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Volume 4. Electric Arc Welding

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THIS VOLUME covers the electric arc welding and cutting processes and equipment that are required for the structural career field.

Unit 1 covers shielded metal arc welding equipment, preparation, challenges, positions, and applications including hard surfacing. Unit 2 and unit 3 covers tungsten inert gas (TIG) welding and metallic inert gas (MIG) welding equipment, preparation, challenges, positions, and applications. Unit 4 covers arc cutting using plasma and shielded metal arc welding equipment.

A glossary is included for your use.

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NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

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Electrical Terms	
Term	**Definition**
Circui t	The path taken by an electric current in flowing through a conductor from one terminal of the source of supply to the other. It starts from the negative terminal of the power supply where the current is produced, moves along the wire or cable to the load or working source, and then returns to the positive terminal (fig. 1–1). Figure 1 –1. Arc welding circuit.
Voltage	The force that causes current to flow in a circuit. Voltage does not flow; only current flows. Voltage pushes the current through the wires similar to a pump providing the pressure used to make water flow through pipes.
Ampere	Also known as Amp is a unit of measure for electricity that expresses the quantity or number of electrons flowing through a conductor per unit of time.
Ohm	An electrical circuit has a certain amount of resistance. An ohm is the amount of resistance in an electrical circuit. One ohm is the result of 1 volt applied across a resistance that allows 1 amp to flow through it.
Arc length	In shielded metal arc welding, the proper length of arc is necessary to make good welds. An arc that is too long produces an unstable welding arc, increases splatter, reduces penetration, causes flat and wide beads, and prevents the gas shield from protecting the molten pool from atmospheric contamination. If too short of an arc is used, the arc does not create enough heat to melt the base metal, the electrode has a tendency to stick, penetration is poor, and beads are uneven with irregular ripples.

Current

When a circuit carrying a current breaks, the current continues to flow across the gap between the terminals until it is no longer able to jump the gap. Superheated gases from the atmosphere and particles of metal from the terminals carry the current allowing it to bridge this gap. This action causes an intensely bright light called an electric arc. Since the resistance is very high in the arc, a great deal of electrical energy is converted into heat, both in the arc and at the points where it enters and leaves the terminals. The proper arc length causes the metal exposed to it to melt instantly.

The direct current (DC) arc-welding machine, used for electric arc welding, gets its electrical power from a generator driven by an electric motor, gas, or diesel engine. The generator voltage usually varies from 18 to 36 volts across the arc, although settings may vary with changes in arc length. Welding machines available are capable of handling a current output from 150 to 600 amperes to accommodate various arc welding requirements. The generator in most welding machines is a variable voltage type arranged to automatically adjust the voltage to the demands of the arc. Some machines allow you to manually adjust the welding current's amperage by flipping a selector switch or a series of plug receptacles. When you can manually adjust both the voltage and amperage of the welder, the machine is known as a dual control type.

Advantages direct current arc-welding has over alternating current are:

- Better at low currents and with small diameter electrodes.
- All classes of covered electrodes can be used with satisfactory results.
- Arc starting is generally easier.
- Maintaining a short arc is easier.
- Easier to use for out-of-position welding because lower currents can be used.
- Easier to use for welding sheet metal.
- Generally produces less weld spatter.

Polarity

Polarity indicates the direction of the current flow in that circuit and is a term used to describe whether an item is positively or negatively charged. In arc welding, the electrical circuit has a negative and positive terminal or pole. In a DC circuit, the current flows in one direction only. You must change polarity for certain welding operations. Heat can be concentrated where it is needed (amount of heat going into the base metal) by changing the polarity. The amount of heat going into the base metal is affected by polarity.

Straight polarity

Straight polarity (fig. 1–2) directs more heat to the metal being welded. The electrode is connected to the negative pole at the welding machine and the work is connected to the positive pole. This polarity is also known as direct current negative (DC–). Straight polarity is used when heavy deposits of metal are required.

Figure 1–2. Arc welding circuit, straight polarity.

Reverse polarity

When arc welding, you need to have the heat concentrated where it will do the most good. This is where we sometimes use reverse polarity. The welding machine is hooked up with the work connected to the negative side and the electrode to the positive side. The machine is set so that the current flows from negative to positive. This polarity is also known as direct current positive (DC+). The reverse polarity concentrates the heat more on the electrode than the material to be welded. (Figure 1–3 shows the reverse polarity circuit.) Reverse polarity is a good choice when you need to keep the material to be welded as cool as possible, such as welding cast iron or when welding overhead.

Figure 1–3. Arc welding circuit, reverse polarity.

Alternating current

When you use an alternating current (AC) welding machine, you've no choice of polarity since a characteristic of AC is to change its polarity twice during each cycle (current flows in one direction the first half of the cycle and in the opposite direction for the second half). For this reason, it is not possible to use AC machines for all types of weld. Alternating current welding has one advantage over DC welding: in AC welding, the polarity change with each cycle reduces magnetic arc blow. Alternating current is well suited for the welding of thick sections using large diameter electrodes. Alternating current's depth of penetration and deposition rates are generally intermediate between those of DC electrode positive and DC electrode negative.

Weld metal deposition

When you are shielded metal arc welding, you have to adjust to four separate and distinct forces that are responsible for the transfer, or depositing, of molten filler metal and molten slag to the base metal. These forces are identified and explained in the following table.

Weld Metal Deposition Forces	
Force	Definition
Gravity	Gravity is the main force responsible for filler metal transfer in flat-position welding. In other positions, smaller electrodes must be used to avoid excessive loss of weld metal and slag, since gravity's influence on the surface tension is unable to retain a large molten metal volume and molten slag in the weld crater.
Gas expansion	In arc welding, gasses are produced from the burning of the electrode covering. The heat generated by the electrical current causes the electrode tip to boil. This action rapidly expands the gases, projecting the electrode's metal and slag in globular form away from the solid electrode tip and into the molten crater. The coating extending beyond the electrode's metal tip controls the gas expansion direction and directs the molten metal globule into the weld crater formed in the base metal.
Electromagnetic	The electrode tip acts as an electrical conductor; the molten metal globule is also an electrical conductor and is affected by magnetic forces with the greatest influence at 90° to the direction of the current flow. These forces produce a pinching effect on the metal globules and act to speed up the molten metal separation from the electrode end. This effect is particularly helpful in transferring metal in horizontal-, vertical-, and overhead-position welding.
Surface tension	Surface tension is the force that keeps the molten metal and slag globules in contact with molten base or weld metal in the crater. It also helps to retain the molten metal in horizontal, vertical, and overhead welding and also to determine the shape of the weld contours.

Magnetic arc blow

A phenomenon of DC arc welding is the arc's tendency to waver as though an air blast is being blown against it. This tendency is often encountered when welding in corners and at the start and end of butt joints. The arc is forcibly moved by a magnetic field set up in the work by the flow of the welding current The direction and arc bending amount depend on the magnetic field direction and strength. Welders use various methods to try to eliminate this interference. The goal is to minimize or counteract the magnetic field at the point at which it is desired to hold the arc. Changing the ground plate position with reference to the arc may change the electrical current path through the work and eliminate the magnetic field surrounding the arc. Changing the electrode angle to the work is helpful in some cases. It is impossible to lay down definite rules because many factors are involved. When welding with AC, there are practically no magnetic arc disturbances.

NOTE: Magnetic arc blow results in excessive splatter and breaks the continuity of the deposited metal, making it necessary to refill the crater, which can leave weak spots.

Heat's effect on arc welding

When you are arc welding, electrical energy changes into heat. The heat's effect on the base metals grain structure is divided into three heat-affected zones.

Heat-Affected Zones	
Zone	Description
Very hot zone	This is next to the molten filler metal. It shows a transition from the molten filler metal to the annealed zone.
Annealed zone	This is next to the heated base metal. It shows a transition from the heated base metal to the annealed zone.
Zone next to the cold base metal	This shows a transition from annealed zone to the unchanged cold base metal.

The rate that heat is applied to the plates is greater in arc welding than it is in oxyacetylene welding; this causes a higher heat concentration at a particular point. The result is a steeper heat gradient with less metal affected by the heat. The electrode that you use has a big impact on the heat-affected area. When you use a non-coated metal electrode, such as stainless steel, the heat-affected zone is small. When you use a heavy-coated steel electrode, the heat-affected area is larger.

Heat affecting factors

The heat-affected area increases with the welding energy used in arc welding. The challenge is to get the current set right because the generated welding heat is directly related to the voltage and amperage settings. Greater penetration for arc welds is not necessarily obtained with an increase in the heat-affected area. This increase is in width rather than depth. Usually, the smaller the heat-affected area, the more rapid is the heat removal from the affected area. You can increase the heat-affected area in arc welding by:

- Maintaining a constant current while decreasing the welding speed.
- Maintaining a constant welding speed while increasing the current.
- Maintaining a constant welding speed while going from a thick plate section to a light plate section.
- Increasing the arc length while settings on the welding machine remain unchanged.
- Preheating the area to increase the heat-affected area.

Hardness in arc welding

The heat-affected area in shielded metal arc welding produces a greater concentrated hardness than that produced with oxyacetylene welding. The challenge is to keep the weld from cracking as it cools. In general, the greater the hardness, the more likely the weld is to crack when the molten metal solidifies. Arc welds on plate containing 35 or higher percentage of carbon show a greater increase in hardness than steels containing a lower carbon amount. In some alloy steels, carbon elements are added to increase the strength, but the carbon also increases the hardness. The carbon content in easily welded plate is usually kept low to prevent excessive hardness in the welding operation. In plain carbon steels having 25 percent carbon or less, welds made by either arc or gas welding do not change hardness, ductility, or tensile strength to a noticeable degree.

602. Selecting and maintaining SMAW equipment

In this lesson, we look at the different types of power sources and accessories for SMAW machines you may use. There are slight variations between manufacturers; however, the general characteristics and maintenance procedures are similar. Let's begin with the different types of power sources.

Welding power sources

Arc welding machines get electrical current from a commercial source, such as an electrical power line, or from a portable source, such as an engine driven generator. These machines allow you to adjust the electrical current to match your arc welding needs. Some allow you to change the AC into DC. Let's look at some of the general characteristics of different arc welding machines.

Welding machine sizes

Welding machines are rated according to their approximate amperage capacity at 60 percent duty cycle. The various sizes of machines may be 150-200, 250-300, or 400-600 amps. The size of the welding machine to be used is governed largely by the kind of welding that is to be done. The following table serves as a general guide to size and service.

Welding Machine Sizes	
Size	Used For
150-200 Ampere	Light to medium duty welding. Excellent for all fabrication purposes and rugged enough for continuous operation on light or medium production work.
250-300 Ampere	Average welding requirements. Used in plants for production, maintenance, repair, tool room work, and all general shop welding.
400-600 Ampere	A machine for heavy duty welding with large capacity and for a wide range of purposes. It is used extensively in heavy structural work, fabricating heavy machine parts, heavy pipe, and tank welding, and for cutting scrap, and cast iron.

Machine classification

We classify welding machines into two main groups: constant potential and constant current. Constant potential welding machines are used primarily for metallic inert gas welding, which we discuss later.

Constant current welding machines are designed primarily for Shielded Metal Arc Welding, sometimes referred to as "stick welding". Constant current welding machines produce a steady supply of current over a wide range of welding voltages regardless of changes in arc length. Since it is difficult to continuously hold the arc length at a prescribed distance while welding, constant current machines have small current changes with changes in arc length. Welding heat and electrode burnoff rate are influenced very little, which allows the welder to maintain good control of the weld puddle. A constant current welding machine has a sloping volt-amp characteristic which allows for easier arc starting with all types of electrodes. This characteristic allows the welder to slightly vary the heat while welding.

Alternating current transformers

These welding machines draw current only when in use; the machines are remarkably economical in electric power consumption. They're easy to adjust to the required current settings and require little maintenance. Transformer welding machines are equipped with an arc booster switch that supplies a burst of current for easy arc starting as soon as the electrode touches the work. After the arc is struck, the current automatically returns to the amount set for the job.

Advantages of a transformer machine include:

- Least expensive, lightest, and smallest of the welding machines.
- Produces AC current.
- Low operating cost, high overall electrical efficiency.
- Noiseless operation.
- Free from magnetic arc blow.

Direct current transformer-rectifiers

These welding machines are equipped with rectifiers and operate by changing or rectifying AC to DC for welding and are usually constant current-control type. These machines produce DC current in straight and reverse polarity. The polarity depends on the kind of electrode used and the material to be welded. Welders use a switch to manually change polarity. The welder can use two control knobs to adjust the welding current. One control provides an approximate or coarse amperage setting; the second control is for fine adjustment of the welding amperage. Other controls are provided for changing the welding current to the open circuit voltage and to the desired polarity. The main advantage of this type is that it allows greater flexibility for welding materials of different thicknesses by changing the slope of the output current to produce a soft or harsh arc. Other advantages include:

- The ability to adjust to produce a digging arc for deeper penetration into thick metals.
- The ability to adjust to produce a soft or quiet arc for welding light gauge metals.

Alternating current-direct current transformer-rectifiers

These welding machines are essentially a transformer that contains an electrical device which changes alternating current into direct current. They may be constant current or constant potential, depending on the design of the machine. These machines produce AC and DC current when the output terminals are changed by a switch between the transformer and rectifier. AC/DC transformer-rectifiers are more electrically efficient and quiet than the generator type. They are very versatile and can handle a great variety of welding tasks. You can choose AC or straight or reverse polarity DC by throwing a switch to one of three positions. These machines can be adjusted for current control as the welder uses a switch to set the desired current range and a dial for fine adjustment. Figure 1–4 shows a typical transformer-rectifier used in Air Force welding shops.

Figure 1–4. Transformer-rectifier welder.

Alternating current-direct current engine-driven generator

When an electrical power source is not available, a gasoline or diesel engine is used to drive the welding generator. The engine is equipped with a governor that controls the demand on the generator. The complete unit usually is mounted on a trailer chassis that can be towed to the work location.

Accessories

All arc-welding machines require certain accessories to make up a complete welding outfit. Generally these include welding cables, electrode holders, ground clamps, and cable connectors. We'll look at each of these in more detail in the following paragraphs.

Welding cables

The cables carry the current to and from the work. One cable runs from the welding machine to the electrode holder, and the other cable is attached to the work or bench. The cable connected to the work is called the ground cable. When the welding machine is turned on and the electrode in the holder comes in contact with the work, a circuit is formed; this allows the electricity to flow. It is important to use the correct diameter cable specified for the welding machine.

> NOTE: If the cable is too small for the current, it overheats and power is lost. A larger cable is necessary to carry a required voltage any distance from the machine. Otherwise, there will be an excessive voltage drop. You must take precautions not to exceed the recommended lengths with larger diameter cables because the voltage drop will lower the efficiency of your welding.

Check with the welding machine manufacturer for the proper cable size and for specific lengths and usages. Welding cable sizes depend on the welding current and the welding cable length. The following are examples of correct sizes and lengths for cable:

- Cable lengths up to 100 feet at 200 welding current require a #2 cable.
- Cable lengths up to 100 feet at 300 welding current require a #1 cable.
- Cable lengths up to 100 feet at 400 welding current require #1 or #0 cable

Use rubber-covered, multistrand copper cable made specifically for arc welding. The more strands in a given size cable makes the welding leads more flexible and easier to handle.

All welding lead connections must be tight because loose connections cause the lug, lead, or clamp to overheat. A loose connection may also produce arcing at the connection. Keep welding leads clean and handle them so that you avoid damaging the insulation.

> NOTE: Prevent welding cables from coming in contact with hot metal, water, oil, or grease, and sharp corners.

Oil and grease break down the rubber surrounding the wire. Bare wires could cause you to get shocked. Keep cables in an orderly manner to prevent them from becoming a tripping hazard.

Electrode holder

An electrode holder is essentially a clamping device for holding the electrode securely in any position. The welding cable passes through the hollow, insulated handle holder. Having an insulated holder is an advantage because it allows you to touch any part of the work without danger of short circuiting. It also allows you to change the electrodes quickly and easily. Electrode holders are made in a number of different sizes and designs to match the electrode's size and welding current. Welding with a machine having a 300-ampere rating requires a larger holder than when welding with a 100-ampere unit. Using a holder that is smaller than specified will cause it to overheat. Make sure that all exposed surfaces, including the jaws, are protected by insulation.

NOTE: Be sure the jaws of the electrode holder are properly insulated. Laying the uninsulated jaw of the holder on the bench while the machine is running will cause a flash.

Ground clamp

The work must be connected to the welding machine. This is done with a second cable. For best results, mount a brass grounding clamp to the grounding cable. Brass is an excellent ground for electrical current and, with a little care, provides excellent service for a long time. You can also fasten ground cables to the work or bench with a C clamp, a special ground clamp, or by bolting or welding the lug on the end of the cable to the bench.

