as weld quality and arc stability, by varying the welding current. Increasing the electrode extension reduces the welding current, as shown in *Figure 11-98*.

Figure 11-97 — Electrode extension or stickout.

In semiautomatic welding, the electrode extension can be varied by the welder to compensate for joint variation without interrupting the welding operation. Electrode extension provides a good control during welding to change the amount of penetration obtained. In FCAW, the electrode extension is a variable that must be held in balance with the shielding conditions and the related welding variables. As the electrode extension is increased, the amount of preheating of the wire is increased. For gas-shielded flux-cored electrodes, an electrode extension ranging from ¾- to 1-1/2-in. (19-38 mm) is normally recommended.

Because the shielding comes from the core of self-shielded electrodes alone, a longer electrode extension is generally recommended to take advantage of the extra preheating effect needed to activate the shielding components in the electrode core. Welding guns for self-shielded electrodes often have nozzles where the contact tube is set inside far enough to ensure a minimum electrode extension. Electrode extensions ranging from ¾- to 3-1/2-in. (19-89 mm) are commonly used. This will vary depending on the type of electrode wire so the manufacturer's data should be consulted for each electrode. An electrode extension that is too long will produce an unstable arc and cause excessive spatter. A short extension will cause an excessive arc length at a particular voltage setting. With gas-shielded electrodes, excessive spatter may result, which can build up in the nozzle and restrict the shielding gas flow. Poor shielding gas coverage can result in porosity and surface oxidation of the weld bead.

Figure 11-98 — Effect of electrode extension on welding current.

The amount of electrode extension also has an effect on the deposition rate. Increasing the electrode extension will increase the preheating effect on the electrode and therefore increase the deposition rate. *Figure 11-99* shows this for a gas-shielded flux-cored electrode.

Figure 11-99 — Effect of electrode extension on deposition rate.

9.3.2 Electrode Angles

The angle at which the welding electrode is held with respect to the weld joint is called the electrode angles. These angles have an effect on the shape of the weld bead and the amount of penetration. The electrode angles are called the travel and work angles and are shown in *Figure 11-100*.

Figure 11-100 — Travel angle and work angle.

The travel angle 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. A drag angle exists when the electrode points in the direction opposite of travel. The work angle is the angle between the electrode and the plane perpendicular to travel.

The angle at which the electrode is held during welding determines the direction in which the arc force acts on the weld pool. The electrode angles are used to shape the weld bead and to prevent the slag from running ahead of the weld pool and becoming trapped in the weld. When making flat position fillet and groove welds, gravity tends to make the molten slag run ahead of the weld pool. To compensate for this, a drag angle is used, which forces the slag back. The proper travel angle depends on the method of FCAW being used, the thickness of the base metal, and the position of welding. Using gas-shielded electrodes, maximum weld penetration is obtained with a 10° drag angle. Drag angles ranging from about 2° to 15° are normally recommended, but a drag angle greater than 25° should not be used. Drag angles greater than this do not provide good control of penetration. As the drag angle is decreased, the bead height decreases and the width increases.

This effect continues into the push angle up to a point where the bead will start to narrow down again. Push angles are generally not recommended because of the greater chances of slag entrapment occurring. For self-shielded electrodes, the drag angles used are similar to those used in SMAW. Flat and horizontal position welding is done using drag angles ranging from 20° to 45°. Larger angles may be used for thin sections. As the thickness of the metal increases, smaller angles are used to increase the penetration. For vertical position, uphill welding, a push angle of 5° to 10° is recommended. When making fillet welds in the horizontal position, the weld metal tends to flow in both the horizontal and vertical directions. To compensate for the vertical flow, a work angle of 40° to 50° from the upper plate is used. The electrode should be centered about one diameter of the electrode below the center of the weld, as shown in *Figure 11-101*. This will prevent an unequal legged fillet weld from being formed.

Figure 11-101 — Positioning the electrode for fillet welds.

10.0.0 WELDING PROCEDURE SCHEDULES

The welding procedure schedules in this chapter give typical welding conditions that can be used to obtain high quality welds under normal welding conditions. FCAW uses a wide variety of operating conditions for welding mainly steels, some stainless steels, and some nickels. The procedure schedules presented in this chapter are in no way a complete guide to the procedures that can be used for FCAW and are not the only conditions that may be used to obtain a specific weld. Other conditions could be used because of factors such as weld appearance, welder skill, method of application, and the specific application that may require variations from the schedules. For example, automatic FCAW normally requires higher amperage settings and faster travel speeds than semiautomatic welding. The type of electrode wire has a significant effect on the conditions. This is because the type of electrode wire indicates whether a shielding is required, the recommended electrical polarity, the recommended amount of electrode extension, and other factors. As the particular requirements of the application become known, the settings may be adjusted to obtain the optimum welding conditions. Qualifying tests or finals should be made under the actual conditions before applying the information in the tables to actual production welding.

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

The following schedules are based on welding plain carbon steels using various types of electrode wires in appropriate positions. Generally, electrode wires over 1/16–in. (1.6 mm) diameter are limited to the flat and horizontal positions. The welding schedules include the semiautomatic and automatic methods of application, using self-shielded and CO_2-shielded electrode wires. The tables use the base metal thickness or fillet size, number of weld passes, electrode diameter, welding current, welding voltage, wire feed speed, gas flow rate (if used), and travel speed as variables. Each table contains the type of shielding gas (if used), type of joint, and the position of welding being used. All of the schedules are based on using DCEP. Both the welding current and wire feed speed values are given because, even through 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. *Figures 11-102 and 11-103* show wire feed speeds and their corresponding welding currents for several sizes of tubular electrode wire.