Cable connectors

If you must extend a welding lead, join the two welding cables together with cable connectors like those shown in figure 1–5. These connectors fit tightly together for a good connection between the two welding leads. They also insulate the welding lead where the connection is made.

Figure 1–5. Cable connectors.

Joining welding cables with devices other than cable connectors is not safe. An example of an unsafe connection is joining welding leads with two ground clamps. In this situation, the uninsulated clamps could touch in the welding circuit, creating an electrical arc and possible fire. Another possibility is your touching the un-insulated clamps, making you part of the welding circuit. This could cause you to receive a serious shock.

Operator maintenance requirements for arc welding machines

Welding machines require routine maintenance to keep them operating safely and properly. One primary task is to always remove dust and grit after use. Although you can perform routine maintenance, you should have a qualified electrician perform any extensive repair or adjustment

The following periodic maintenance schedule should help to prevent a major breakdown and prolong the arc welding machine's life. You can find maintenance requirements in your shop's machine maintenance guides or the owner's manual. Keep an inspection record for each machine, noting all maintenance performed and dates performed.

Cleaning and inspection

Review and follow your shop's maintenance schedule to keep the welding machine in good operating condition. On a daily or as-used basis, check the cables, ground, and electrode holder for bare wires and loose connections. On a weekly basis, check the welding machine for loose nuts, bolts, screws, or parts. These work loose due to the vibrations caused by the cooling fan and generator.

Air is drawn into the machine by the cooling fan and circulated through passages and around the windings. An accumulation of dust in these areas can cause increased operating temperatures. Clean out the machine with dry compressed air. If the machine is greasy, take it apart and thoroughly clean it as needed or on a monthly basis.

Electrical parts

Using the monthly inspection, check the brushes and commutator. Also check the switch contact points and bearings. To assure positive brush contact, replace brushes that have worn enough to reduce their spring tension, and brush springs that have been weakened from overheating.

Each time the brushes are replaced, check the commutator for cleanliness and wear. A commutator in good condition has a deep bronze color. Remove ridges or pockets on the commutator surface by turning it down on the lathe. Sand electrical switch contacts smooth if they're pitted. Replace badly burned contacts.

> NOTE: The electrical parts maintenance, repair, and replacement mentioned, is usually done by vehicle maintenance or another trained professional. If done incorrectly, it could cause serious injury or even death, as well as damage the machine.

Lubrication

Usually, we lubricate a welding machine's moving parts based on the hours that it is in operation. To find out, check the manufacturer's maintenance schedule. It's a good idea to make sure that the machine is lubricated at least every 4 to 6 months even if it's not used much. When lubricating the welder, be sure that you don't use too much grease. Excess grease can be thrown on the commutator or windings, causing the insulation to deteriorate and possibly causing a short circuit. Use the grease specified by the manufacturer on the data plate or in the maintenance requirements.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

601. SMAW principles

1. Briefly explain each of the following terms:

   a. Circuit.

   b. Voltage.

   c. Ampere.

   d. Ohm.

2. Why is a long arc length undesirable when performing arc welding?

3. What polarity is present when the electricity flows from the electrode to the work?

4. List the four forces responsible for transferring the molten metal when arc welding.

5. What condition causes arc blow?

6. What three heat-affected zones do you encounter when arc welding?

7. Does greater penetration mean you'll have a larger heat-affected area? Why?

8. How does the arc length affect the heat-affected area?

9. How is the heat-affected area changed when you keep the current constant but decrease the welding speed?

10. Comparing arc welding to oxyacetylene welding, which produces greater hardness in the heat-affected zone?

602. Selecting and maintaining SMAW equipment

1. What size welding machine is used for average welding requirements and in plants for production, maintenance, and all general shop welding?

2. Welding machines are classified into what two main groups?

3. Which welding machine is the least expensive, lightest, and smallest?

4. Which welding machine can provide AC and DC straight and reverse polarity welding current?

5. What can we use to produce welding current when we are working in the field where no commercial source of electrical power is available?

6. What is the advantage of having an insulated electrode holder?

7. When you are joining welding cables, what do you use to extend them?

8. Where can you find detailed instructions about the maintenance of arc welding machines?

9. What four electrical parts must you check monthly?

10. How often do you lubricate a welding machine's moving parts?

1–2. SMAW Electrodes and Machine Setup

In this section, we discuss the different types of electrodes, machine setup, and weld preparations. You must be able to determine which electrodes are suited for different welding tasks and how to properly setup a SMAW machine and prepare metal for specific jobs. Let's begin with SMAW electrodes.

603. Selecting SMAW electrodes

When selecting an electrode for a job, you must know the electrode's specific characteristics, properties, welding current, polarity, and position, as well as properties of the base metal, diameter of the electrode, and type of joint. Many electrode classification charts list the basic characteristics or differences in electrodes to help you to determine the best electrode to use. The electrode you select must be able to produce the required characteristics needed. The ideal electrode provides these characteristics:

- Smooth and constant arc.
- Smooth weld bead with maximum strength and minimum spatter.
- Able to fill in the crater for the required amperage used.
- Easy slag removal.

When selecting an electrode you always consider the properties of the base metal. The electrode used must produce a weld with approximately the same mechanical properties as the base metal. The electrode must also match the composition of the metal to be welded.

Proper diameter is important when selecting the appropriate electrode for a job. The electrode you select must not be larger than the thickness of metal to be welded.

NOTE: The largest diameter that you use for overhead and vertical positions is $\frac{3}{16}$ inch.

You must also consider welding current and polarity when selecting an electrode. Electrodes are designed to be used with AC, DC straight, or DC reverse polarity. Some manufacturers designate DC electrodes as DC-Electrode Negative (DC-EN) and DC-Electrode Positive (DC-EP). This designation helps to minimize electrode polarity confusion.

Some electrodes are made to produce better results in certain positions. As you make your electrode selection, match it to the position as well as the job.

Electrode classification

The most commonly used electrodes in the structures career field are the E 6010, E 6011, E 6013, and the E7018. Before you can select an electrode, you need to know how it's classified. The Air Force uses two common classification methods. The first is the American Welding Society (AWS) classification number and color code method (the industry standard). The other is the military specification method. Let's take a closer look at these classification methods.

American Welding Society classification

The AWS classifies electrodes with letters, numbers, or a combination of them—for example, E–6010 or E–7010–A1. These numbers and/or letters identify the material that you can weld with the electrode along with the electrode's color coating. The AWS number code can have either four or five digits. The (E) at the beginning signifies electric welding. The numbers tell you the weld's tensile strength for that particular electrode (rod) and indicate the recommended welding position and current use.

Four-digit number electrodes

Most mild steel and low alloy electrodes use a code with a four-digit number, such as E–6010, E–7014, and E–7018. The four-digit electrode number, E–6010, is broken down as follows:

Breakdown of 4 Digit Electrode Number: E–6010	
Digits	Meaning
1st & 2nd	Tensile strength in thousands of psi
3rd	Recommended welding position.
4th	Special characteristics.

As the chart shows, always read the first two digits together. They designate tensile strength in thousands of pounds per square inch (psi). The E–6010 electrode, for instance, has a 60,000-psi strength; whereas E–7014 has a 70,000-psi strength. The third digit (the 1 in E–6010) specifies the position (or positions) in which you can use the electrode most satisfactorily. This digit, 1, 2, or 3, indicates the recommended welding position as follows:

Digits Indicating Recommended Welding Position	
Digit	Recommended Welding Position
1	All positions.
2	Flat and horizontal positions.
3	Flat position only.

The fourth digit can be from 0 through 8. It identifies special characteristics such as the electrode coating, weld quality, arc required, weld penetration amount, or power supply needed. The following table shows an example of what the fourth represents:

What the Electrode's Fourth Digit Represents			
Number	Meaning	Number	Meaning
0	DC reverse polarity when the third digit is 1	4	AC or DC reverse polarity or straight polarity
0	AC or DC when the third digit is 2 or 3	5	DC reverse polarity low-hydrogen
1	AC or DC reverse polarity	6	AC or DC reverse polarity low-hydrogen
2	AC or DC straight polarity	7	AC or DC (iron powder plus low hydrogen sodium covering) reverse polarity or straight polarity
3	AC or DC reverse polarity	8	AC or DC (iron powder plus low hydrogen sodium covering) reverse polarity

Five-digit number electrodes

We read electrodes with five-digit numbers slightly different than we do four digit numbers. The difference is that for these you read the first three digits together; for example, E–10010 designates an electrode having a 100,000 psi tensile strength. The fourth digit specifies the welding position (or positions). The fifth digit indicates special characteristics. Here is a breakdown for the five-digit number E–10010.

Breakdown of Five Digit Number: E–10010	
Digits	Indication
1st, 2nd, & 3rd	Tensile strength in thousands of psi.
4th	Recommended position or positions.
5th	Current type.

Filler group classification

The AWS uses a filler group classification to identify electrodes by filler material. The category divides electrodes into groups that share certain filler material. The table below explains the filler group classifications.

Filler Groups	
Class	Explanation
F–1	Alloy steel electrodes are used in welding chrome molybdenum and chrome nickel molybdenum steels when heat treatment is required. The corresponding AWS electrode specifications would be E–7020 or E–10020. These electrodes are generally used with straight polarity, but may also be used with AC. Only the smaller diameter electrodes, $^{5}/_{64}$- and $^{3}/_{32}$- inch, are adaptable to all positions. The larger diameter electrodes are generally used for horizontal fillets and flat work where deep penetration is not required.
F–2	Corresponds to the AWS electrodes whose last two digits are 12 or 13, such as E–6012 or E–6013.
F–3	Corresponds to the AWS electrodes whose last two digits are 10 or 11, such as E–6010 or E–6011. These electrodes are used with DC reverse polarity, except when specified as an AC electrode. Penetration is deep, which is normally preferred for good fit-up and vertical or overhead welding. These electrodes are not used when heat treatment is required.
F–4	Companion electrodes to the class C electrodes under the same specification and are used when deeper penetration is required. They're used to weld chrome molybdenum (4135 and 41400) and chrome nickel molybdenum (8735 and 8740) steels (with preheat of the parts to 400 to 500 ºF). The corresponding AWS electrode specifications would be E–7030 or E–10030. These electrodes are generally used with reverse polarity, but they may also be used with AC. They're all-position electrodes.

American Welding Society color code

This code uses three markings: (1) primary, (2) secondary, and (3) group. (See the electrode color identification data chart below.) The primary and secondary color indicates the electrode composition, while the color group indicates the current type. The electrode's primary color is on the electrode's top or on its grip end. The electrode's secondary color is located on the grip end midway between the electrode's end and its flux coating.

The group color is located on the flux coating just below the electrode's grip end.

We show the color coding for some common electrodes in the following table.

ELECTRODE COLOR IDENTIFICATION DATA					
Mild Steel					
Coating Color	End	Spot	Group	Special	AWS Class
White					E–6010
Brick Red					E–6010
Tan		White			E–6012
Gray		White			E–6012
White		Blue			E–6011
Dark Tan		Brown		Green	E–6013
Gray Brown	Black	Brown			E–7014 E–6014
Tan		White		Green	E–6012
Brown		Blue			E–6011
Dark Gray	Black	Yellow			E–7024 E–6024
Red Brown		Silver			E–6027
Gray	Black	Yellow		Green	E–7024 E–6024
Gray	Black	Orange	Green		E–7018 E–6018
Gray Brown	Black	Black			E–7028 E–6028
Low Alloy, High Tensile Steel					
Pink	Blue	White			E–7010–A1
Pink	Blue			Green	E–7010–G
Dark Red	Blue	Yellow	Silver		E–7020–A1
Gray				9018	E–9018–G
Gray				11018	E–11018–G
Stainless Steel					
Pale Green	Yellow		Black	308–15	E–308–15
Gray	Yellow		Yellow	308–16	E–308–16
Gray	Brown		Yellow	308L–16	E–308L–16

ELECTRODE COLOR IDENTIFICATION DATA					
Mild Steel					
Pale Green	Red		Black	310–15	E–310–15
Gray	Red		Yellow	310–16	E–310–16
Gray	Brown	White	Yellow	316L–16	E–316L–16
Pale Green	Yellow	Green	Black	318–15	E–318–15
Pale Green	Yellow	Blue	Black	347–15	E–347–15
Gray	Yellow	Blue	Yellow	347–16	E–347–16
Bronze & Aluminum					
Peach	Yellow	Blue	Blue		E–CuSn–C
Peach					Al–43
Cast Iron					
Light Tan	Orange				Est
Black	Orange	Blue	White		Eni

As you can see in the table, not all electrodes have all three markings. Also, some electrodes have a special marking at their center. This marking, which is usually three spots, is a manufacturer's trademark. If you want more information on AWS, check their worldwide website http://www.aws.org/w/a.

Military specifications

Military specifications use a code such as MIL–E–15599, type 6010, C1 1 to identify electrodes for specific welding tasks. Figure 1–6 shows a sample page taken from Technical Order (TO) 34W4–1–5, section D, Operator Manual—Welding Theory and Application. It shows some military specifications codes and explains what you can weld with the electrode. It also references the military specification with federal stock number to make it easy to order electrodes through the federal supply system. You can get more details on military specifications by reviewing TO 34W4–1–5.

Figure 1–6. Electrode specifications.

Electrode coatings

When heated to high temperatures, steel readily combines with the oxygen and nitrogen in the air surrounding the arc. This results in oxide and nitride formation, causing brittleness in the weld. To control this, an electrode’s wire core is coated with a substance that prevents the oxides and nitrides from forming during the welding process. The coatings on metal arc welding electrodes range from fluxing agents, such as the fluxes used in certain oxyacetylene welding applications, to chemical compositions for specific arc welding applications. These coatings produce a gas that excludes air from the arc and forms a slag, which acts as a blanket on the pool of molten steel and purifies it. These coatings provide easier arc starting, stabilize the arc better, reduce splatter, and permit better penetration. The flux gases protect the weld from outside atmospheric contaminants.

The flux forms a slag over the deposited metal, which further protects the weld until the metal cools sufficiently so that it is no longer affected by outside atmospheric contamination. The slag also slows the cooling rate of the deposited metal, thereby permitting a more ductile weld to form.

Metal arc electrodes may be classified as either thinly coated or light-coated electrodes or shielded metal arc or heavy-coated electrodes. They are described more fully in the table below.

Metal Arc Electrode Classifications	
Type	Description
Light-coated electrodes	Light-coated electrodes are made from wire. The material used to make the wire has a definite composition that is designed to maintain quality throughout. The wire surface has a thin coating that is applied by washing, dipping, or drawing. These coatings are chiefly of iron oxide and titanium dioxide. The use of light-coated electrodes is very limited because these electrodes are very difficult to weld with and they produce brittle welds with low strength. Practically all welding is done with heavy-coated or shielded metal arc electrodes.
Heavy-coated electrodes	Like the light-coated electrodes, shielded metal arc or heavy-coated electrodes are also made from wire. The material used to make the wire has a definite composition, which is designed to maintain quality throughout. The wire is then wrapped with a heavy coating instead of having the coating applied. The heavy coatings are divided into three classifications: x Cellulose. x Mineral. x Cellulose and mineral (mixed together in various amounts). The cellulose coatings are made from wood pulp, sawdust, cotton, or various compositions obtained from the manufacture of rayon and are used on reverse polarity electrodes. The mineral coatings are made of metallic oxides or silicates and are used on straight polarity electrodes.

Electrode characteristics

The electrode types that you use have their own special characteristics, which either help or hinder your welding job. You must know these characteristics in order to select the correct electrode for a job. The table below covers four of the five electrodes and their characteristics; the more detailed discussion of the heavy-coated electrodes follows the table.

Electrode Types and Characteristics	
Type	Characteristics
Fast-freeze electrodes	E 6010 and E 6011 electrodes both produce a snappy, deep penetrating arc and fast-freezing deposits. They have little slag and produce flat beads. Fast-freeze electrodes are used for all types of all-position welding.
Fill-freeze electrodes	E 6012, E 6013, E 7014, E 7016, and E 7018 electrodes all produce a moderately forceful arc with a deposit rate between the fast-freeze and fast-fill electrodes. These electrodes provide complete slag coverage and weld beads with distinct, even ripples. Fill-freeze electrodes are general purpose electrodes and can be used in all positions.
Fast-fill electrodes	E 6020, E 6027, E 7024, and E 7028 electrodes all produce a soft arc and have a fast deposit rate. These electrodes all have a heavy slag and produce exceptionally smooth weld beads. Fast-fill electrodes are generally used for production welding.
Light-coated electrodes	These electrodes have a light protective coating, but usually do not produce slag. The electrodes that do produce slag produce only a very thin layer, which does not give very much protection to the weld.