Many of the charts include welding conditions for both groove and fillet welds given on the same chart. Generally, fillet welds will use the higher current levels for the ranges given and groove welds will use the lower end of the current range.

Figure 11-102 — Wire feed speed vs. welding current for externally-shielded tubular wires.

Figure 11-103 — Wire feed speed vs. welding current for self-shielded tubular wires.

Table 11-16 — Flux cored arc welding of plain and low-alloy steels using external shielding.

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^3/hr (L/mm)	Travel Speed in/min (mm/s)
1/8 (3.2)	1	3/32 (.24)	24-26	300	100 (42)	35-45 (17-21)	44 (19)
3/16 (4.8)	1	3/32 (2.4)	24-26	350	120(51)	35-45 (17-21)	42 (18)
3/16 (4.8)	1	1/8 (3.2)	24-26	450	90 (38)	35-45 (17-21)	47 (20)
1/4 (6.4)	1	3/32 (2.4)	24-26	400	155 (66)	35-45 (17-21)	24 (10)
1/4 (6.4)	1	3/32 (2.4)	25-27	500	105 (44)	35-45 (17-21)	30 (13)
5/16 (7.9)	1	3/32 (2.4)	28-30	500	205 (87)	35-45 (17-21)	22 (9)
5/16 (7.9)	1	1/8 (3.2)	28-30	500	105 (44)	35-45 (17-21)	22 (9)
3/8 (9.5)	1	3/32 (2.4)	28-30	500	205 (87)	35-45 (17-21)	15 (6)
3/8 (9.5)	1	1/8 (3.2)	29-31	575	130 (55)	35-45 (17-21)	20 (8)
1/2 (12.7)	1	3/32 (2.4)	29-31	525	220 (93)	35-45 (17-21)	11 (5)
1/2 (12.7)	1	1/8 (3.2)	30-32	625	150 (63)	35-45 (17-21)	14 (6)
5/8 (15.9)	3	3/32 (2.4)	29-31	475	190 (80)	35-45 (17-21)	12 (5)
5/8 (15.9)	3	1/8 (3.2)	28-30	500	105 (44)	35-45 (17-21)	14 (6)
3/4 (19.1)	3	3/32 (2.4)	29-31	500	205 (87)	35-45 (17-21)	13 (5)
3/4 (19.1)	3	1/8 (3.2)	29-31	500	105 (44)	35-45 (17-21)	13 (5)

Table 11-17 — Welding procedure schedules for flux cored arc welding carbon and low-alloy steel using external shielding.

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^3/hr (L/mm)	Travel Speed in/min (mm/s)
1/8 (3.2)	1	3/32 (.24)	24-26	350	120(51)	35-45 (17-21)	60 (25)
3/16 (4.8)	1	3/32 (2.4)	24-26	400	155 (55)	35-45 (17-21)	36 (15)
3/16 (4.8)	1	1/8 (3.2)	24-26	425	75 (32)	35-45 (17-21)	38 (16)
1/4 (6.4)	1	3/32 (2.4)	24-26	400	155 (66)	35-45 (17-21)	24 (10)
1/4 (6.4)	1	3/32 (2.4)	25-27	450	90 (38)	35-45 (17-21)	26 (11)
5/16 (7.9)	1	3/32 (2.4)	25-27	440	175 (74)	35-45 (17-21)	20 (8)
5/16 (7.9)	1	1/8 (3.2)	26-28	460	93 (39)	35-45 (17-21)	20 (8)
3/8 (9.5)	1	3/32 (2.4)	26-28	475	190 (80)	35-45 (17-21)	15 (6)
3/8 (9.5)	1	1/8 (3.2)	28-30	500	105 (44)	35-45 (17-21)	16 (7)
1/2 (12.7)	3	3/32 (2.4)	24-26	400	155 (66)	35-45 (17-21)	18 (8)
1/2 (12.7)	3	1/8 (3.2)	25-27	450	90 (38)	35-45 (17-21)	20 (8)
5/8 (15.9)	3	3/32 (2.4)	26-28	450	180 (90)	35-45 (17-21)	14 (6)
5/8 (15.9)	3	1/8 (3.2)	27-29	450	90 (38)	35-45 (17-21)	14 (6)
3/4 (19.1)	6	3/32 (2.4)	28-30	400	155 (66)	35-45 (17-21)	20 (8)
3/4 (19.1)	6	1/8 (3.2)	28-30	470	96 (41)	35-45 (17-21)	22 (9)

Table 11-18 — Flux cored arc welding of plain and low-alloy steels using external shielding.

Metal Thickness 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/mm)	Travel Speed in/min (mm/s)
1/8 (3.2)	1	3/32 (2.4)	24-26	325-350	120 (51)	35-45 (17-21)	56 (24)
3/16 (4.8)	1	3/32 (2.4)	24-26	350-375	130 (55)	35-45 (17-21)	48 (20)
1/4 (6.4)	1	3/32 (2.4)	25-27	375-400	137 (58)	35-45 (17-21)	41 (17)
3/8 (9.5)	2	1/8 (3.2)	26-28	450-500	107 (45)	35-45 (17-21)	24 (10)
1/2 (12.7)	2	1/8 (3.2)	28-30	475-525	120 (51)	35-45 (17-21)	14 (6)
5/8 (15.9)	2	1/8 (3.2)	30-32	575-600	155 (66)	35-45 (17-21)	14-16 (6)
3/4 (19.1)	3	1/8 (3.2)	30-32	575-600	155 (66)	35-45 (17-21)	15-20 (6-8)
7/8 (22.2)	3	1/8 (3.2)	30-32	575-600	155 (66)	35-45 (17-21)	13-18 (5-8)
1 (25.4)	4	1/8 (3.2)	31-32	575-600	155 (66)	35-45 (17-21)	12-20 (5-8)

Table 11-19 — Flux cored arc welding of plain and low-alloy steels using external shielding.

Metal Thickness 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/mm)	Travel Speed in/min (mm/s)
1/8 (3.2)	1	3/32 (2.4)	16-18	225-250	65 (27)	35-45 (17-21)	55 (23)
3/16 (4.8)	1	3/32 (2.4)	17-19	275-300	90 (38)	35-45 (17-21)	36 (15)
1/4 (6.4)	1	3/32 (2.4) 1/8 (3.2))	26-28 27-29	350-375 375-400	240 (102) 125 (53)	35-45 (17-21) 35-45 (17-21)	22 (9) 14 (6)
3/8 (9.5)	1	3/32 (2.4) 1/8 (3.2)	27-29 29-31	400-425 500-525	270 (114) 185 (78)	35-45 (17-21) 35-45 (17-21)	17 (7) 14 (6)
1/2 (12.7)	1	3/32 (2.4) 1/8 (3.2)	27-29 29-31	425-450 525-550	290 (123) 190 (80)	35-45 (17-21) 35-45 (17-21)	14 (6) 13 (5)
5/8 (15.9)	3	3/32 (2.4) 1/8 (3.2)	27-29 29-31	400-425 475-500	270 (114) 170 (72)	35-45 (17-21) 35-45 (17-21)	14-20 (6-8) 13-18 (5-8)
3/4 (19.1)	3	3/32 (2.4) 1/8 (3.2)	27-29 29-31	400-425 475-500	270 (114) 170 (72)	35-45 (17-21) 35-45 (17-21)	14-20 (6-8) 13-18 (5-8)

Table 11-20 — Flux cored arc welding of plain and low-alloy steels using self-shielding electrode wires.

Thickness of Base metal in (mm)	No. of Passes	Electrode Diameter in (mm)	Welding Voltage	Welding Current	Wire Feed Speed in/min (mm/s)	Travel Speed in/min (mm/s)
11 ga. (3.2)	1	3/32 (2.4)	25	200-225	80 (34)	16 (7)
3/16 (4.8)	1	3/32 (2.4)	26	250-275	95 (40)	12 (5)
1/4 (6.4)	1	3/32 (2.4)	26	350-375	130 (55)	10 (4)
3/8 (9.5)	2	1/8 (3.2)	28	400-425	95 (40)	12-14 (5-6)
1/2 (12.7)	2	1/8 (3.2)	29	425-450	107 (45)	14 (6)
5/8 (15.9)	3	1/8 (3.2)	28-30	400-425	95 (40)	12-16 (5-7)
3/4 (19.1)	3	1/8 (3.2)	28-30	425-450	107 (45)	12-16 (5-7)
7/8 (22.2)	3	1/8 (3.2)	28-31	475-500	120 (51)	12-16 (5-7)
1 (25.4)	4	1/8 (3.2)	28-31	425-450	107 (45)	12-16 (5-7)

Table 11-21 — Flux cored arc welding of plain and low-alloy steels using self-shielding electrode wires.

Thickness Of Base Metal in (mm)	No. of Passes	Electrode Diameter in (mm)	Welding Voltage	Welding Current	Wire Feed Speed in/min (mm/s)	Travel Speed in/min (mm/s)
1/8 (3.2)	1	3/32 (2.4)	19	200-225	60 (25)	12 (5)
3/16 (4.8)	1	3/32 (2.4)	20	250-275	80 (34)	9 (4)
1/4 (6.4)	1	1/8 (3.2)	28	375-400	110 (47)	14 (6)
3/8 (9.5)	2	1/8 (3.2)	28-30	400-425	135 (57)	13-16 (5-7)
1/2 (12.7)	2	1/8 (3.2)	27-29	425-450	150 (63)	14-16 (6-7)
5/8 (15.9)	3	1/8 (3.2)	29-31	400-425	130 (55)	13-18 (5-8)
3/4 (19.1)	3	1/8 (3.2)	28-30	425-450	150 (63)	13-16 (5-7)
7/8 (22.2)	3	1/8 (3.2)	29-31	475-500	170 (72)	13-18 (5-8)
1 (25.4)	4	1/8 (3.2)	29-31	425-450	150 (63)	13-16 (5-7)

Table 11-22 — Flux cored arc welding of plain and low-alloy steels using small diameter externally-shielded electrode wires.