Heavy-coated electrodes

The heavy-coated electrodes are the ones most commonly used because their coating improves the weld's physical properties. The coatings also control arc stability and increase welding speed and improve welding control in the vertical and overhead positions. This control is produced because the heavy coated electrode (filler metal rod) actually burns (melts) about $^{1}/_{16}$ inch inside of the coating. Figure 1–7 shows how heavy-coated electrodes provide shielding.

Figure 1–7. Arc characteristics of heavy-coated electrodes.

The cellulose-coated electrode depends on a gaseous shielding, or a covering, for protection. The mineral-coated electrode uses the slag as a shield. The slag is mainly silicon dioxide and aluminum oxide, which forms a blanket over the weld deposit to reduce the molten metal's cooling rate. Some common heavy-coated electrodes' characteristics in the AWS class are described in the following paragraphs.

E–6010 electrode

The E–6010 electrode is a widely used shielded metal arc welding (SMAW) electrode, mainly because it can be used in all positions. The weld deposit has physical properties as good as other electrodes and is considered fast-freeze. We sometimes refer to it as the cellulose type because the coating contains a considerable amount of cellulose, such as wood flour or paper flour, combined with other ingredients which are added to get certain qualities, such as slag volume and fluidity. The arc heat causes the coating to burn and generate gasses in large volumes, which effectively shield the molten metal from air, thus preventing harmful oxides and nitrides from forming. This electrode has good penetration, as well as quick weld metal slag cooling, which makes it ideal for vertical and overhead work. The E-6010 electrode is designed primarily for welding mild and low alloy steel. Use it where there is an absolutely good fit-up due to its deep penetrating arc characteristics.

E–6011 electrode

The E–6011 is a fast-freeze electrode and is designed to perform the same work with alternating current that the E–6010 performs on reverse polarity direct current. It is an all-position electrode with somewhat more slag than the E–6010. The coating contains gas, slag-forming ingredients, and other material for sustaining the arc when both current and voltage are alternating from maximum positive values through zero to maximum negative values. The welding current range for various electrodes that can be used satisfactorily is narrower than in the case of E–6010, which means that the welding current controls must be more exact.

E–6012 electrode

The E–6012 electrode is used with DC straight polarity but does very well with AC, as is the case with most straight polarity electrodes. It is an all-position electrode that is used for fast welding and produces less splatter than most other types. The penetration is not deep; consequently, the E–6012 electrode has many advantages on jobs where the fit-up is poor or where light-gauge material is used. Its tendency to burn through the material is less than that of the E–6010 or E–6011. The bead profile is not as flat as that of the E–6010, but it is often desirable for producing horizontal fillets with good weld appearance.

E–6013 electrode

The E–6013 fill-freeze electrode, operating on AC, serves the same purpose as the E–6012 operating on DC straight polarity. Although it is satisfactory with DC straight polarity, its original intent was to pair it with E–6011, as the E–6012 pairs with the E–6010. The E–6013 is an all position electrode used most effectively for welding lightweight tubular assemblies and sheet metal. The coating contains a high percentage of material for stabilizing and maintaining an arc. Maintaining the arc and slag removal are easier, spatter loss is low, and the bead is flatter and smoother with shallower penetration than that usually obtained with the E–6012.

E-7018 electrode

The E-7018 fill-freeze electrode is a low-hydrogen, all position high speed, fast deposition-rate electrode designed to pass the most severe x-ray requirements when applied in all welding positions, using either AC or DC reverse polarity. Its puddle fluidity permits gases to escape when the lowest currents are used for out-of-position welding. The penetration and deposition rate are both typically moderate.

Conserving and storing electrodes

You must be concerned with using as much of an electrode as possible to prevent being wasteful. Do not discard electrodes until they are down to 1 ½ to 2 inches long. Ensure you always store electrodes in a dry place. Keep mild steel and iron powder electrodes at a normal room temperature and 50 percent maximum relative humidity. Low-hydrogen electrodes are especially vulnerable to moisture; after you remove them from their container, store them in a drying oven at a temperature between 250 and 400 °F.

> NOTE: Do not bump, bend, or step on electrodes. This causes the coating to weaken and fall off.

604. SMAW machine setup and general safety procedures

There are many ways to set up arc welding equipment. Your goal is to always do it safely. Let’s take a look at ways that you can set up for arc welding and always work safely.

Setup

The common setup factors include:

- Welding task.
- Welding machine type.
- Electrode selection.
- Current selection.
- Safety procedures.

Before welding, consider all five factors; they’re dependent on each other and enable you to correctly set up and produce a quality weld. The welding task that you must perform will influence your electrode selection. This affects the current and voltage and helps determine the welding machine that you use. If your work requires deep penetration and is on thick plate, you need a different electrode than that required for a shallow penetration weld. At the same time, the proper welding current and polarity selection depends on the electrode, plate thickness, and the position of weld. When welding in the flat position with an electrode of the same size, you can use higher current than when you weld in vertical or overhead positions. Since these relationship factors affect each other, we can only use generalized data, such as we show in figure 1–8, to aid us in setting up for arc welding. Consequently, you may set up for arc welding in a slightly different way than others because of individual preferences. However, there is one factor that we all must always be aware of and follow—SAFETY!

Figure 1–8. Electrode diameter/length and amp setting range.

Safety precautions

Many accidents are caused by defective equipment, not following safety precautions, and by not knowing safety rules or practices. In an emergency not covered by the rules listed here, follow your supervisor's instructions, shop safety guides, and any Air Force Occupational Safety and Health (AFOSH) safety standards.

Electrical shock hazards

The AC and DC open circuit voltages are low in comparison with voltages used for lighting circuits and motor-driven shop tools and, normally, cause neither injury nor shock. However, these voltages can cause severe shock when your body or clothing is wet. You must always consider this every time you weld, particularly in hot weather when you are sweating. Consequently, always check the welding equipment to make certain that the electrode connections and the insulation on the electrode holders and cables are in good condition. Keep your hands and body insulated from the work, metal electrode, and holder. Avoid standing on wet floors or coming in contact with grounded surfaces.

Check your welding cables to make sure their rated electrical current capacity is capable of handling your welding task. Excessive current creates heat in the cables, which damages the insulation and can lead to severe electric shocks or fires. Inspect the cables periodically for loose connections, defects due to wear, or other damage. Defective or loose cables can cause a fire or an electrical shock. Replace defective electrode holders and always tighten connections to the holder.

Protection from toxic fumes

When welding on metals that are coated with or contain materials that emit toxic fumes, you must protect yourself from their effects. Some materials that emit toxic fumes are paint and galvanizing or plating material. Always comply with all safety precautions concerning toxic fumes. If you are unsure, check your shop's welding safety procedures or ask your supervisor before you do any welding.

A good way to reduce or eliminate toxic fumes is to clean the toxic material from the metal's surface before you begin welding. If you cannot remove the toxic material, some common ways to protect yourself are by using local exhaust or dilution ventilation or by wearing an air-supplied respirator.

Dilution ventilation

Dilution ventilation is not the most effective for controlling fumes. It works by diluting the contaminated air in the work area by circulating it with cleaner air. You can do this by opening windows or using fans to move the air around. If fans move air around within the work area, there must be some fresh outside air brought in or the air must be filtered. If the air in the workspace is moved around without introducing any outside or filtered air, the entire workspace eventually becomes filled with toxic fumes.

Local exhaust ventilation

Local exhaust ventilation is the most effective method for controlling toxic fumes. This method is designed to collect air contaminants close to the welding operation and remove them from the workspace. There are many local exhaust systems available. They include the movable exhaust collector, the cross-draft table, and the downdraft table.

Whichever exhaust system you use, there is one rule to always keep in mind: AVOID BREATHING THE FUME PLUME! The fume plume is the cloud of contaminated air that rises from the arc and molten weld pool. It contains such toxic gases as carbon monoxide, phosgene, and nitrogen oxides. To limit your exposure, position the work, your head, and the exhaust equipment in such a way that the fume plume stays clear from the air you breathe. Exhaust effectiveness tests have shown that fume removal is more effective if the airflow is across the welder's face, instead of from behind the welder.

Eyes

Safety precautions that you take to protect your eyes are critical when arc welding. Consider the helmet your most important safety equipment item. It uses a shaded lens to filter out the harmful light produced during arc welding. The following chart shows the different shade numbers and the welding amperage range in which they are used.

Lens Shade Number	Amperage Range
10	75 to 200 amperes
12	200 to 400 amperes
14	Over 400 amperes

During the welding process, small particles of metal fly upward from the work and may lodge on the lens. To protect your eyes, always insert a clear plastic lens inside the welding helmet.

NOTE: Since you must have clear vision at all times during welding, always replace the cover lens when accumulated spatter interferes with your vision.

Since the arc rays are also harmful to the eyes of anyone in the area, you must protect people from looking at the arc by welding in a booth or behind a welding curtain. When you must do welding in the open, warn persons in the area about the arc welding hazards. Specifically mention the possible eye damage caused by looking directly at the arc. If possible, people should stay out of the welding area. If they must stay in the area, we recommend that they protect their eyes with tinted safety goggles or shields.

Because the welding helmet does not provide total protection, wear goggles or safety glasses at all times when welding. While removing slag, tiny particles are often deflected upward. Without proper eye protection, these particles may cause a serious eye injury.

Clothing

Wear protective clothing when welding. Wear leather gauntlet style gloves to protect your hands and forearms from the heat and injurious rays emitted by the arc. A leather apron is also recommended for protection against flying molten metal particles. A leather jacket or leather sleeves are required for vertical and overhead welding. Wear high-top shoes with safety toes. Turn down trouser cuffs and wear leggings for the most hazardous operations. Do not wear torn or ragged clothing, as it catches fire easily and exposed body parts can be painfully burned.

Welding permit

When you weld outside of the welding shop area, you must get written permission using an AF Form 592, USAF Welding, Cutting, and Brazing Permit. We use this form to ensure that adequate precautions for fire and personal safety have been taken.

The AF Form 592 is usually issued by the fire protection flight's technical service element (base fire department). It is your responsibility to make sure you have this permit in your possession before you start any spark-producing operations. This form also notifies the fire department that you'll be performing a hazardous operation and that the possibility of fire is greater where you are working.

When you are welding, you must have an additional person serve as a fire watch. The fire watch duty person stands by with a fire extinguisher handy. This individual's primary duty is to immediately put out a fire if one occurs. This person must also stand-by and observe the weld area to make sure that it cools to the point that a fire has no chance to start. The fire watch standby time is based on the welding type and on the material subject to combustion near the weld.

Before welding or cutting on drums, tanks, or other containers that previously stored flammable materials, purge them and test them for flammable material and gas presence. Refer to AFOSH Standard 91–5, Welding, Cutting, and Brazing, for specific purging and testing procedures.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

603. Selecting SMAW electrodes

1. How does the American Welding Society classify electrodes?

2. In a four-digit electrode number, what does the third number indicate?

3. What do the first three numbers in a five-digit electrode number indicate?

4. Electrode E–7020 belongs to which filler group class?

5. Using the Electrode Color Identification Data chart, indicate the color coding used on each of the following electrodes:

   a. E–7018.

   b. E–6012.

   c. E–6028.

   d. E–11018G.

6. How do electrode coatings prevent brittleness in the weld?

7. Associate the following terms with light-coated or heavy-coated electrodes by writing the corresponding term by each one.

_______________ a. Cellulose coated.

_______________ b. Improves welding control in the vertical position.

_______________ c. E–6010.

_______________ d. Controlled gaseous shield.

8. Which electrodes have little slag, produce flat beads, and are used for all types of all-position welding?

604. SMAW machine setup and general safety procedures

1. List the five factors you must consider when setting up for arc welding.

2. When are you particularly susceptible to severe shock from AC and DC open-circuit voltages?

3. What ventilation rule must you keep in mind when welding?

4. To provide eye care when welding, what feature of your helmet do you check?

5. How can you effectively protect your hands when welding?

6. What form must you obtain before welding, cutting, or brazing outside of the shop area?

1–3. SMAW Procedures

Sometimes you need to weld a metal component to a flat metal surface, but the area where they join does not allow using a single bead weld to join them together. In this situation, one approach is to build up the flat surface to allow making a good weld joint. The lessons in this section explain what you need to do to accomplish that.

605. Bead welding and padding flat surfaces

You can correct minor welding fit up challenges when flat surfaces are involved, that is, if you know how to build them up. In this lesson, we discuss how you can do that by running welding beads on flat surfaces through a process called padding—more commonly known as surfacing.

Bead welding

Your first requirement for bead welding is to make sure that you have clean working surfaces. Oil, dirt, and other foreign matter on the metal to be welded can cause welding defects such as lack of fusion, porosity, or slag inclusions. Next, you must select the proper electrode for the welding task. When welding, we recommend you tilt the electrode 15° to 30° in the welding travel direction and 90° transverse (work angle) as shown in figure 1–9. Tilting the electrode gives you a clearer crater view and helps to control the molten slag. The proper arc length or gap between the end of the electrode and the plate should be approximately equal to the electrode diameter. However, when striking the arc (fig. 1–10) and starting the weld, hold a long arc momentarily to preheat the base metal and permit fusion at the beginning of the weld. At the end of the weld, shorten the arc length to prevent forming a crater or depression. If the current, polarity, and length of the arc are correct, the metal melts forming a pool of molten metal at the point where the arc strikes the plate. Molten metal is forced out of the pool by the arc blast. A small depression forms in the base metal and the molten metal piles up around it; this arc crater is shown in figure 1–11. The crater size and depth depend on the current setting, travel speed, electrode diameter, and arc length. The crater depth allows you to observe and control the penetration or depth to which the arc melts into the base metal. The penetration depth should not be less than $^{1}/_{16}$-inch.

Figure 1–9. Electrode angle for welding beads.

Figure 1–10. Striking the arc.

Figure 1–11. Arc crater.

The travel speed depends on the bead desired, current value, and electrode size. Gauge the travel speed by observing the crater's trailing edge. By closely watching the crater and its trailing edge, you can determine the penetration and reinforcement width and height. Since the travel speed and current setting are related factors in determining the weld quality, you must learn to recognize the weld appearance resulting if either factor is wrong. Figure 1–12 shows the results of using various welding speeds and current values.

Figure 1–12. Arc welding results.

Padding

Padding or surfacing (building up) is a welding operation we use to increase metal thickness (T). You can use it to build up worn parts to their original dimensions or to build up a flat surface. Padding large parts is generally done in stringer bead layers welded at right angles to each other (fig. 1–13). Padding small parts is usually done in a thin metal layer or layers. You can produce it by weaving your electrode to produce a wide and thin cross section bead.

Figure 1–13. Padding layers.

Electrode selection for padding

Use a heavy-coated electrode if dense, ductile, hard, or corrosion-resistant properties are required in the deposited metal. There are many factors for you to consider for electrode selection. Perhaps the most important is the material size; for example, the mass of a 6-inch diameter shaft would permit you to use a larger electrode with higher current values than you would a 1-inch diameter shaft.

Welding procedures for padding

In padding it is essential to merge (overlap) successive and adjacent stringer beads. When laying each pass, hold the electrode so that it fuses into the base metal and adjacent beads at the same time (fig. 1–14). When the beads are not merged in this manner, defects show up as voids and slag inclusions (fig. 1–15). You usually have a choice of running the beads either parallel or at right angles to the longest work dimension. You normally weld parallel to the work because it permits a longer time interval before the concentrated arc heat comes back to the starting point. This procedure minimizes welding stresses by giving the weld area more time to dissipate arc heat.

Figure 1–14. Excellent padding example.

Figure 1–15. Poor padding example.

We usually encircle the part edges being padded with a welding bead (fig. 1–16) to make welding stringer beads easier. It also reduces crater cracks and overheating caused by the work edges being melted away.

Figure 1–16. Padding, first step.

To do the padding, hold a long arc momentarily in starting each pass. Fill all craters and carefully avoid overheating the edges. When you use coated electrodes, you must clean every bead. You can use a chipping hammer and wire brush to clean them. When one bead layer is deposited, turn the plate so that the next layer is deposited at a right angle to the previous layer. Quench the plate often enough to keep it from becoming too hot. Tilt the electrode 5° to 15° in the welding direction of travel and 90° transverse (work angle). However, in order to obtain a clearer view of the molten puddle, crater, and arc, tilt the electrode 15° to 30° in the welding travel direction and 90° transverse (work angle).

> NOTE: For multiple pass welds each bead deposited must overlap each preceding bead by ¼ of the bead width in all welding types and positions.

606. Flat position welding

In this lesson, we will discuss flat welding procedures. The flat position is usually the best position for preparing and welding joints because it gives you good control over gravity and other conditions. Your first concern is selecting the best joint to use. The selection is sometimes dictated by welding location, blue prints, or other written specifications, but very often a choice is possible. Of course, the best joint is the most economical one that will stand up under intended usage.