Fillet Weld Size or Metal Thickness 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/mm)	Travel Speed in/min (mm/s)
1/8 (3.2)	1	.045 (1.1)	22-24	150	200 (85)	35-45 (17-21)	30 (13)
3/16 (4.8)	1	.045 (1.1)	22-24	200	270 (114)	35-45 (17-21)	24-30 (10-13)
1/4 (6.4)	1	.045 (1.1)	23-25	220	320 (135)	35-45 (17-21)	15-18 (6-8)
3/8 (9.5)	2	.045 (1.1)	24-25	220	320 (135)	35-45 (17-21)	8-10 (3-4)
1/2 (12.7)	2	.045 (1.1)	24-26	220	320 (135)	35-45 (17-21)	8-10 (3-4)
3/4 (19.1)	3	.045 (1.1)	24-26	220	320 (135)	35-45 (17-21)	8-10 (3-4)

11.0.0 PREWELD PREPARATIONS

Several operations may be required before making a weld. These operations include preparing the weld joint, setting up or fixturing the weldment, possible maintenance of welding gun and cable assembly, 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 fit-up, the quality requirements, the governing code or specification, and the welder.

11.1.0 Preparing the Weld 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 gas cutting, plasma arc cutting, air carbon arc gouging, shearing, machining, grinding, and chipping. When they can be used, the thermal cutting methods, oxyfuel gas, plasma arc cutting, and air carbon arc cutting are generally faster than the mechanical cutting methods, with the exception of shearing. Oxygen fuel gas cutting is used on carbon and low-alloy steels. Plasma arc cutting is used on carbon, low-alloy, and stainless steels 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. 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 sometimes have to be ground lightly to remove scale or contamination. Common types of prepared weld joints are the square-, V-, U-, J-, bevel-, and combination grooves. The more complex types of bevels require a longer joint preparation time, which makes the joint preparation more expensive.

Since FCAW is used on all metal thicknesses, all of the different joint preparations are widely used. 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 by machining. Machining produces the uniform groove. Carbon arc cutting is used extensively for preparing U-grooves in steels and for removing part of root passes so that the joint can be welded from both sides. Chipping is sometimes done on the back side of the weld, when full penetration is required and a thermal cutting method is not being used.

Weld backings are commonly used in FCAW to provide support for the weld metal and to control the heat input. Copper, steel, stainless steel, and backing tape are the most common types of weld backing. 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. Often, these are removed by oxy-fuel, air-carbon arc cutting, or grinding. Stainless steels are good backing materials for welding stainless steels. 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

The welds made by FCAW are susceptible to contamination during the welding process. The surface of the base metal should be free of grease, oil, paint, plating, dirt, oxides, or any other foreign material. This is especially critical when welding stainless steel. FCAW is less sensitive to contaminants than GMAW because of the scavengers and deoxidizers present in the flux core. Some flux-cored electrodes are made specifically for welding over rust and scale. This is done to make preweld cleaning less expensive. Very dirty workpieces are usually cleaned by using solvent cleaners followed by vapor degreasing. Simple degreasing is often used for cleaning carbon and low-alloy steels that have oxide free surfaces. Acid pickling is generally used for cleaning scale and rust, and can be removed mechanically by grinding and abrasive blasting.

The type of cleaning operation will vary, depending on the type of metal. 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. 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, several other tasks should be performed. One is to grind or file the edges of the joint smooth so that there are no burrs present. Burrs can cause physical pain as well as create a place to trap contaminants in a weld joint. Grinding is often used on plain carbon and low-alloy steels to remove burrs and rust or mill scale from the area in and around the joint. The surfaces of the joint and surrounding area should be wire brushed. Mild steel brushes are used for cleaning plain carbon and low-alloy steel. Stainless steel wire brushes are used for cleaning stainless steel. The joint surfaces and surface of the previous weld bead should also be cleaned off between passes of a multiple-pass weld. Stainless steel brushes should be used on these metals to avoid contamination due to rust or carbon from the mild steel wire brushes. Welding should be done soon after cleaning, especially on metals that form surface oxides, such as stainless steel. Wire brushing does not completely remove the oxide but it reduces the thickness and makes them easier to weld. Gloves should be worn while cleaning stainless steels to prevent oil or dirt from the fingers or from getting on the joint surfaces, which can also cause contamination.

11.3.1 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. The alignment is called fit-up. When fixturing is not used, it usually indicates that the resulting weld distortion can be tolerated or corrected by straightening operations. The three major functions of fixtures are:

1. Locate and maintain parts in their position relative to the assembly.
2. Increase the welding efficiency of the weld.
3. 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. The use of those devices is dependent on the specific application. These devices are more often used when large numbers of the same part are produced. When a fixture is 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 improves the appearance and the 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. Positioners are particularly important in FCAW because they allow the use of larger diameter flux-cored electrode wires when the weld joint can be rotated into the flat or horizontal fillet. The larger diameter electrodes produce higher deposition rates, are less expensive, and generally reduce the overall welding costs. Flat position welding usually increases the quality of the weld because it makes the welding easier.

11.4.0 Preheating

The use of preheat is sometimes needed, depending on the type of metal being welded, the base metal thickness, and the amount of joint restraint. For a refresher, refer again to topic 7.0.0 and *Table 11-12*. The specific amount of preheat needed for a given application is often obtained from the welding procedure.