Joint consideration

In making the selection, you must consider three main factors:

- The load and unload characteristics under compression, tension, bending, fatigue, impact stress, or any combination of them.
- The manner in which the load is applied. It is described as steady, variable, or sudden.
- The joint preparation cost and the actual welding.

Other considerations are warping effects, welding ease, and joint smoothness. In this lesson, we discuss the four most common joints: (1) lap, (2) tee, (3) butt, and (4) edge. We also see how each one is affected by the three factors stated above.

Lap joint

The lap joint has two plates where one overlaps the other. You complete the joint by welding the edge of one plate to the surface of the other plate. The lap joint is frequently used where a flush joint is not required. Its preparation and welding ease makes it an ideal joint for structural work.

The two most common arc welded lap joints are the single fillet lap joint (fig. 1–17) and the double fillet lap joint (fig. 1–18). The single fillet lap joint is used more frequently, since it requires no preparation to the plate edges. If the loading is not too severe, this joint is suitable for welding all plates; but if fatigue or impact loads are encountered, concentrated stress can occur at the welded plate edges. Under tension, the plates will pull out of line, thus subjecting the root to bending and possible joint failure. The double fillet lap joint is more suitable for these and more severe loading conditions than can be met by the single-fillet lap joint. A lap joint is not desirable under fatigue or impact conditions, but it is capable of developing high efficiency under shear and tension stresses.

Figure 1–17. Single-fillet lap joint, welded (flat position).

Figure 1–18. Double-fillet lap joint, welded (flat position).

Tee joint

A tee joint is formed when the edge of one plate is joined approximately perpendicular to the face of another plate (two pieces of metal at a 90° angle). In forming this you use a fillet weld that is approximately triangular in a cross section. A tee joint is only welded on one side and should not be used if it is subjected to heavy stress from the opposite direction of the weld. If you must use a tee joint, you can weld both sides to make the joint more stress resistant.

A square edge or plain tee joint is used for joining metals up to $\frac{5}{16}$-inch thick in which no edge preparation is required (fig. 1–19, view A). If extra strength is desired, you can make the fillet weld wider. When thicker metal is involved, up to $\frac{3}{16}$-inch, use a single bevel, as shown in view B of figure 1–19, and weld the joint from one side. A double-bevel tee joint is used on steel over $\frac{1}{2}$-inch thick, with the joint welded from both sides (fig. 1–19, view C).

Figure 1–19. Tee joint preparation (flat position).

Lap joint welding procedure

The amount of overlap depends on the thickness of the plates and the strength required of the welded pieces. Standard overlap is five times the thickness (5T) of the thinnest piece or no less than 1 inch. When you are joining metal greater than 1/8-inch thick, the plate edges should overlap approximately three to four times the metal thickness. The metal should be tack welded as often as required to hold it in proper alignment. The number of tack welds used is optional. If you must force the fit up by means of fit-up dogs (fig. 1–20), short welds are preferred to tack welds. Lap joints subject to heavy bending stresses should be welded on both sides (double lap).

Figure 1–20. Using fit up dogs (flat position).

Hold the electrode at a 45° angle from vertical, and tilt the top of the electrode to a 30° angle in the weld travel direction. When you start the weld hold a long arc momentarily to ensure adequate penetration. Thick metal plates conduct heat away more quickly than light metal sheets; therefore, the welding travel speed should be slower for the thick plates. For the same reason, higher current values may be used on thick plates. Direct the arc so that penetration is obtained in both the upper and lower plates. When one pass or bead will not provide the proper weld size, make a multiple-pass fillet weld. In making lap joints on plates of a different thickness, hold the electrode at a 20° to 30° angle from vertical. Take care not to overheat or undercut the thinner plate edge.

Multiple pass fillet welding is recommended on heavy plates 3/8-inch thick and over and when an exceptionally strong lap joint is required. Multiple pass consists of two or more layers of bead overlapping the previous bead. Deposit the root pass using a whipping motion with a 30° travel angle, clean the weld, and then proceed to welding the second pass while holding the electrode at a 30° angle from vertical, and tilt the top of the electrode to a 15° angle in the weld travel direction (fig. 1–21); weave the electrode, pausing for an instant at the toe of the weave to deposit extra metal. Make sure to maintain a consistent bead width along the plate.

Figure 1–21. Electrode angles (flat position).

Tee joint welding procedures

A tee joint may be welded in the flat, horizontal, vertical, or overhead positions. Make the fillet weld in a tee joint by depositing multiple stringer bead passes (fig. 1–22), or by weaving the electrode to form a wide bead (fig. 1–23). The electrode should be held at a 45° angle to both plates and at a 30° angle to the welding travel direction (fig. 1–24). Stringer beads are generally preferred for fillet welds of maximum strength and ductility, since each successive bead layer tends to refine the previous grain structure layer. Use a slight whipping motion. The multiple-pass flat fillet weld's first three passes are shown in figure 1–22. After depositing the root bead, remove all the slag. Proceed by holding the electrode at a work angle of 70° and a travel angle of 30°. Deposit the first intermediate weld pass to partly cover the root bead. Remove the slag completely. Hold the electrode at a work angle of 30° and travel angle of 30°. Deposit the second intermediate weld pass to partly cover the root bead and partly cover the first pass. Remove the slag completely. If more weld material is required, make additional passes using the different bead configurations from the first three passes. A cover pass can be added to a multi-pass fillet T-joint, if required, by weaving the electrode.

Figure 1–22. Multiple welding bead passes (flat position).

Figure 1–23. Electrode weave motion (flat position).

Figure 1–24. Electrode angle for a tee joint (flat position).

Figure 1–25 shows several weave motions for depositing a weave bead (overlay) to cover the stringer beads of a multiple-pass flat fillet weld. A weave with a slight pause at each apex angle is easy for you to learn and it is a good one for beginners to start with (top view of fig. 1–25). The other views show more advanced motions, including each starting point.

Figure 1–25. Weave motions (flat position).

Lap joint welding requirements

When the lap weld (figs. 1–17 and 1–18) is properly made, the upper leg equals the metal thickness. The lower leg equals 1½ times the metal thickness, while the throat thickness should equal the base metal thickness.

The weld specifications for metals of unequal thickness are based on the thinner sheet thickness. Penetration for metals $^1/_8$-inch thick should be $^1/_{16}$-inch. For thinner gauges, the penetration should be 30 to 50 percent of the metal thickness. The face on lap joints should be slightly convex in shape, permitting a smooth stress line flow through the weld face. Any abrupt change in face shape, such as undercutting or overlapping at the edge or toe of the weld, will cause stress point concentration, thus reducing the weld strength. Figure 1–26 shows proper and improper stress distribution.

Figure 1–26. Lap joint weld stress distribution (flat position).

In many cases, the welded joint strength is affected by the weld location in relation to the parts joined. Other factors being equal, welds that have their linear dimensions transverse to the stress lines are approximately 30 percent stronger than welds with linear dimensions parallel to the stress lines. Figure 1–27, B, illustrates this condition. In welds that have their linear dimensions approximately parallel to the force line, the stress on the weld is in the shear. The shear, in this case, is greater at the weld ends than in the middle. In certain cases, to get greater resistance to the weld tearing action, it is advisable to hook the bead around the joints (fig. 1–28).

Figure 1–27. Weld location in relation to the line of stress (flat position).

Figure 1–28. Welding around corners to resist tearing (flat position).

Tee joint welding requirements

The requirements for tee joints are expressed by their nomenclature (figure 1–29). Regardless of whether stringer or weave beads are used in making a tee joint, the weld size remains the same. The term “leg” is used to measure a tee joint fillet weld. A “leg” is the distance from the root of the joint to the toe of the fillet weld. You can compute the size by using an isosceles triangle (see the weld cross section, 1½ T, shown by the dashed lines in fig. 1–30). The leg lengths and the thickness of the throat are based on the base metal thickness, also shown in figure 1–30.

Figure 1–29. Tee joint nomenclature.

Figure 1 –30. Tee joint specifications (flat position).

When welding tee joints, undercutting is a frequent defect that occurs along the toe of the upper leg. This defect is a groove melted in the base metal adjoining the toe of the weld (shown on the right in fig. 1–31) A welding current that is too high and improper electrode angle is the usual cause Correcting the current setting and changing the electrode angle and manipulating the electrode to wash molten metal up to the toe of the vertical leg usually corrects this defect. Good and bad tee joint characteristics are shown in figure 1–31.

Figure 1 –31. Good and bad tee- joint characteristics.

Butt joints

A butt joint is used to join two plates having surfaces in approximately the same plane. Several edge preparation methods can be used to make butt joint welds in the flat position. The term "groove" describes edge preparation methods that you can use. We cover the basic types shown in figure 1–32.

Butt joint preparation

There are many factors that can influence the way that you prepare a butt joint for welding. The factors for you to consider include plate thickness, groove selection, and preparation equipment. After considering these factors, prepare joint edges by flame cutting, shearing, flame grooving, machining, chipping, or grinding

Butt Joint Preparation	
Metal	Preparation
Sheets up to $^{1}/_{8}$-inch thick	Preparing metal sheets up to $^{1}/_{8}$-inch thick requires that you make sure that plate edges to be welded are square and clean. You do not have to bevel either plate edge prior to welding. In fact, the term used to identify this butt joint connection is the square groove (fig. 1–32, view A).
Plates $^{1}/_{8}$- to ¼-inch thick	Preparing metal plates $^{1}/_{8}$- inch to ¼- inch can be done in many ways. We cover three that you can make. The easiest is the square groove provided that you weld both plate sides (top and bottom). If you can only weld on one side, use the single groove or the single “V” groove. The single groove has one plate that has a 30° bevel (fig. 1–32, view B). The single “V” groove has both plates with a 30° bevel (fig. 1–32, view D). Preparing a bevel increases the fusion area and strength in the weld.
Plates ¼-inch thick and thicker	Plates ¼- inch and thicker require you to groove (bevel) one or both plate sides. There are various grooves that you can use; we’ll look at two, the single “V” groove and the double “V” groove. The included angle can range from 60° to 90°. This means that each plate has a 30° to 45° bevel. The bevel that you make varies with the plate thickness. Generally, the thicker the plate, the greater the bevel. To make the single “V” groove, you bevel each plate on one side (fig. 1–32, view D). To make the double “V” groove you bevel each plate on both sides (fig. 1–32, view E).

Figure 1 –32. Butt joints (flat position).

NOTE: Butt joints prepared from both sides and then welded are usually stronger, produce less distortion, and ensure better weld metal qualities than joints prepared from one side only.

Butt joint weld requirements

The butt joint welding requirements include metal thickness and edge preparation. For example, metal sheets that are $^1/_8$-inch or less in thickness usually require that you weld the two metal sheets together on one side. On plate that is $^1/_8$-inch or greater in thickness, you may be required to weld on one or both plate sides. Another factor is the groove degree bevel (angle) that you use on the plate edges to prepare them for welding. The welds shown in figures 1–33 and 1–34 illustrate the specification requirements for butt joints on low carbon steel plates.

Figure 1–33. Butt joint specifications (sheets).

Figure 1–34. Butt joint specifications (plates).

The fusion zone width for thick plates is governed by the way that you prepare the joint. When you bevel the edges, the weld should be approximately $^1/_8$-inch wider than the width of the included bevel. The fusion depth into the beveled joint edges should be at least $^1/_{16}$-inch. A $^1/_8$-inch height reinforcement is usually sufficient for thick plate. The penetration for butt welds must be 100 percent, regardless of the plate thickness. For double-edged penetration; you get 50 percent penetration from each side to produce the required full base metal penetration. In general, butt joints prepared from both sides permit easier welding, produce less distortion, and ensure better weld metal qualities in heavy sections than joints prepared from one side only.

Butt joint welding procedure

A primary butt joint welding procedure concern is holding contraction stresses to a minimum while maintaining the desired shape and strength. The following example shows a typical contraction problem/solution. When you are welding long seams, the metal deposited at the joint can contract and cause the edges to pull together and possibly overlap. You can adjust for the contraction by using a wedge to hold the edges apart. Move the wedge forward as you weld. If you use a wedge for spacing, you must remember that it is based on the metal that you are using and its thickness. Metal less than 1/16- inch thick may be welded by flanging the edges. When flanging, tack the metal at intervals along the seam before welding.

You can also use jigs to hold metal parts in position for welding. You can align most points and hold them in place with angle iron pieces and C-clamps, or you may have to use special jigs and clamps for some jobs.

When the joint edges are beveled, the spacing should be exactly the same as the shoulder thickness at the joint edge bottom. Tack weld the parts in place at short intervals along the seam. Look for slag deposits after each tack weld. If slag is found, you must remove it before you make another tack weld. You must keep slag from contaminating your tack welds. To make the root bead, use a small diameter electrode that gives good penetration and fusion at the joint base. A 1/8- or 5/32- inch diameter electrode is suitable for this purpose. Remember, the first bead layer that you deposit must seal the space between the two plates and provide fusion at the root of the joint.

To get penetration when starting to weld a butt joint, hold a long arc momentarily. Tilt the top of the electrode slightly in the weld travel direction; the holding time depends on the electrode and the current setting. After making the first pass, remove the slag from the root bead by chipping and wire brushing. You must do this after each pass to make a proper weld. Use a 5/32- or 3/16- inch electrode to make additional filler metal layers in the joint.

A weaving motion makes it possible to deposit more metal in a single pass when you are welding in a "V" on thick plates. The electrode movement is semicircular across the line of weld, and a slight pause in electrode movement at the toes of the weld will aid in preventing undercutting. The layers that you deposit depend on the metal thickness that you are welding. To do this, you build up (padding) a series of small stringer or weave beads, keeping the heat input and the hard zone formation in the base metal to a minimum. Each bead or layer will refine the grain in the weld immediately beneath it and will anneal or soften the hardness produced in the base metal by the previous bead.

To weld thick sections beveled from both sides, deposit the weave beads alternately on one side and then on the other to reduce distortion that might occur in the welded structure. Thoroughly clean each bead or layer of weld metal, and remove all scale, oxide, and slag before you deposit any additional metal. Control the electrode motion to make each bead uniform in thickness and to prevent undercutting or overlap at the weld edges.

> NOTE: For multiple pass welds, each bead deposited must overlap each preceding bead by ¼ of the bead width in all welding types and positions.

Welding heat concerns

The heat developed at a joint by welding causes the metal to expand and, upon cooling, to contract. The uneven expansion and contraction can cause distortions (fig. 1–35). This distortion is caused by a greater amount of hot metal at the top of the weld than at the root, thus causing more contraction across the top of the weld joint. If the parts to be welded are restrained to where they cannot expand or contract properly, the parts can buckle, warp, or distort.

Figure 1–35. Distortion caused by heat.

Welding thick metal presents many challenges. To meet the weld requirements for thick metal plate, prepare the joint edges by beveling. This aids in getting 100 percent root penetration for the joint. Since the plate is thick and the bevel adds to the welding area, welds cannot be made by a single weld bead, so a series of either stringer or weave beads is used. Pass welding is the method used to deposit weld metal in multiple passes. It is used in welding thick plates to avoid carrying a large molten metal pool, which can cause slag inclusions or cold spots in the weld. A large molten metal pool is difficult to control, requires high heat with a slow weld travel speed, which results in excessive grain growth and unnecessary joint face melting.

By using multiple-pass welds on thick plates, you can concentrate on getting good penetration at the weld root in the first pass. On succeeding layers, you can concentrate on getting good fusion with the bevel sides on and in the preceding layer. You can easily control the final layer to get a good, smooth surface. The weld metals lower layer often cools to a black heat and then rises to a temperature that permits grain refinement (a form of heat treatment). The metal depth affected by this action depends on the welding heat penetration. In some welding work, when grain refinement in the welded joint top layer is needed, you can deposit an extra weld metal layer on the finished weld and then machine it off after cooling. The extra welding pass supplies additional welding heat to further refine the weld metal in the final layer at the joint surface.

When all else fails, perhaps the simplest thing to do (before welding) is to angle the pieces slightly in the opposite direction in which contraction is to take place. Then, upon cooling, the contraction forces will pull the pieces back into position.

Edge joint

The edge joint is used to join the edges of parallel plates and weld thin sheet metal to reinforcing plates on I-beams or angle iron. The procedures for setting up and welding edge joints are basically the same procedures used to set up and weld butt joints.

Edge joint preparation

Preparing edge joints on light-gauge metals, up to $^{1}/_{8}$-inch, requires that you clean the edge joint area and make sure that it is suitable for welding. To prepare metal that is $^{1}/_{8}$-inch or thicker, you most likely need to prepare the edge joint to provide good fusion. You can prepare the edge joint in various ways. The usual way to prepare metal $^{1}/_{8}$ to $^{3}/_{8}$-inch thick is to make a single bevel in one plate edge. For metal over $^{3}/_{8}$-inch thick, you can make a double "V" groove. You can do this by making a bevel in each plate; when you position them for welding, they form a "V". By preparing joints as described, you can increase the fusion area into the base metal resulting in a stronger weld joint.

Edge joint weld requirements

The weld shown in figure 1–36 illustrates the weld requirements for edge joints on sheet metal. When welding on light-gauge sheet metal, the penetration into the base metal should be 30 to 50 percent of T. Reinforcement should be 25 percent of T and the weld should be as wide as the thickness of the two metal sheets.

Figure 1–36. Edge joint specifications (sheets).

Figure 1–37 shows the requirements for welds on thick metal plate sections such as angle iron and flat bar. These requirements are for metals that are $^{3}/_{16}$-inch and greater. Penetration into the base metal should be at least $^{1}/_{16}$-inch, and reinforcement should be $^{1}/_{8}$-inch. The weld width is approximately $^{1}/_{8}$-inch wider than the beveled joint edges, but not wider than the thickness of the two plates.

Figure 1–37. Edge joint specifications (plates).

Edge joint welding procedure

When welding edge joints, clamp the sections together. This will reduce distortion as you weld. Tack welding along the joint is a good way to keep long joints aligned.

The electrode is tilted slightly in the weld travel direction and can be weaved on thick metal joints. You should be able to complete most edge joints with one welding pass. But, if more than one pass is required, make sure you remove the slag from each weld layer surface before welding the next pass. If you weld over slag, you get a weak weld.

607. Horizontal position welding

Gravity and other conditions must be approached differently when welding in the horizontal position in comparison to welding in other positions. To weld in the horizontal position, the metal parts are at a 45° incline or more from the horizontal and the line of weld runs horizontally (fig. 1–38). In this lesson, we discuss the different joints used and how you can prepare and weld them in the horizontal position.

Figure 1–38. Horizontal welding positions.

Making lap joints

To make lap joints, tack weld two overlapping plates in place and deposit a fillet weld in the horizontal position along the joint. Hold the electrode to form an angle approximately 45° from the lower edge and tilt it 20° in the welding travel direction. The electrode position to the plates is illustrated in figure 1–39. When performing the first pass, you must use a weaving motion. Make sure you pause at the edge of the top plate long enough to ensure good fusion and no undercutting. You can make satisfactory lap joints on ¼-inch or thicker plate by depositing a sequence of stringer beads (fig. 1–39). To make lap joints on plates of a different thickness, hold the electrode at an angle between 20° and 30° from vertical. Do not overheat or undercut the thinner plate edge. Control the arc to wash the molten metal to the thin plate edge.

Figure 1–39. Electrode position for lap joints (horizontal position).

Tee joints

The tee joint resembles the letter "T." You make the tee joint by positioning the two plates at approximately right angles. You can tack the vertical plate edge to the horizontal plate surface (fig. 1–40). Design and prepare the horizontal tee joint the same way as you did the flat tee joint, which we discussed earlier. Use a fillet weld to make the tee joint and a short arc to provide good fusion at the root and along the legs of the weld. Hold the electrode at a 45° angle to the plate surface and incline it approximately 20° in the weld travel direction (fig. 1–41).

Figure 1–40. Tee joint tack welds (horizontal position).

Figure 1–41. Electrode position for a tee joint (horizontal position).

You can weld thin metal (¼-inch or less) with a fillet weld in one pass, with little or no electrode weaving. Welding thicker plates may require two or more passes, in which you make each pass after the first in a semicircular weaving motion (fig. 1–42). A slight pause at the end of the weave ensures good fusion between the weld and the base metal without any undercutting. You can make a fillet-welded tee joint on ½-inch or thicker plate by depositing stringer beads in the sequence shown in figure 1–43 for a ½-inch fillet. For the second pass, hold the electrode at a 70° angle to the plate surface and incline it approximately 20° in the weld travel direction. The weld angle for the third pass is 30° to the plate surface and inclined approximately 20° in the weld travel direction. Make multiple pass welds for the horizontal lap joint at the same angles as you did for the tee joint.

> NOTE: For multiple pass welds, each bead deposited must overlap each preceding bead by ¼ of the bead width in all welding types and positions.

Figure 1 –42. Multiple pass fillet -weld weave motions (horizontal position).

Figure 1 –43. Fillet welds on thick plate. (horizontal position).

You can use chain or staggered intermittent fillet welding (fig. 1–44) for long tee joints. You can use fillet welds when high weld strength is not required. However, arrange the short welds so the finished joint is equal in strength to a fillet weld along the entire weld joint length from one side only.

> NOTE: Using chain intermittent welds can reduce warping and distortion in the metal parts.

Figure 1–44. Intermittent fillet welds (horizontal position).

Welding butt and edge joints

Since butt and edge joints are so much alike, let's discuss them together. The preparation and setup for butt and edge joints in the horizontal position is the same as for the flat position. The requirements for completed weld beads are also the same as in the flat position.

However, the welding procedure for butt and edge joints in the horizontal position is different than it is for the flat position. When welding these joints in the horizontal position, you must overcome the effect of gravity on the molten weld puddle. For multiple pass welds on the butt joint, during the first pass (root), hold the electrode at 90° to both plates with the tip of the electrode angled up 5°.

> NOTE: To ensure complete penetration, you must maintain a keyhole. The keyhole looks like an old fashioned keyhole.

If you keep the diameter of the keyhole constant, the amount of penetration will be uniform. For the second pass (hot pass), use a slight weave bead with the electrode held at 90° to both plates with the tip of the electrode angled up and down 5° into each toe of the root pass. This pass ties the root pass into both plates and helps push the root pass through for complete joint penetration. For the first filler pass, hold the electrode at a 90° angle to both plates with the tip of the electrode angled down 10° and incline it approximately 20° in the weld travel direction. For the next filler pass, hold the electrode at a 90° angle to both plates with the tip of the electrode angled up 10° to 15° and incline it approximately 20° in the weld travel direction.

Edge joints are only suitable for very light material because they are the weakest of all the joints. In order to aid in fighting the effects of gravity, hold the electrode at 90° to both plates with the tip of the electrode angled up 5° and incline it approximately 20° in the weld travel direction.

The following table shows three things you can do to help control the molten puddle and prevent it from sagging:

Controlling the Molten Puddle	
What You Can Do	Benefit
Lower the amperage setting.	Gives you a smaller and more easily controlled puddle.
Angle the electrode up 5 to 10°.	Forces the arc to hold the molten metal up.
Use a narrow weave motion with the electrode.	Spreads the heat more evenly throughout the joint, which keeps the puddle smaller and gives you better weld puddle control.

608. Vertical position welding

Welding in the vertical position means that you weld up or down. Reading this lesson gives you what you need to know about vertical position welding. We cover general and specific procedures required, including electrode selection, polarity setting, arc length, weave technique, and controlling gravity.

General welding procedures for all joints

Welding on a vertical surface is more difficult than welding in the flat or horizontal position because the force of gravity tends to cause metal to flow downward. For this reason, make the current settings lower than those you use for the same electrode in the flat or horizontal position and the currents you use for welding upward on vertical plates slightly higher than those you use for welding downward on the same plate. The proper travel angle between the electrode and the base metal is necessary in order to deposit a good bead weld. The electrode travel angle varies for different joint types.

Electrodes

We use fill-freeze and fast-freeze electrodes in the vertical position to help prevent gravity from pulling down the molten metal (sag) from the electrodes and plates. Fill-freeze electrodes include E 6013 mild steel, or E 7018 low hydrogen. Fast-freeze electrodes include E 6010 or E 6011 mild steel. The maximum electrode diameter for vertical position welding is 3/32 inch.

Using smaller electrodes helps to maintain a small molten puddle, permitting surface tension to overcome the force of gravity. You usually use the current settings recommended by the electrode manufacturer. For more details on electrodes and current settings, you can review the AWS, TO 34W4-1–5, and military specifications. If you do not know where to find these references, check with your supervisor.

> NOTE: Make your arc length slightly less than the electrode diameter, the shorter arc helps minimize sagging.

Bead welds

We use bead welds to weld either upwards or downwards in the vertical position. To begin welding upward, hold the electrode at a right angle to both plates. To help prevent sagging, angle the electrode 10° to 15° up or push (view A, fig. 1–45) You can increase or decrease angles to control the puddle and bead size. You then move the electrode in an upward whipping motion to create the weave bead pattern (view B, fig. 1–45) We use vertical up welding in the vertical position for welding heavy gauge metal of ¼ inch or more in thickness. Penetration is deeper than vertical down welding.

To weld downward, hold the electrode at a right angle to both plates and 15° to 30° drag with the arc pointing upward to the deposited molten metal to create pattern (view C, fig. 1–45). You can increase or decrease angles to control the puddle and bead size. You then move the electrode in a downward and alternating side to side movement to create a slight semicircular weave pattern (view D, fig. 1–45) We use vertical down for welding light gauge metals that are less than ¼ inch because penetration is shallow, which makes it easier to produce welds without burning through the metal and we can perform such a weld rapidly, which is very important when it comes to production.

Figure 1–45. Bead welding (vertical position).

Specific welding procedures for different joints

Each joint that you weld in the vertical position has specific procedures that you must follow to produce a good weld. Let's take a look at the specific procedures for lap, tee, butt, and edge joints.

Lap joints

When welding a lap joint on metals that are ¼-inch or less, use a single-pass weld. Start by holding the electrode 45° to the joint and angled 10° to 15° into each toe, use a slight weave motion. Follow the guidelines in bead welds for work angles.

When lap joints are needed on thick plates you usually must weld more than one metal layer (multiple pass weld) to provide adequate penetration and strength (fig. 1–46) Start with a root pass, by holding the electrode 45° to the joint. This ensures even penetration into both plates. For the second pass, angle the electrode 10° to 15° into each toe of the root pass using a slight weave motion. If a third pass is required, angle the electrode 10° to 15° into each toe of the second pass and use a slight weave motion. This ties the second pass into both plates. Follow the guidelines in bead welds for work angles.

Figure 1–46. Weaving deposits in layers (vertical position).

To weld lap joints in the vertical position, move the electrode in a triangular weave pattern (fig. 1–47). For vertical up, start at the bottom and weld upward. Move the electrode in a triangular weaving motion. A slight pause in the weave, at the points, improves the sidewall penetration and provides good fusion at the root of the joint. Make sure you direct the electrode more toward the vertical plate marked (G). Hold a short arc and pause slightly longer at the plate surface. Be careful not to undercut either of the plates or to allow the molten metal to overlap at the edges of the weave. If the weld metal should overheat, momentarily shift the electrode away from the crater quickly without breaking the arc (fig. 1–49). This permits the molten metal to solidify without running down. Return the electrode immediately to the weld crater to maintain the desired weld size.

Figure 1–47. Triangular weave pattern (vertical position).

A slight pause at the end of the weave develops good fusion without undercutting at the plate edges. To avoid trapping slag, thoroughly clean each weld layer by removing the slag coating with a chipping hammer and wire brush. The precautions outlined above ensure good fusion and uniform weld-metal deposits.

Tee joints

If you are welding a single-pass tee joint, follow the same procedures as you did with the lap joint. For a multiple-pass tee joint, follow the same procedures as you did with the lap joint. To weld tee joints in the vertical up position, start at the bottom and weld upward. Move the electrode in a triangular weaving motion (fig. 1–48). A slight pause in the weave at the points, as we indicate in the figure, improves the sidewall penetration and provides good fusion at the root of the joint.

Figure 1–48. Starting fillet welds (vertical position).

If the weld metal should overheat, momentarily shift the electrode away from the crater quickly without breaking the arc (fig. 1–49). This permits the molten metal to solidify without running down. Return the electrode immediately to the weld crater to maintain the desired weld size.

Figure 1–49. Shifting the electrode to control overheated weld metal.

When more than one pass is necessary to make a tee weld, use the weaving motions we show in figures 1–50 and 1–51. A slight pause at the end of the weave develops good fusion without undercutting at the plate edges. To avoid trapping slag, thoroughly clean each weld layer by removing the slag coating with a chipping hammer and wire brush.

Figure 1–50. Right and left weaving motions (vertical position).

Figure 1–51. Half circle shaped weaving pattern (vertical position).

Butt joints

We prepare butt joints on plates in the vertical position for welding in the same way that we do butt joints in the flat position. To get good fusion and penetration with no undercutting, hold a short arc and carefully control its motion. The recommended method is vertical up to weld butt joints on beveled plates ¼ inch in thickness by using a triangular weave motion (view A, fig. 1–52). Make welds on ½ inch or thicker plate in several passes (multiple-pass weld) (fig. 1–52, view B). Hold the electrode 90° to both plates and angle it 10° to 15° into each toe of the root pass. This ties the root pass into both plates and helps push the root pass through for complete joint penetration. A third pass may or may not be required depending on the thickness of the metal. Do the third pass the same as you do the second pass, except that you must angle the electrode 10° to 15° into each toe of the hot pass. Use the third pass to fill the joint in preparation for the cover pass. For the cover pass, hold the electrode just like you did for the other passes, except you must angle the electrode 10° to 15° into each toe of the third pass. Deposit the last pass (cover) with a semicircular weaving motion with a slight "whip up" and pause the electrode at the bead edge. When you use a backup strip, make the welds in the same manner.

Figure 1–52. Butt joint welding (vertical-position).

Edge joints

To weld edge joints in the vertical position, prepare and set up the joint the same way you did edge joints in the flat position. To overcome the effect of gravity on the molten puddle, use the same technique and machine adjustment we discussed in the lesson on horizontal welding. You can reduce the amperage setting, angle the electrode upward from 5 to 10°, and use a narrow weave motion to give you better puddle control.

609. Overhead position welding

Welding in the overhead position is generally the most difficult. It requires that you weld while looking up and often stand or kneel in an awkward position. You also have to overcome gravity, which tends to cause the molten metal to drop down or sag on your weld. This makes it harder for you to make proper welding beads with good penetration. In this lesson, we discuss the general and specific procedures for welding beads and fillets in different joints.

General procedures

There are certain procedures that you must follow to produce quality welds in the overhead welding position. Probably the most important thing to do is to follow the procedures that allow you to maintain control of the molten metal pool. You control it by using an extremely short arc. By adjusting the current carefully, you can make and hold a short arc length. If you hold an arc that is too long, it can increase the difficulty in transferring metal from the electrode to the base metal, and large globules of molten metal can drop from the electrode and base metal. If this happens, you can shorten and lengthen the arc at intervals; however, be careful not to carry too large a pool of molten metal in the weld. Usually, only a slight electrode movement is necessary to deposit weld metal. If you have problems, check your current setting and electrode angle.

Use only electrodes designed for overhead welding. Fast-freeze electrodes such as E 6010 and E 6011 are recommended. Electrodes that are $^{3}/_{16}$-inch diameter or less are the most common for overhead welding. Generally, the larger the electrode diameter, the more difficult it is to maintain welding control of the molten pool.

Bead welds

For bead welding in the overhead position, hold the electrode 90° to the base metal (fig. 1–53), and tilt it approximately 10° to 15° in the welding travel direction. This action gives you a better view of the arc and weld crater. The recommended way to make weave beads is with an electrode that is $^{3}/_{16}$ inch or less in diameter (see fig. 1–54 for bead pattern). 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 the weld deposit to overheat and also create a large molten metal pool that can be hard to control

Figure 1–53. Electrode angles (overhead position).

Figure 1–54. Weave motion (overhead position).

NOTE: Weld with the knuckles of the hands pointing up and palms down. This prevents hot particles from getting trapped in the palm of your glove. It also allows spatter to roll of of your glove.

Fillet welds

To make fillet welds on either lap or tee joints in the overhead position, hold a short arc with no electrode weaving. Hold the electrode approximately 45° to both vertical plate and move it uniformly in the welding travel direction (view B, fig. 1–55) Control the arc motion to secure good penetration to the root of the weld and good fusion with the sidewalls of the vertical and horizontal plates. If 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 to allow the metal to solidify. Return the electrode immediately to the crater and continue welding.

> NOTE: There is the possibility of some falling molten metal. Be sure you roll down the sleeves on your welding leather and turn the collar up to the neck. Wear a protective cap under your welding hood, and wear heavy duty boots.

Fillet welds for either lap or tee joints on thick plate in the overhead position require multiple pass welds. We show the order in which you deposit these beads in view A, figure 1–55. The first pass is a stringer bead with no electrode weaving motion. Make the second, third, and fourth passes with a slight circular motion of the electrode with the tip tilted about 10° to 15° in the direction of welding (view C, fig. 1–55). This electrode motion permits greater control and better distribution of the weld metal being deposited. Remove all slag from the surface of each pass by chipping or wire brushing before you apply additional beads in the joint. Determine the welding passes that you must make with the metal's thickness and intended use. However, there may be times when other requirements call for you to weld a specific number of passes on one or both plate sides.