The preheat temperature of the base metal is often carefully controlled. Several good methods of doing this are furnace heating, electric induction coils, and electric resistance heating blankets. On thin metals, hot air blasts or radiant lamps may be used. With these methods, temperature indicators are connected to parts being preheated. Another method of preheating is using torches, which give more localized heating than the previously mentioned methods. However, when using torches for preheating, it is important to avoid localized overheating and deposits of incomplete combustion products from collecting on the surface of the parts to be welded. Colored chalks and pellets are often used to measure the preheat temperature. Chalks and pellets melt at a specific, predetermined temperature. Another method of measuring the temperature is by using a hand-held temperature indicator. These indicators can give meter readings, digital readings, or recorder readings, depending on the type of temperature indicator.

Test your Knowledge (Select the Correct Response)

9. Which of the following is NOT a major type of welding variable?

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

10. Fixtures and jigs are devices that are used to hold the parts to be welded in proper relation to each other. What is this alignment called?

   A. Fixed-up
   B. Jigged-up
   C. Fit-up
   D. Butted-up

12.0.0 WELDING DEFECTS and PROBLEMS

Flux cored arc welding, like other welding processes, has welding procedure problems that may develop, which can cause defects in the weld. Some defects are caused by problems with the materials. Other welding problems may not be foreseeable and may require immediate corrective action.

12.1.0 Discontinuities Caused by Welding Technique

A poor welding technique and improper choice of welding parameters can cause weld defects. Defects that can occur when using the FCAW process are slag inclusions, wagon tracks, porosity, wormhole porosity, undercutting, lack of fusion, overlapping, burn through, arc strikes, craters, and excessive weld spatter. Many of these welding technique problems 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 cleaned to avoid creation of a discontinuity. Other problems that can occur and reduce the quality of the weld are arc blow, loss of shielding, defective electrical contact between the contact tube and the electrode, and wire feed stoppages.

12.1.1 Slag Inclusions

FCAW produces a slag covering over the weld. Slag inclusions (*Figure 11-104*) occur when slag particles are trapped inside the weld metal, which produces a weaker weld. Slag inclusions can be caused by:

1. Slag left on the previous weld pass
2. An erratic travel speed
3. Improper electrode angles that let the slag get ahead of the arc
4. A weaving motion that is too wide
5. A travel speed that is too slow which lets the weld puddle get ahead of the arc
6. an Amperage setting too low

Figure 11-104 — Slag inclusions.

This defect can be prevented by:

1. Cleaning the slag off of the previous weld bead, especially along the toes of the weld
2. Using a uniform travel speed
3. Increasing the drag angle to prevent the slag from getting ahead of the arc
4. Using a tighter weaving motion
5. Increasing the travel speed so that the arc is at the front of the weld puddle
6. Increasing the amperage setting

12.1.2 Wagon Tracks

Wagon tracks (*Figure 11-105*) are linear slag inclusions that run the longitudinal axis of the weld. They result from allowing the slag to run ahead of the weld puddle and by slag left on the previous weld pass.
This is especially common when slag forms in undercuts on the previous pass. This discontinuity occurs along the toe line of the previous weld bead and can be corrected

Figure 11-105 — Wagon tracks.

by correcting the electrode travel angles, increasing the travel speed, or by doing a better slag cleaning.

12.1.3 Porosity

Porosity (*Figure 11-106*) is gas pockets in the weld metal that may be scattered in small clusters or along the entire length of the weld. Porosity weakens the weld in approximately the same way that slag inclusions do. Porosity may be internal, on the surface of the weld bead, or both. Porosity may be caused by:

Figure 11-106 — Porosity.

1. Inadequate shielding gas flow rate for gas-shielded electrodes
2. Wind drafts that deflect the shielding gas coverage
3. Contaminated or wet shielding gas
4. Excessive welding current
5. Excessive welding voltage
6. Excessive electrode extension
7. An excessive travel speed, which causes freezing of the weld puddle before gases can escape
8. Rust, grease, oil, moisture, or dirt on the surface of the base metal or electrode
9. Impurities in the base metal, such as sulfur and phosphorous in steel

Porosity can be prevented by:

1. Increasing the shielding gas flow rate
2. Setting up wind shields
3. Replacing the cylinder of shielding gas
4. Lowering the welding current (reducing the wire feed speed)
5. Decreasing the voltage
6. Decreasing the electrode extension
7. Reducing the travel speed
8. Cleaning the surface of the base metal or electrode
9. Changing to a different base metal with a different composition

12.1.4 Wormhole Porosity (Piping Porosity)

Wormhole porosity (*Figure 11-107*) is the name given to elongated gas pockets and is usually caused by sulfur or moisture trapped in the weld joint

The best methods of preventing this are to clean the surfaces of the joint and preheat

Figure 11-107 — Wormhole porosity.

to remove moisture. If sulfur in the steel is the problem, a more weldable grade of steel should be selected.

12.1.5 Undercutting

Undercutting (*Figure 11-108*) 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. Undercutting causes a weaker joint and it can cause cracking. This defect is caused by:

1. Excessive welding current
2. Arc voltage too high
3. Excessive travel speed, which does not allow enough filler metal to be added
4. Erratic feeding of the electrode wire
5. Excessive weaving speed
6. Incorrect electrode angles, especially on vertical and horizontal welds

Figure 11-108 — Undercutting.

On vertical and horizontal welds, undercutting can also be caused by too large an electrode size and incorrect electrode angles. This defect can be prevented by:

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

12.1.6 Lack of Fusion

Lack of fusion (*Figure 11-109*) occurs when the weld metal is not fused to the base metal. This can occur between the weld metal and the base metal or between passes in a multiple-pass weld. This is less of a problem with FCAW than with SMAW and short-circuiting transfer GMAW because of the deeper penetration obtained. More care should be taken when using a weaving technique because there is a greater chance of creating this discontinuity.

Figure 11-109 — Lack of fusion.

Incomplete fusion between passes in a multiple-pass weld often is the result of welding over a previous weld bead that has excessive convexity. If an excessively convex weld bead is created, the surface should be ground off enough so that complete fusion can be made in the next pass. Causes of this defect can be:

1. Excessive travel speed

2. Electrode size too large
3. Welding current too low
4. Poor joint preparation
5. Letting the weld metal get ahead of the arc

Lack of fusion can usually be prevented by:

1. Reducing the travel speed
2. Using a smaller diameter electrode
3. Increasing the welding current
4. Better joint preparation
5. Using a proper electrode angle

12.1.7 Overlapping

Overlapping (*Figure 11-110*) is the protrusion of the weld metal over the edge or toe of the weld bead. This defect can cause an area of lack of fusion and create a notch that can lead to crack initiation. If overlapping is allowed to occur, grinding off the excess weld metal after welding can be done. Overlapping is often produced by:

Figure 11-110 — Overlapping.

1. A travel speed that is too slow, which permits the weld puddle to get ahead of the electrode
2. An arc welding current that is too low
3. An 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 by or corrected by:

1. A higher travel speed
2. Using a higher welding current
3. Using the correct electrode angle

12.1.8 Melt-Through

Melt-through (*Figure 11-111*) occurs when the arc burns through the bottom of the weld. It is usually caused by the heat input being too high. This can be caused by:

1. Excessive welding current
2. Too slow of a travel speed

Figure 11-111 — Melt-through.

3. Too wide of a root gap

This can be prevented by:

1. Reducing the welding current
2. Increasing the travel speed
3. Reducing the size of the root gap

12.1.9 Excessive Weld Spatter

FCAW may produce a small amount of spatter but excessive weld spatter creates a poor weld appearance, wastes electrodes, causes difficult slag removal, and can lead to incomplete fusion in multipass welds. Excessive spatter can also block the flow of shielding gas from the nozzle that causes porosity. The amount of spatter produced by FCAW will vary, depending on the type of metal transfer, type of electrode, and the type of shielding gas used. (Electrode wires that produce a large droplet size globular metal transfer will produce more spatter than those that produce a fine globular transfer. Self-shielded electrodes tend to produce higher spatter levels than gas-shielding types.)

The shielding gas provides slightly better arc stability. A gas-shielded electrode that is used with carbon dioxide shielding will produce higher spatter levels than the same electrode used with argon-carbon dioxide or argon-oxygen mixtures. This is due to the coarser droplet size promoted by the carbon dioxide shielding. Excessive weld spatter may also result from operating the electrode wire outside the operating ranges of amperage, voltage, and electrode extension for which the manufacturer designed the electrode. Methods of reducing the amount of spatter would be to reduce the welding current, welding voltage, or electrode extension. When gas-shielded wires are being used, changing the shielding gas from carbon dioxide to an argon-carbon dioxide mixture will further reduce spatter levels. If spatter is caused, it can be removed 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 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 that can act as an initiating point for cracks.

12.1.11 Craters

Weld craters (*Figure 11-112*) are depressions on the weld surface at the point where the arc was broken. These craters 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 can be filled in with a small deposit of filler metal. The best way of preventing weld craters is to reverse the travel of the electrode a little way back into the weld bead from the end of the weld bead before breaking the arc. Another

Figure 11-112 — Weld crater.

method is to stop the travel long enough to fill the crater before breaking the arc.

12.2.1 Cracking

An improper welding procedure, welder technique, or materials may cause cracking. All types of cracking can be classified as either hot cracking or cold cracking, and these cracks can be oriented transversely or longitudinally to the weld. Transverse cracks are perpendicular to the axis of the weld, where longitudinal cracks are parallel to the axis of the weld. Transverse cracks are often the result of longitudinal shrinkage strains acting on excessively hard and brittle weld metal. Longitudinal cracks are often caused by high joint restraint and high cooling rates. Hot cracking is a defect that occurs at higher 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 base metal. It can also occur because of 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 it can continue through successive layers if it is not repaired. Hot cracking may be prevented or minimized by:

1. Preheating
2. Using uncontaminated shielding gas, base metals, and filler metals
3. Increasing the cross-sectional area of the weld bead
4. Changing the contour of the weld bead
5. Using base metal with very low sulfur, phosphorous, and lead contents
6. Using filler metals that are high in manganese when welding steel

Crater cracks are shallow hot cracks that are caused by improperly breaking the arc. Several types are shown in *Figure 11-113*.

Figure 11-113 — Crater cracks.

Crater cracks may be prevented the same way that craters are prevented: by reversing the travel of the electrode a little way back into the weld from the end of the weld or 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, the use of a dry, high purity shielding gas, and a proper cleaning procedure can help reduce this problem. Cold cracking is often less of a problem with FCAW than GMAW because of the higher heat input of FCAW, which provides more of a preheating effect. The preheating helps to reduce slightly the problems with cold cracking due to excessive cooling rates.

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, as shown in *Figure 11-114*.

Figure 11-114 — Centerline crack.