Figure 1–55. Fillet welding (overhead position).

> NOTE: To avoid falling sparks and hot metal drippings, stand to the side rather than directly underneath the arc. Minimize the weight of the cable by draping it over a shoulder.

Specific welding procedures

There are specific procedures that you must follow to produce quality welds in the overhead welding position. Let's look at some specific procedures for welding beads and fillets in different joints.

Lap joints

You prepare and set up lap joints the same way as you do for the flat position. A good method to weld lap joints is to start by tack welding the plates in position. You are now ready to make the root pass into the root of the joint. Hold the electrode 45° to both plates and keep the electrode at a 10° to 15° travel angle to produce a weld with good penetration. Before you make your second and third pass, make sure that you clean off all slag first. If you don't, you'll have a weak weld.

Tee joints

Prepare and set up tee joints the same way as you do for the flat position. A good method to weld tee joints is to start by tack welding the plates in position. Next, make your root pass in the root of the joint. Hold the electrode 45° to both plates and keep the electrode at a 10° to 15° travel angle to produce a weld with good penetration. Before you make your second and third pass, make sure that you clean off all slag first. If you don't, you'll have a weak weld. It takes four total passes to make a weld with good penetration (fig. 1–55, view A).

Butt joints

Prepare the plates for butt welding in the overhead position in the same way as you do in the flat position. You can obtain the most satisfactory welding results by using backup strips. If the plates are beveled with a feather edge and you don't use a backup strip, the weld tends to burn through repeatedly unless you are very careful. For overhead welding a butt joint, a bead pattern weld rather than weave pattern is preferred. Clean each bead and chip the rough areas out before depositing another layer. We show the electrode position and the order to be followed in depositing welding beads on ¼ and ½-inch plates in views B and C, figure 1–56. Make the first pass with the electrode held 90° to the plate, and 10° to 15° in the direction of travel (view A, fig. 1–56). The electrode should not be too large because if it is, it prevents holding a short arc, which is needed for good penetration at the root of the joint. The larger electrode usually means that more current is needed, which creates a very fluid puddle that is difficult to control.

Figure 1–56. Multiple pass butt joint (overhead position).

Edge joints

Prepare and set up edge joints for overhead welding the same way you prepare and set up edge joints in the flat position. Stringer beads are preferred to give you better puddle control. Complete welds on light-gauge sheet metal with one pass. When you are welding on thick metal plates that have been prepared with a "V" groove, use the technique and bead deposit sequence shown in figure 1–56 for multiple-pass butt joints.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

605. Bead welding and padding flat surfaces

1. In bead welding what is the first step to produce good padding?

2. What electrode angle do you use when bead welding?

3. When welding beads what is the minimum acceptable penetration?

4. What determines the travel speed when bead welding?

5. How do you deposit the layers when padding?

6. When padding why do you first encircle the plate edges with beads?

606. Flat position welding

1. Name the two most common lap joints.

2. How do you form a tee joint?

3. What is the approximate minimum plate overlap when welding a lap joint in ¼-inch thick steel plate?

4. Why are stringer beads preferred for fillet welds of maximum strength and ductility?

5. What are the weld requirements for a lap joint?

6. What causes stress points in lap joints?

7. What are the weld requirements for a tee joint?

8. What are the chief causes of undercutting on tee joints?

9. Define a butt joint.

10. How can you prepare edges on thick plates for butt joints?

11. What governs the fusion zone width for welding thick plates?

12. What is the minimum penetration when welding butt joints?

13. List three devices that you can use to control contraction and keep butt joint edges aligned.

14. What can you do to reduce distortion when welding butt joints from both sides?

15. What is the edge joint used for?

16. What joint preparation is required for an edge joint on ½-inch thick metal plate?

17. How wide do you make the bead when welding edge joints on thin sheet metal?

18. What do you do to prevent distortion when welding edge joints?

607. Horizontal position welding

1. Why do you use a weaving motion when welding horizontal lap joints?

2. When you are welding lap joints on plates of different thicknesses, at what angle do you hold the electrode?

3. When welding horizontal tee joints at what angle do you hold the electrode?

4. How many stringer beads do you use to weld a ½-inch-thick tee joint in the horizontal position?

5. When you weld a tee joint in the horizontal position how do you hold warping to a minimum?

6. How does butt and edge joint preparation for horizontal welding differ from preparation for flat position welding?

7. When you are horizontal welding what three actions can you take to overcome the force of gravity on the molten puddle?

608. Vertical position welding

1. What force must you overcome when welding vertically?

2. How do the current settings for vertical welding compare with those used for welding in the flat position?

3. What is the maximum diameter electrode recommended for vertical position welding?

4. For what thickness metal do you use vertical up welding? Why?

5. What are the electrode angles for welding a vertical lap joint?

6. While welding a vertical tee joint what can you do when the weld overheats?

7. What is the recommended method for vertically welding butt joints that are ¼-inch in thickness?

609. Overhead position welding

1. What purpose does a short arc serve in overhead welding?

2. What are the two most common electrodes and diameters that you use for overhead welding?

3. What can excessive weaving cause in bead welding?

4. At what angle and in which direction do you hold an electrode for fillet welding?

5. At what angle do you hold the electrode for welding a lap joint?

6. When welding a tee joint in the overhead position, how many total passes do you need in order to make a weld with good penetration?

7. What purpose do backup strips serve for butt joints?

8. What can excessive current create when welding a butt joint?

9. Why are stringer beads preferred when welding an edge joint?

1–4. Hard Surfacing

We don't use the shielded metal arc on carbon steel alone, nor do we use it just for welding. It is almost as versatile as the oxyacetylene flame and can be used for welding gray iron castings and applying hard-facing alloys. In this section, we discuss procedures for performing hard surfacing

610. Performing SMAW hard surfacing

Hard surfacing or hard facing is the process of applying extremely hard alloys to a softer metal's surface to increase resistance to wear, abrasion, corrosion, or impact. You can hard surface most steel, but you cannot always hard surface metals such as brass and bronze. In most cases, you can apply hard-facing alloys to a softer metal's point, surface, or edge by using the electric arc process. When treated with these special alloys, the wearing surfaces of scrapers, grader blades, trencher teeth, front end loader parts, and other parts will outwear non-treated steel.

Metal preparation

Before hard surfacing, clean the metal's surface. You can remove scale, rust, dirt, and other foreign substances by grinding, machining, or chipping. If you cannot use these methods, prepare the surface by filing, wire brushing, or sandblasting. The latter methods can leave small particles that usually float out during hard surfacing. Make sure you round all edges, grooves, corners, and recesses to prevent overheating the base metal.

Preheating

Take the same precautions in preheating the base metal for hard surfacing that you'd take in preheating it for welding. Anneal steels in the heat-treated condition before you apply the hard-surfacing layer. Quenching in water usually cracks the hard-surfacing layer; therefore, use oil instead when you have to heat metal to the critical temperature after hard surfacing. Oil helps the metal cool without cracking. When it is impossible or undesirable to anneal high carbon steels, deposit the hard surfacing by using the transition bead method. Use the same method before hard surfacing low alloy steel with high tensile strength. First, deposit a thin stainless steel layer, such as 25 percent chromium and 20 percent nickel rod or 18 percent chromium and 8 percent nickel rod (columbium stabilized). Next, build up the section to approximately the original dimension, using an 11 to 14 percent manganese or high-strength rod. Finally, finish by hard surfacing with a group 2 alloy rod.

Hard-surfacing deposit thickness

In most cases, you can rebuild worn sections with hard-surfacing deposits. If used, these deposits range from $^{1}/_{32}$-inch to as thick as needed. When you need to build up worn metal more than ½-inch, build the metal up with group 1 alloy to within $^{1}/_{16}$- to ¼-inch of the finished size. Add the finish hard surface deposit with group 2 or 3 alloys. Allow some excess deposit to permit grinding to the desired dimensions. When you apply harder and more brittle group 4 or 5 hard-surfacing materials, either as a final deposit or in a single layer, carefully control the deposit shape. This is important because impact or shock loads may be transmitted through the hard-surfacing metal into the tougher base metal. When not backed up by tough base metal, corners, sharp edges, or built-up sections chip or break off in service.

Hard surfacing with shielded metal arc

You do hard surfacing by arc welding in the same manner. It is similar to joining metal by arc welding, except that the added metal's characteristics are not the same as the base metal. The added metal's characteristics would be changed or impaired if it were excessively diluted by or blended with the base metal. For this reason, applying the hard-surfacing metal with the minimum welding heat possible should restrict penetration into the base metal. In general, the current, voltage, polarity, and other conditions recommended by the electrode manufacturer are based on this factor.

You can apply every hard-surfacing metal, except some alloys in groups 4 and 5, with every electrode coating or with a bare electrode by using reverse polarity. The flux coating on coated electrodes reduces spatter loss, assures good penetration, prevents oxidation, and helps to stabilize the arc. You use the bare, hard-surfacing electrodes when applying a heavy bead is necessary or depositing the metal against a copper form. For best results, use a long arc to deposit the filler metal.

On parts subject to heavy wear, you can cover the entire surface with a hard-surfacing alloy layer. On most jobs, a hard surface cover over the point and a welded stringer bead network over other wearing surfaces are adequate.

When equipment will be exposed to the abrasive action of sand, soil, and small stones, run hard-surfacing alloy stringer beads perpendicular to the flow. Run stringer beads close together along the point; then space stringer beads a small distance apart (fig. 1–57). Since the hard surfaced part is usually used on road equipment, dirt gets packed between the beads and further protects the base metal.

Figure 1–57. Stringer beads, perpendicular to flow.

For equipment designed to handle rocks, run stringer beads parallel with the material flow (fig. 1–58). This pattern supports the rocks while offering the least flow resistance. Running stringer beads is more economical than hard facing the entire surface, and the beads provide a good wearing surface.

Figure 1–58. Stringer beads, parallel to flow.

When self-cleaning beads are desired, the diamond pattern is recommended. You can see in figure 1–59 how dirt would slide up and over to one side or the other, thereby cleaning itself.

Figure 1–59. Stringer beads, Diamond pattern.

> NOTE: For more details on electrodes and current settings, you can review the AWS, TO 34W4-1–5, military specifications, and references listed in the STS. If you do not know where to find these references, check with your supervisor.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

610. Performing SMAW hard surfacing

1. What are three preferred cleaning methods used to prepare metal for hard surfacing?

2. Why do you round the corner edges when preparing metal for hard surfacing?

3. What must you do first when hard surfacing steel is in the heat-treated condition?

4. What effect does water quenching have on hard-surfacing deposits?

5. What is the minimum thickness you use to build up worn metal for hard surfacing?

6. What are the advantages of using a coated electrode for hard surfacing?

Answers to Self-Test Questions

601

1. a. Path taken by an electric current in flowing through a conductor from one terminal of the source of supply to the other. It starts from the negative terminal of the power supply where the current is produced, moves along the wire or cable to the load or working source, and then returns to the positive terminal.

   b. The force that causes current to flow in a circuit. Voltage does not flow; only current flows, voltage pushes the current through the wires similar to a pump providing the pressure used to make water flow through pipes.

   c. Also known as Amp is a unit of measure for electricity that expresses the quantity or number of electrons flowing through a conductor per unit of time.

   d. An electrical circuit has a certain amount of resistance. An ohm is the amount of resistance in an electrical circuit. One ohm is the result of 1 volt applied across a resistance that allows 1 amp to flow through it.
2. An arc that is too long produces an unstable welding arc, increases splatter, reduces penetration, causes flat and wide beads, and prevents the gas shield from protecting the molten pool from atmospheric contamination.
3. Straight polarity.
4. (1) Gravity.
   (2) Gas expansion.
   (3) Electromagnetic force.
   (4) Surface tension.
5. A magnetic field set up in the work by the flow of the welding current.
6. (1) The very hot zone next to the molten filler metal, (2) the annealed zone next to the heated base metal, and (3) the zone next to the cold base metal.
7. No; because penetration applies to depth and not width, so the heat-affected area should not increase.
8. The longer the arc length, the greater the heat affected area.
9. The heat-affected area increases when the speed decreases.
10. Arc welding.

602

1. 250-300 Ampere.
2. Constant potential and constant current.
3. Alternating current transformer.
4. Alternating current, direct current transformer-rectifier.
5. Alternating current, direct current engine-driven generator.
6. It can be touched to any part of the work without danger of short-circuiting.
7. Cable connectors.
8. In your shop's machine maintenance guides or the owner's manual.
9. (1) Brushes.
   (2) Commutator.
   (3) Switch contact points.
   (4) Bearings.
10. At 4- to 6-month intervals, depending on the number of operating hours.

603

1. Letter, numbers, or a combination of both.
2. The recommended welding position.
3. The tensile strength in thousands of psi.
4. F–1.
5. a. Black end, orange spot, and green group.
   b. White spot only.
   c. Black end and black spot.
   d. No color-codes (only a manufacturer's trademark 11018).
6. By controlling oxide and nitride formation during the welding process.
7. a. Heavy-coated.
   b. Heavy-coated.
   c. Heavy-coated.
   d. Heavy-coated.
8. E 6010 and E6011.

604

1. (1) Welding task.
   (2) Welding machine type.
   (3) Electrode selection.
   (4) Current selection.
   (5) Safety procedures.
2. In hot weather when you are sweating.
3. Avoid the fume plume.
4. The # of the shaded lens.
5. Wear leather gauntlet type gloves.
6. AF Form 592, USAF Welding, Cutting, and Brazing Permit.

605

1. Make sure you have a clean working surface—free of oil, dirt, and other foreign matter.
2. 15° to 30° in the welding travel direction.
3. $^{1}/_{16}$-inch.
4. The bead desired, current value, and electrode size.
5. At right angles to each other.
6. To make welding stringer beads easier, reduce cracks, and overheating caused by the work edges being melted away.

606

1. Single-fillet lap joint and double-fillet lap joint.
2. Join the edge of one plate approximately perpendicular to the face of another plate.
3. ¾- to 1-inch (3 to 4 times the metal thickness for metal over $^{1}/_{8}$- inch).
4. Each successive weld pass refines the grain structure of the previous pass.
5. Upper leg—1 T; lower leg—1½ T; throat—1 T.
6. An abrupt change in the shape of the weld face, such as undercutting or overlapping at the toe of the weld.
7. Upper leg—1½ T; lower leg—1½ T; throat—1 T.
8. Welding current that is too high and improper electrode angle.
9. The welding of two plates having surfaces in approximately the same plane.
10. By flame cutting, shearing, flame grooving, machining, chipping, and grinding.

11. The way that you prepare the joint.
12. 100 percent.
13. (1) Angle iron.
    (2) C-clamps.
    (3) Special jigs.
14. Weld beads alternately on one side and then the other.
15. To join the edges of parallel sheets and to weld plates to angle iron beams.
16. Double V.
17. The thickness of the two pieces of metal.
18. Clamp the joint or tack weld along the joint.

607

1. To ensure good fusion and to prevent undercutting.
2. At an angle between 20° and 30° from vertical.
3. At a 45° angle to the plate surfaces and inclined approximately 20° in the direction of the weld.
4. Three.
5. By using chain or intermittent welds.
6. The preparation is the same.
7. (1) Use a lower amperage setting.
   (2) Angle electrode upward 5º to 10º.
   (3) Use a narrow weave motion.

608

1. Gravity.
2. Make your current settings for vertical lower than those you use for flat welding.
3. $^3/_{32}$- inch.
4. Heavy gauge metal of ¼-inch or more in thickness. Because penetration is deeper than with vertical down welding.
5. Hold the electrode 45º to the joint and angled 10º to 15º into each toe.
6. Shift the electrode away from the crater quickly without breaking the arc, and return the electrode immediately to the weld crater to maintain the desired weld size.
7. Vertical up, using a triangular weave motion.

609

1. It helps maintain control of the molten pool.
2. E 6010, E 6011; $^3/_{16}$-inch or less.
3. It can cause the weld deposit to overheat and also create a large molten metal pool that can be hard to control.
4. 45° to both vertical plates and 10° to 15° in the weld travel direction.
5. 45° to both plates and keep the electrode at a 10° to 15° travel angle.
6. Four.
7. They help make the most satisfactory welding results.
8. A very fluid puddle which is difficult to control.
9. Better puddle control.

610

1. (1) Chipping.
   (2) Machining.
   (3) Grinding.
2. To prevent overheating the base metal.
3. Anneal the base metal.
4. It will crack thehard surfacing deposit.
5. $^{1}/_{32}$-inch.
6. Reduced spatter loss, good penetration, oxidation prevention, and a stabilized arc.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the best answer to each question, and circle the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (601) The measurement of the resistance in an electrical circuit is called
   b. current.
   c. voltage.
   c. an ohm.
   d. an ampere.

2. (601) What term is used when referring to an item's positive or negative charge?
   a. Polarity.
   b. Flow rate.
   c. Resistance.
   d. Neutral balance.

3. (601) Which side does most of the heat gather on when using straight polarity?
   a. Electrode.
   b. Machine.
   c. Cable.
   d. Work.

4. (601) In flat-position welding, the main force responsible for filler metal transfer is
   a. gravity.
   b. gas expansion.
   c. surface tension.
   d. electromagnetic.

5. (601) The heat's effect on the base metal's grain structure is divided into how many heat-affected zones?
   a. 1.
   b. 2.
   c. 3.
   d. 4.

6. (601) The heat-affected area in arc welding increases if the current is constant and the
   a. welding speed increases.
   b. welding speed decreases.
   c. ground clamp is re-secured.
   d. ground clamp repositioned.

7. (601) In which welding process does the heat-affected area produce a greater concentrated hardness?
   a. Oxyacetylene.
   b. Metallic Inert Gas.
   c. Tungsten Inert Gas.
   d. Shielded Metal Arc.

8. (602) Which welding machine is used extensively in heavy structural work, fabricating heavy machine parts, heavy pipe and tank welding, and for cutting scrap and cast iron?
   a. 50–100 Ampere.
   b. 150–200 Ampere.
   c. 250–300 Ampere.
   d. 400–600 Ampere.

9. (602) Welding machines are classified as constant
   a. current and direct current.
   b. potential and constant current
   c. current and alternating current.
   d. potential and alternating current.

10. (602) Which welding machine is the least expensive, lightest, smallest, produces AC current, has low operating cost, high overall electrical efficiency, noiseless operation, and is free from magnetic arc blow?
    a. Alternating current transformer
    b. Direct current transformer-rectifier.
    c. Alternating current-direct current transformer-rectifier.
    d. Alternating current-direct current engine-driven generator.

11. (602) The factors that determine welding cable diameter are the cable's
    a. length and welding current.
    b. connectors and ohm rating.
    c. strand size and conductor material.
    d. amp rating and insulation thickness.

12. (602) What determines an arc welding machine's electrode holder size?
    a. Voltage control.
    b. Current selected.
    c. Welding process.
    d. Amperage capacity.

13. (602) What do you use to clean dust out of an arc welding machine?
    a. A water hose.
    b. Soap and water.
    c. An oil soaked rag.
    d. Dry compressed air.

14. (602) How often a welding machine's moving parts are lubricated is usually determined by the machine's
    a. hours in operation.
    b. electric capacity.
    c. type.
    d. age.

15. (603) The two methods the Air Force uses to classify welding rods are
    a. commercial specifications and international codes.
    b. American Welding Society and international codes.
    c. commercial specifications and military specifications.
    d. American Welding Society and military specifications.

16. (603) What does the fifth digit in a five-digit electrode number designate?
    a. Current type.
    b. Tensile strength.
    c. Amperage rating.
    d. Recommended position.

17. (603) What classification system uses the terms primary, secondary, and group as part of a color code system?
    a. Military specification.
    b. National Stock Number.
    c. American Welding Society.
    d. International electrode chart.

18. (603) Where can you find information on military specification codes and other details on electrodes?
    a. TO 34W4 1 5.
    b. TO 38W5 1 3.
    c. TO 44W5 1 5.
    d. TO 48W4 1 3.

19. (603) The two materials used for coating heavy-coated electrodes are
    a. zinc and fiber.
    b. flux and oxidizers.
    c. cellulose and mineral.
    d. copper and deoxidizers.

20. (603) What type of electrodes are E6010 and E6011?
    a. Fast-fill.
    b. Fill freeze.
    c. Fast-freeze.
    d. Light-coated.

21. (603) An electrode that produces a gaseous shielding for the molten metal is identified as a
    a. bare electrode.
    b. carbon electrode.
    c. mineral-coated electrode.
    d. cellulose-coated electrode.

22. (603) Which fill-freeze electrode is a low-hydrogen, all position high speed, fast deposition-rate electrode designed to pass the most severe x-ray requirements when applied in all welding positions, using either AC or DC reverse polarity?
    a. E 6010.
    b. E 6011.
    c. E 7013.
    d. E 7018.

23. (604) Which exhaust ventilation method is the most effective for controlling toxic fumes?
    a. Local.
    b. General.
    c. Dilution.
    d. Variable.

24. (604) Which exhaust ventilation method collects air contaminates close to the welding operation and removes them from the work area?
    a. Local.
    b. Dilution.
    c. Special purpose.
    d. General purpose.

25. (604) If people must stay in an area where welding is being performed they should wear
    a. gloves.
    b. gauntlets.
    c. tinted goggles.
    d. a leather apron.

26. (604) What office usually issues an AF form 592, USAF Welding, Cutting, and Brazing Permit?
    a. Civil Engineering customer service element.
    b. Squadron safety element.
    c. Fire protection flight.
    d. Operations branch.

27. (605) When bead welding, crater size and depth depends on current setting, travel speed, electrode
    a. type, and arc width.
    b. type, and arc length.
    c. diameter, and arc width.
    d. diameter, and arc length.

28. (605) When padding multiple bead layers, what do you generally use to clean each bead run before welding an additional layer?
    a. Wire brush.
    b. Sand blaster.
    c. Ball peen hammer.
    d. High pressure hose.

29. (605) When you are padding with multiple layer beads, the layers should be
    a. quenched often enough to eliminate excessive heat.
    b. quenched only after they are completely padded.
    c. smoothed with a hand grinder after each layer.
    d. allowed to cool slowly between layers.

30. (606) The two most common arc welded lap joints are the
    a. double and full fillet.
    b. single and triple fillet.
    c. double and triple fillet.
    d. single and double fillet.

31. (606) When starting an arc on lap joints, it is important to
    a. weld toward the edge.
    b. guard against undercutting.
    c. hold a short arc to preheat the metal.
    d. hold a long arc to ensure penetration.

32. (606) You can relieve stress in lap joint welding by
    a. creating a flat weld face.
    b. undercutting the weld edge.
    c. undercutting the toe of the weld.
    d. creating a slightly convex weld face.

33. (606) What term is used to describe a butt joint connection made in $^{1}/_{8}$-inch thick metal plate?
    a. Flat groove.
    b. Square groove.
    c. Double vee groove.
    d. Single edge groove.

34. (606) What is the required penetration percentage when welding a butt joint?
    a. 25.
    b. 50.
    c. 75.
    d. 100.

35. (606) How do you obtain penetration at the beginning of a butt joint?
    a. Preheat the edge.
    b. Preheat the center.
    c. Hold a long arc momentarily.
    d. Hold a short arc momentarily.

36. (606) When welding a joint, the contraction is greatest at the joint's
    a. top.
    b. toe.
    c. root.
    d. bottom.

37. (606) When you are welding thick plates, a large molten metal pool can cause
    a. slag inclusions.
    b. faster weld travel speed.
    c. decreased contamination.
    d. lowered heat requirement.

38. (606) In welding, you use the edge joint to join plates that are
    a. lapped.
    b. butted.
    c. parallel.
    d. perpendicular.

39. (606) How much penetration is required to weld edge joints in ½-inch thick metal?
    a. ¼ inch.
    b. $^{3}/_{16}$ inch.
    c. $^{1}/_{8}$ inch.
    d. $^{1}/_{16}$ inch.

40. (607) When you use a weaving motion on lap joints in the horizontal position, a slight pause at the top plate edge
    a. causes overlap.
    b. ensures firmness.
    c. causes undercutting.
    d. ensures good fusion.

41. (607) What plate thickness allows you to make satisfactory lap joints by depositing a sequence of stringer beads?
    a. $^{1}/_{8}$ inch.
    b. ¼ inch.
    c. $^{3}/_{8}$ inch.
    d. ½ inch.

42. (607) How do you hold the electrode when you are welding tee joints in the horizontal position?
    a. At a 30° angle to the plate surface.
    b. At a 45° angle to the plate surface.
    c. Inclined 30° in the weld travel direction.
    d. Inclined 45° in the weld travel direction.

43. (607) You arrange chain-intermittent fillet welds on a long horizontal tee joint so that short welds are equal in strength to
    a. the full base metal.
    b. the metal alloy filler.
    c. a fillet weld along the entire joint length on both sides.
    d. a fillet weld along the entire joint length on one side only.

44. (607) Using chain-intermittent fillet welds on long horizontal tee joints results in
    a. more cracking of the metal parts.
    b. more warping of the metal parts.
    c. less cracking of the metal parts.
    d. less warping of the metal parts.

45. (607) How do you angle the electrode to control the molten pool when welding butt and edge joints in the horizontal position?
    a. Up 5° to 10°.
    b. Up 15° to 20°.
    c. Down 5° to 10°.
    d. Down 15° to 20°.

46. (608) When welding in the vertical position, how do the electrode size and current setting compare to the flat position?
    a. Smaller electrode, lower current.
    b. Smaller electrode, higher current.
    c. Larger electrode, reverse polarity.
    d. Larger electrode, straight polarity.

47. (608) You make a fillet weld in overhead welding by making an arc
    a. slightly longer than the electrode diameter.
    b. slightly less than the electrode diameter.
    c. equal to the diameter of the electrode.
    d. equal to the thickness of the plate.

48. (608) To apply bead welds vertical-up, hold the electrode
    a. 10° up.
    b. 30° down.
    c. 10° to the joint.
    d. 30° to the joint.

49. (608) If the molten puddle becomes too fluid in the vertical welding position for fillet welds,
    a. reduce the current.
    b. change the electrode.
    c. stop welding and quench the plate.
    d. whip the electrode away and then back quickly.

50. (608) When welding a vertical butt joint, how do you achieve fusion and penetration without undercutting?
    a. Whip the arc back and forth.
    b. Weave the arc in small semicircles.
    c. Pause at the edge of the upper plate.
    d. Hold a short arc and control its motion.

51. (609) What type of arc do you use to maintain control of the molten metal pool when you are welding in the overhead position?
    a. Longer than average.
    b. Extremely long.
    c. Extremely short.
    d. Average.

52. (609) What is the recommended electrode diameter to use in the overhead welding position?
    a. $^{3}/_{8}$ inch.
    b. $^{5}/_{16}$ inch.
    c. $^{3}/_{16}$ inch or less.
    d. ¼ inch or greater.

53. (609) To make fillet welds on either lap or tee joints in the overhead position, hold a
    a. short arc, with slight weaving.
    b. long arc, with slight weaving.
    c. short arc, with no weaving.
    d. long arc, with no weaving.

54. (609) If the molten puddle becomes too fluid in the overhead welding position for fillet welds,
    a. reduce the current.
    b. change the electrode.
    c. stop welding and quench the plate.
    d. whip the electrode away and then back quickly.

55. (609) Which is the preferred pattern for welding butt joints in the overhead position?
    a. Diagonal.
    b. Concave.
    c. Weave.
    d. Bead.

56. (610) What is the minimum thickness of hard surfacing deposits used to build up worn metal surfaces?
    a. $^{1}/_{32}$ inch.
    b. $^{1}/_{16}$ inch.
    c. $^{3}/_{32}$ inch.
    d. $^{1}/_{8}$ inch.

57. (610) What hard surfacing pattern do you use where self-cleaning is desired?
    a. Parallel.
    b. Diagonal.
    c. Diamond.
    d. Perpendicular.

Please read the unit menu for unit 2 and continue ➔

Argon is the most popular gas used for TIG welding. It is heavier than air, so it provides a better blanket over the weld to protect it from contaminants.

Helium

Helium is a colorless, odorless, nontoxic, and tasteless inert gas. Much lighter than air, it is the second lightest of all gases. Helium is nonflammable and, like argon, is placed under pressure in cylinders at pressures of 2,000 or 2,500 psi. You can identify the cylinder by its distinctive color markings of gray with a buff (light brown) top. The cylinder is considered empty when the pressure is reduced to 25 psi. Helium is also much cheaper than argon; however, you use about one-third more helium because it is a lighter gas. Because helium is several times lighter, it does not settle down around the work, and does not protect the weld as well as argon. Sometimes you will use an argon/helium mix to weld metals that require a higher heat input.

NOTE: Make sure you follow all safety procedures for handling cylinders that you learned previously. If you are unsure, read the material safety data sheet (MSDS) or ask your supervisor.

Gas shielded welding methods

There are various methods used in gas shielded welding. We concentrate on two: TIG (fig. 2–1), and metallic inert gas (MIG) (fig. 2–2). A significant difference between the two is that tungsten inert gas uses a nonconsumable tungsten electrode, while MIG uses a consumable alloy wire with approximately the same chemical composition as that of the metal being welded. Both are fusion-welding processes that use the heat produced by an electric arc between a metal electrode and the work. The principles involve the arc, or heating source, and are the same as those for shielded metal arc welding. However, in the gas-shielded process, an inert gas (helium or argon) flows from the orifices in the torch head past the electrode to form a protective blanket over the weld area. The gas shield's primary purpose is to keep oxygen, nitrogen, and carbon elements that are present in the air from coming in contact with the molten metal and contaminating the weld.

Figure 2–1. Tungsten inert gas shielded process.

Figure 2–2. Metallic inert gas shielded process.

Gas shielded welding uses

Tungsten inert gas shielded welding is especially adapted for light gauge metal that requires the highest quality weld and/or finish. The process uses a good heat concentration, precise heat control, and the ability to weld with or without filler metals. It is also popular for welding small or thin-walled objects. For thicker gauge metal, metallic inert gas-shielded welding is preferred.

Gas shielded welding advantages

You can use the TIG welding process on a wide variety of light gauge, commercial metals up to ¼-inch. TIG welding concentrates its low heat input from the electrode to a central point, which allows for welding on very thin metals with minimal distortion and/or alteration of the base metal properties. Gas-shielded welding produces welds that are stronger, more ductile, and more corrosion-resistant than the welds made with shielded metal arc welding. The protective gas shield in gas shielded welding envelops the weld and allows the joint to be made without flux; thus, eliminating flux caused corrosion and cleaning. The entire TIG welding process takes place without spatter, sparks, or fumes. MIG welding produces some spatter, but you can very easily clean such spatter from the work.

612. Selecting and maintaining TIG welding equipment

Before you use the TIG welding process, you must know what TIG welding equipment is needed and how it functions in order to make high quality welds. In this lesson, we cover the required equipment along with its function.

Power source

Tungsten inert gas welding requires alternating (AC) or direct current (DC). The choice of AC or DC current depends on the metal and weld requirements. Direct current electrode negative (DCEN/DCSP or DC-) welding is commonly used for ferrous metals and AC high-frequency (ACHF) welding for aluminum and non-ferrous metals. Direct current electrode positive (DCEP/DCRP or DC+) can be used for welding both ferrous and non-ferrous metals. The welding current may be supplied by an AC-DC engine-driven generator or an AC-DC transformer-rectifier (fig. 2–3). It is important that the power source provides good current control in the low current range. Standard DC welding machines are often selected because they provide good current output over a broad range. Some welding machines use a superimposed high frequency or (high frequency arc ignition) to permit starting the arc without having the electrode contact the work.

Figure 2–3. TIG welding machine.

Gas shielded welding torch

We use several gas shielded welding torch designs. They all operate basically the same except for the method by which they're cooled—by air or by water.

Air-cooled torch

The air-cooled torch (fig. 2–4) is designed to manually weld thin-gauge metals. It is excellent for weld-repairing aluminum and stainless steel parts. You can use this torch for welding with high-frequency stabilized alternating current or straight-polarity direct current, depending on the job requirements. It can perform continuously on AC or DC current up to l00 amperes.

Figure 2–4. Air-cooled, inert gas shielded welding torch.

Water-cooled torch

Water-cooled torches are rated in amperes for different welding needs. If your welding task calls for using 200 amperes, we recommend that you use a water-cooled torch like the one shown in figure 2–5. It has channels that allow pump driven water to circulate through it to remove heat as the torch is being used. Most pumps circulate the water at 1 to 2 pints per minute. A fuse is installed in the torch's power lead line to protect it from overheating in case of water stoppage. The torch head has five basic parts:

Water-Cooled Torch Head Parts	
Part	Description
Collet body	The gas is fed to the weld zone through the collet body with the use of a gas nozzle (gas shielding cup/ceramic cup).
Collet or electrode holder	Goes inside the collet body. Holds the electrode into the torch. Different size collets are used for each different size electrode.
Tungsten electrode	
Gas-shielding cup (ceramic cup/gas nozzle)	Provides directional control for the shielding gas and is threaded onto the collet body. Gas nozzles are interchangeable to accommodate a variety of gas flow. Size of the gas nozzle used depends on the type and size of the torch and the diameter of the electrode used.
Gas-shielding cup cap	

Figure 2–5. Water-cooled, inert gas shielded welding torch.