This problem may be caused by:

1. Too small of a weld bead for the thickness of the base metal
2. Poor fit-up
3. High joint restraint
4. Extension of a crater crack

The chief methods of preventing centerline cracks are:

1. Increasing the bead size
2. Decreasing the gap width
3. Positioning the joint slightly uphill
4. Preventing weld craters

Figure 11-115 — Underbead cracks.

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 11-115*.

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, hydrogen, and a brittle microstructure. Rapid cooling causes a brittle microstructure or excessive heat input. Underbead and base metal cracking can be reduced or eliminated by using preheat.

12.3.0 Other Problems

A number of other welding problems may occur, such as those caused by magnetic fields, improper moisture, or indirect electrode arc.

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 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 11-116*.

Figure 11-116 — Arc blow.

Arc blow 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 fit-up. 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. Several methods can be used to correct the arc blow problem:

1. Welding toward an existing weld or tack weld
2. Reducing the welding current and the arc voltage
3. Placing 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
4. Change position of fixture or demagnetize base metal or fixture

12.3.2 Inadequate Shielding

Many discontinuities that occur in FCAW are caused by inadequate shielding of the arc. Inadequate shielding can cause oxidation of the weld puddle and porosity in the weld bead. This will usually appear as surface porosity. This problem can easily be 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 when using gas-shielded flux-cored arc wires are:

1. Blockage of gas flow in the torch or hoses, or freezing of the regulator with carbon dioxide

2. A leak in the gas system
3. Weld spatter blocking the nozzle of the welding gun
4. A very high travel speed
5. Improper flow rate
6. Winds or drafts
7. Too much distance between nozzle and work

The most common causes of inadequate shielding for self-shielded electrodes are:

1. Electrode extension that is too short and does not allow proper activation of shielding gas core components
2. A very high travel speed
3. Winds or drafts- self-shielding electrodes can withstand higher winds and drafts than gas-shielded electrodes; popular for use in field conditions where wind is a problem

In general, inadequate shielding is more of a problem with gas-shielding electrodes.

There are several ways that this problem can be corrected or prevented. The torch and hoses should be checked before welding to make sure that the shielding gas can flow freely and is not leaking. The nozzle and contact tube should be cleaned of spatter 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 carbon dioxide shielding in the overhead position, highest gas flow rates may have to be used to provide adequate shielding. Carbon dioxide is heavier than air and will tend to fall away from the weld area. An excessive gas flow rate can cause excessive turbulence in the weld puddle. When winds or air drafts are present, several corrective steps may be taken. One method is to switch from a gas-shielded electrode to a self-shielded electrode. Setting up screens around the operation is another method of solving this problem. Increasing the gas flow rate is helpful when using gas-shielded electrodes, or increasing the electrode extension when using self-shielded electrodes. 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 FCAW 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 for power transferred to the electrode, which can have an effect on the arc characteristics. It can also cause an irregular weld bead and possible 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, 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

Wire feed stoppages are generally less of a problem with FCAW than with GMAW because of the larger diameter electrode wires used in FCAW. However, this can still be a problem. 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:

1. A clogged contact tube
2. A clogged circuit in the welding gun assembly
3. Sharp bends or kinks in the wire feed conduit
4. Excessive pressure on the wire feed roll, which can cause breakage of the wire
5. Inadequate pressure on the wire feed rolls
6. Attempting to feed the wire over excessively long distances
7. A spool of wire clamped too tightly to the wire reel support

Wire feed stoppages, in many cases, must be corrected by taking the disassembling the gun and cutting and removing the wire, or by cutting and removing the wire from the wire feeder. 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:

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

13.0.0 POSTWELD PROCEDURE

Several operations may be required after welding, such as cleaning, inspection of the welds, and postheating. These items 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

FCAW produces a moderate slag covering that must be removed after welding. Slag removal is also required between passes of a multipass weld to prevent slag inclusions and incomplete fusion.

Slag removal is generally done using a chipping hammer. A certain amount of spatter is created in FCAW, which can make slag removal slightly more difficult. If an excessive amount of spatter is created, slag removal may become very difficult. After the slag has been removed, wire brushing or buffing can be done to remove the loose slag particles and to remove discoloration around the bead. Mild steel brushes can be used on most steels but stainless steel brushes should be used on stainless steel to prevent contamination. Spatter can be removed by grinding or wire brushing. FCAW usually produces a smooth weld surface. If a different weld profile is needed, grinding can be used, although grinding of weld profiles should be avoided due to the expense.

13.2.0 Inspection and Testing

Inspection and testing of the weld is done after cleaning to determine the quality of the weld joint. There are many different methods of inspection and testing which will not be covered in detail in this course. The uses of these methods wiII 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. There are 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, while 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. 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 usually needed 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. When maximum corrosion resistance is required, air carbon arc gouging is used on stainless steels only when grinding or wire brushing of the groove face to remove carbon deposits is done. For stainless steels, chipping is a common method for 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 FCAW or some other welding process. The welds are then reinspected to make sure that 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, depending on the type of metal being welded, the specific application, and the governing code or specifications. Many of the low-carbon and low-alloy steels 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 that are 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 steels 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. Full annealing is the heating up of a material to cause recrystallization of the grain structure, which causes softening. This softening process is done by heating a ferrous metal to a temperature above the transformation range and slowly cooling 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 that produces a quicker cooling rate and an annealed weldment is slowly cooled in a furnace. A normalizing heat treatment will refine the metal grain size and give a tougher weld, while 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 operation is performed on many steels after welding to relieve the residual stresses due to welding. This also reduces warpage during machining that may occur with a high residual stress buildup. 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 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 (Select the Correct Response)

10. What causes slag inclusions?

    A. Steady travel speed
    B. A weaving motion that is too narrow
    C. Slag left on the previous weld pass
    D. Using an electrode that is too small

11. Which of the following is a nondestructive test?

    A. Etching
    B. Liquid penetrant
    C. Tensile strength
    D. Free-bend

14.0.0 WELDER TRAINING and QUALIFICATION

To become a fully certified welder, you must know the requirements for training and qualifications. While these requirements may differ somewhat from organization to organization, and you may need to demonstrate your skills to qualify for a particular project and specific welding task, the basic guidelines are the same for achieving the training and qualifications.

14.1.0 Welder Training

FCAW requires a certain degree of skill to produce good quality welds. In semiautomatic welding, the welder has to manipulate the welding gun and control the speed of travel. Less skill is required to operate this process when compared to the manual welding processes because the machine controls the arc length and feeds the electrode wire. Welders skilled in manual welding processes and GMAW generally have less difficulty learning FCAW. This process uses similar equipment and welding techniques to those used in GMAW. At higher current levels, when using larger diameter wires, FCAW has a smoother arc and is easier to handle than larger diameter solid wires with a carbon dioxide shielding. Because of the deep penetrating characteristics of the process, lack of fusion and incomplete penetration are easier to avoid and compensate for than GMAW using short-circuiting transfer.

The exact content of a training program will vary, depending on the specific application of the process. A training program should have enough flexibility so that it can be adapted to changing needs and applications. Because of this, the emphasis may be placed on certain areas of training based on the complexity of the parts to be welded, type of metal, and governing code or specification. A welding course that covers all position welding requires more training time than one that simply covers flat position welding only. A welding course for pipe requires more training time than one for welding plate. The major purpose of the 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.

14.1.1 Basic Flux Cored Arc Welding

The basic FCAW training program is used to teach the students the basic skills necessary to weld plate. This course provides training on how to make quality fillet and groove welds. The course also gives the students the knowledge of how to set up the equipment, clean the base metal, basic operating principles, and the difficulties that are commonly encountered. The training also covers the different welding techniques used for gas-shielded and self-shielded electrodes. Also covered are the techniques for welding out-of-position using small diameter electrodes. The training obtained by the student should give the skill to perform a job welding plate. This course should also provide the background skill and knowledge required to take an advanced course for a specific application, such as for welding pipe. The following is an outline for a course approximately 35 hours long:

Topic

1. Flux Cored Arc Welding Introduction
2. Safety and Health of Welders
3. Stringer Bead, Flat Position and Adjustment of the Welding Equipment for Gas-Shielded Electrodes
4. Fillet Weld, Lap Joint, Flat Position with a Gas-Shielded Electrode
5. Fillet Weld, Lap Joint, Horizontal Position with a Gas-Shielded Electrode
6. Equipment Set-up, Operation, and Adjustment

7. Stringer Bead, Flat Position and Adjustment of the Welding Equipment for Self-Shielded Electrodes
8. Fillet Weld, Lap Joint, Flat Position with a Self-Shielded Electrode
9. Fillet Weld, Lap Joint, and Horizontal Position with a Self-Shielded Electrode
10. Joint Preparation and Weld Quality
11. Single-V-Groove Weld, and Butt Joint, Flat Position with a Gas-Shielded Electrode
12. Single-Bevel-Groove Weld, Butt Joint, Horizontal Position with a Gas-Shielded Electrode
13. Single-Bevel-Groove Weld, Butt Joint, Horizontal Position, Cut and Etch Test
14. Fillet Weld, Tee Joint, Vertical Position - Uphill Travel with an All-Position Gas-Shielded Electrode.
15. Single-V-Groove Weld, Butt Joint, Vertical Position - Uphill Travel with an All-Position Gas-Shielded Electrode
16. Single-V-Groove Weld, Butt Joint, Vertical Position - Uphill Travel, Guided Bend Test
17. Fillet Weld, Tee Joint, Overhead Position with an All-Position Gas-Shielded Electrode

14.2.1 Welder Qualification

Before a welder can begin work on any job covered by a welding code or specification, he or she must become certified under the code that applies. Many different codes are in use today, and it is exceedingly important that the specific code is referred to when taking qualification tests. In general, the following type of work is covered by codes: pressure vessels and pressure piping, highway and railway bridges, public buildings, tanks and containers that will hold flammable or explosive materials, cross country pipeline, aircraft, ordnance material, ships and boats, and nuclear power plants.

Several of the specifications include consideration of the FCAW process. These are:

1. ASME Boiler and Pressure Vessel Code, Section IX, Welding and Brazing Qualifications
2. AWS 01.1, Structural Welding Code
3. AWS 05.2, Standard for Welded Steel Elevated Tanks, Standpipes, and Reservoirs for Water Storage
4. AWS 010.9, Standard for Qualification of Welding Procedures and Welders for Piping
5. AWS 014.1, Specification for Welding Industrial and Mill Cranes
6. AWS 014.2, Specification for Metal Cutting Machine Tool Weldments