The shielding gas enters through a plastic hose fitted to the rear of the torch handle, passes through the body, and emerges from the gas orifices in the torch head. The gas-shielding cup directs the inert gas to the weld area.

In TIG welding, a replaceable electrode holder (collet) slides into the collet body to hold the electrode in place. The holders are made in various sizes to hold electrodes from 0.020- to 0.125-inch in diameter and from 3- to 12-inches in length.

Hose

A flexible rubber or plastic hose is used to circulate water for cooling the torch and power lead cable. The bare flexible lead cable is enclosed in the water outlet hose. A separate hose is used for the water inlet and another is used for feeding the shielding gas to the torch. If the water stops flowing, you must stop welding in order to prevent damaging your equipment.

Water stoppage can also result from dirt in the torch passages. You might be able to remove the dirt by temporarily reversing the water hoses so that water flows in the opposite direction. Sometimes the water stoppage is due to a leak. You can usually trace waterline leaks to four possible causes:

- Excessive water pressure.
- Poor equipment maintenance.
- Improperly sealed hose connections.
- Cracks in the torch body.

You can usually stop most leaks quickly. For example, when a hose is damaged near a fitting, it is only necessary to cut away the damaged section and reattach the hose to the fitting. A liquid sealant or a hose clamp should make a leak proof joint. When you shorten the water outlet hose, you must then remove an equal length of electrical cable. However, cracks in the torch body can take more time. You may be able to solder it or you may have to replace it.

The argon or helium hose must be gas tight to not allow any gas leaks. If the molten pool becomes cloudy or the tungsten electrode turns blue on cooling, this indicates a leak in the hose or in the hose connections. If the plastic hose is subjected to temperatures above 125 °F, it will become soft and lose its strength. Therefore, protect it and do not allow it to come into contact with hot metal. Hoses also become brittle and crack as they age. These are the reasons why you should check your hoses before each use. If you cannot stop the leak, replace the hose.

Gas-control equipment

You can use a single or two stage regulator or a regulator with a flow meter to control the gas flow. A flow meter provides better gas flow control than the single or two stage regulators. A flow meter is calibrated to show the flow of gas in cubic feet per hour (cfh) or liters per minute (lpm). The shielding gas flow is controlled by metering devices such as a combination regulator and flow meter (fig. 2-6). It steps down the high pressure in the cylinder or manifold cylinders to a lower working pressure. The gas flow is shown on a flow-meter tube. In operations where the gas consumption is high, you can install a central cylinder manifold system and pipe the gas to the various welding stations. The flow meter is equipped with a manual throttle valve for adjusting the gas flow allowing you to set the flow as needed. The flow-meter tube is calibrated at a positive pressure, which normally allows for back-pressure to give a true gas flow reading. Gas flow is controlled by turning the adjusting screw on the flow meter. The rate of flow required depends on the metal being welded.

Figure 2-6. Argon gas flow regulator/ meter.

When a combination regulator flow meter is not available, you can use a regulator that is identical in design and construction to the two-stage oxygen regulator for argon. When only oxygen regulators are available for welding with helium, use an adapter to attach the regulator to the helium cylinder. An adapter is also necessary to attach the hose to the regulator.

You must install a flow meter between the regulator and torch. It indicates gas flow to the torch in liters per minute or cubic feet per hour. You can determine gas flow in cubic feet per hour from the flow-meter setting. A flow of 1 liter per minute is equivalent to a flow of 2.12 cubic feet per hour. Mount the cylindrical tube of the flow meter vertically since a lightweight metal spinner in the tube indicates gas flow by rising or falling with the gas flow.

Auxiliary equipment

The foot control is a foot-operated rheostat installed in the welding machine field circuit to change the arc for varying metal thickness. This is a convenient way to make slight changes in the current settings as you weld. Another advantage of foot control is that you can shut off the welding current while the gas continues to flow. This protects the weld during cooling and helps to prevent crater cracking. If a machine does not have a built-in water- and gas-flow control, you can install a water-gas shutoff valve. Insulate the valve from the grounded side of the welding circuit. On some welding machines, you can shut off the water flow and gas flow to the torch by hanging the torch on a hooked arm provided for that purpose.

> NOTE: You must always protect the leads of the welding machine from spark damage. Make sure you remove any flammable material from the welding area.

Protective equipment

The protective equipment required for inert gas welding is the same as that for metal arc welding—leather sleeves or jacket, apron, gloves, safety glasses, and a welding helmet with appropriate lens.

Equipment maintenance

The basic operator maintenance requirements for TIG welding machines are similar to the maintenance performed on shielded metal arc welding machine mentioned in the previous unit. Always disconnect the power to the welding machine before performing any maintenance procedures. Check all the electrical circuit connections to make sure they are tight. Make sure there is not a build up of dust or debris around the connections. Check the electrical wiring for any cuts, nicks, or frays, and replace if needed. Check all water lines and gas hoses for any cuts or abrasions. Check all connections for leaks using a soap-based leak detector, check all of the connections on the gas cylinder for any leaks. Replace any of these hoses as needed. Most TIG torch maintenance involves replacing broken gas cups and damaged collets. Inspect the torch body for any cracks or breaks in the insulation. Visually check the threaded connections for any damage. If more extensive repairs are required, refer to the manufacturer's handbook for repair procedures on your particular torch. If you cannot make the repairs, contact your supervisor for contract repair or replacement.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

611. TIG welding principles

1. Explain the term inert gas

2. What is a significant difference between TIG and MIG welding?

3. How does inert gas prevent weld contamination?

4. How do welds produced by gas-shielded welding compare with those made with ordinary metal-arc welding?

612. Selecting and maintaining TIG welding equipment

1. List the two power sources available for use in gas shielded welding.

2. What is the purpose of using a superimposed high frequency?

3. What are the advantages of using a water-cooled welding torch?

4. What are four possible causes of water line leakage?

5. If you have a gas flow of 5 liters per minute, what is the flow per hour?

6. What protective equipment must you wear when TIG welding?

2–2. Application Procedures

We use tungsten inert gas welding extensively for repairs on thin-gauge metal. It is also a very effective means to weld heat and corrosion-resistant alloys, such as aluminum and stainless steel.

613. Job preparation

The time that you take to properly set up your inert gas welding equipment allows you to correct problems before you begin welding. By setting up your equipment for your welding task, you can make high quality welds. The set up procedures that we explain are welding current, shielding gas, electrodes, and gas shielding cups.

Welding current

The welding current for TIG welding is either AC or DC. However, for certain distinctive weld characteristics, you must consider certain factors before you adjust the welding machine current. For example, the polarity you use in DC welding depends on the metal you are to weld. Direct current electrode negative (DCEN/DCSP or DC–) is suitable for welding stainless steel, copper, copper alloys, and low and medium-alloy steels. In straight-polarity welding, the electrons flow from the electrode to the plate, which causes greater concentration of heat on the plate and produces less distortion However, in direct current electrode positive (DCEP/DCRP or DC+) welding, the opposite occurs; the electrons flow from the plate to the electrode causing a greater concentration of heat at the electrode, which then tends to melt off the end of the electrode. For any given current setting, DCEP/DCRP requires an electrode that is approximately four times larger in diameter than would be used for DCEN/DCSP. These opposite heating effects influence not only the welding action but also the shape of the weld (fig. 2–7). Welding on most commercial metals can be accomplished using DCEN/DCSP.

Figure 2–7. TIG weld contour comparison.

By using a small diameter electrode with DCEN/DCSP, you can produce a narrow, deep weld. By using a large diameter electrode with DCEP/DCRP, you can produce a wide and relatively shallow weld. DCEP/DCRP produces a cleaning action that removes the heavy oxide coating on metal, permitting flux-free welding on metals such as aluminum and magnesium

Alternating current high frequency (ACHF), in principle, is a 50–50 combination of DCEN/DCSP and DCEP/DCRP. It reverses, in cycles, between the two polarities. In effect, the straight-polarity component delivers adequate heat to the work, resulting in satisfactory penetration and speed, while the reverse-polarity component breaks up the oxide film. Foreign matter on the surface of the plate—such as moisture, oxides, and scale—tends to prevent the current flow in the reverse-polarity direction. If no current flows in the reverse direction, rectification has occurred. To prevent this, superimpose a low-intensity arc on the standard welding current (60 cycle), high voltage (300-volt), and high frequency (120,000). When high frequency is superimposed on AC current, a continual flow of electrons is jumping the gap between the electrode and the work piece, piercing the oxide film and forming a path for the welding current to follow. This makes arc stabilization possible while maintaining a reverse polarity current flow.

Some advantages obtained from using high-frequency current are:

- You can start the arc without touching the electrode to the work piece.
- Better arc starting and stability are obtained; a longer arc is possible.
- Welding electrodes have a longer life.
- Using wider current ranges is possible.

Figure 2–7 shows a typical weld contour produced with high-frequency stabilized AC. AC produces better weld results on aluminum and magnesium than DCEP/DCRP.

Shielding gas

Gas purity may have considerable effect on welding, depending on the extent to which the metal is affected by contaminates. Consequently, stainless steel, as a rule, is not significantly affected by small percentages of contaminates in the shielding gas. In contrast, nonferrous metals, such as aluminum, are sensitive to impurities; weld them with high-purity inert gas. The commercially available argon and helium gases average well over 99.95 percent in purity.

We generally use argon for alternating current TIG welding applications, such as welding aluminum, magnesium, and copper. In helium gas shielding, the arc is relatively hard to start when using very low welding current. This issue is not encountered with argon, and its low-arc voltage characteristic is particularly helpful in welding thin material because the tendency to burn through is reduced. We mainly use helium in DCEN/DCSP welding.

In manufacturing we make wide use of carbon dioxide and carbon dioxide mixtures as shielding gases. These gases give good results when used to weld carbon steel. When using carbon dioxide, make sure that your welding wire has a deoxidizer in it.

Electrodes

The electrode supplies the arc required to melt the base metal; it is not consumed into the weld. The bead is formed by the arc melting the base metal. In inert gas shielded welding, there are two electrode types—(1) tungsten, nonconsumable electrode used in TIG welding, and (2) metal, consumable electrode used in MIG welding.

Tungsten electrodes

Electrodes may be either pure tungsten (99.4 percent pure) or a tungsten alloy. The electrode types used for gas shielded welding are: (1) tungsten with thorium, (2) tungsten with zirconia, and (3) tungsten, 99.4 percent pure. Alloyed tungsten has 1 or 2 percent thorium or zirconium.

Thoriated tungsten electrodes are superior to pure tungsten electrodes because of their better arc starting and stability, higher current carrying capacity, and higher resistance to contamination. Two percent thorium electrodes maintain their formed point longer than 1 percent thorium electrodes and are primarily used in the aircraft and missile industries. One percent thorium electrodes are used to weld steel.

Zirconiated tungsten electrodes have better electrode performance for welding using alternating current. They resist contamination and retain the balled end better during welding.

The tungsten electrodes are practically nonconsumable. However, if an electrode touches the molten pool, a small ball will form on the end of the tungsten rod. The contaminated end may cause an erratic arc, but you can stabilize this by striking the arc on a copper plate. Remove the excess metal pickup from the end of the electrode by grinding or breaking it off. Electrode loss due to heat and contaminates is a primary concern in TIG welding. You can prevent electrode loss by allowing the gas to flow a short time after the arc is broken. This gives the electrode time to cool in the shielded gas environment. The electrode diameter that you use depends on the electric current setting needed for welding.

Make sure the electrode extends beyond the end of the gas-shielding cup a distance equal to its diameter for butt welding and slightly farther for fillet welding. Selecting the right electrode for each job is important in preventing electrode damage (pure tungsten melts at 6,125 °F) and poor welds caused by a current that is too high or too low. Excessive current causes tungsten particles to transfer to the weld, while insufficient current allows the arc to wander erratically over the electrode end. The recommended electrode sizes for various welding current ranges are shown in figure 2–8.

Figure 2–8. Electrode diameters, gas cup numbers, and amp settings.

NOTE: The electrode must be shaped correctly to produce a good weld. Use a sharp point with DC welding and a spherical (balled) end with AC welding.

Filler rods

Filler rods are required when welding heavy gauge metals; they can be added to thin metals to reinforce the metal being welded. Filler rods must always be of the same composition as the base metal. Special filler rods are made for TIG welding. They contain large amounts of deoxidizers, thereby producing less spattering in the weld and sounder weld joints. The diameter of the filler rod should be same as the thickness of the metal being welded.

> NOTE: Oxyacetylene filler rods are not recommended for use with TIG welding because they contaminate the electrode.

Gas-shielding cups

Gas-shielding cups used with TIG welding can be made from plastic, metal, or ceramic material. They're made in various sizes; the size you select depends on the electrode diameter that is used (fig. 2–8). The cup number indicates the cup opening diameter in multiples of $\frac{1}{16}$-inch. Thus, a number 8-cup has a ½-inch cup opening. Another consideration in cup selection is the amperage used during welding. The continued use of the torch at high amperage tends to deteriorate the shielding gas cup. For this reason, metal, or water-cooled cups are good choices for currents above 100 amperes.

614. TIG welding procedures

There are times when you may need to weld a joint and have it match the qualities found in the metal that you are welding. For example, ferrous alloy and carbon steel have good heat and corrosion resistance qualities; you may want your welded joint to have these qualities too. In this lesson, we discuss how you can prepare and weld edge, butt, lap, tee, and corner joints to have these qualities. We have selected stainless steel as our choice because it has good heat and corrosion resistant qualities. We also cover the procedures for welding joints of carbon steel. Let's start our discussion with some factors that can help you achieve welding success.

Stainless steel welding factors

Choosing the best welding process is important to get a weld that matches the qualities you need. The inert gas shielded welding process is the preferred way to weld stainless steel and other corrosion-resistant steels and alloys. We use this process extensively to fabricate and repair hospital and kitchen parts because it produces less warping, prevents oxidation, and maintains the maximum corrosion resistance in the welded part. By using special fixtures, certain techniques, proper current settings, and welding speed, you can produce high quality welds.

Since the metal expansion coefficient for stainless steel is approximately 60 percent greater than carbon steels, you need to take specific procedures to correctly align, space, and tack weld the joint edges. Your goal is to keep the metal from warping during welding. The specific procedures that you use are primarily influenced by the metal thickness. For example, thin gauge metals tend to warp more than thicker gauge metals; so, you must make your tack welds at closer intervals. Carbide precipitation (carbon separation from the stainless steel) is another factor to consider in welding stainless steel. It is an unstable condition that occurs in austenitic stainless steel that contains carbon in a saturated solid form. Welding causes the saturated carbon to precipitate. You can keep it to a minimum by confining the arc or heat to as small an area as possible that still allows proper fusion. Smaller electrodes, higher amperages, and faster welding speeds also reduce carbide precipitation. Since the tungsten electrode has a very high melting point, it permits higher amperages with smaller diameter electrodes. You can also use higher welding speeds, which results in a narrow heat-affected zone and more rapid cooling.

Figure 2–9 shows the right and wrong ways to grind the tungsten electrode when welding steel. We show the correct way to grind the electrode in figure 2–9, view B. As you can see in the figure, the grind marks run toward the point instead of across the electrode. By having the grind marks running toward the point, you get a smoother arc, less arc waver, and no current flow restrictions.

Figure 2–9. Grind marks on electrodes.

There are two potential problem areas involving your weld joint's underside. The first is controlling atmospheric contamination (oxygen, nitrogen, and carbon elements), which can cause weld porosity or a poor surface appearance. The second is conducting heat away from the joint edges to prevent the weld from melting through. There are four techniques you can use to control these potential problems:

- A backup metal strip positioned on the joint underside.
- Flux applied to the joint underside.
- An inert gas directed to the joint underside.
- A backup metal strip in combination with an inert gas.

The first technique, the backup metal strip, is made from scrap steel or copper. You can use it on thick or thin metal to conduct excess heat away and prevent the weld from melting through.

Only use backing strips on flange type joints (fig. 2–10). If the strip comes in contact with the weld underside, the penetration will be rough and uneven. On square edge butt joints, groove the backup strip directly below the joint edges (fig. 2–11). This groove permits the weld metal to penetrate uniformly through the joint.

Figure 2–10. Backup plate used on a flange-type joint.

Figure 2–11. Backup plate used on square-edge butt joint.

The second technique involves applying a flux to the joint to reduce atmospheric contamination in your weld. We often use it with thin-gauge metal.

Use the third and fourth techniques when the weld must conform to extremely rigid specifications. Take extra care to exclude all atmospheric contamination from the weld. You can do this by introducing shielding gas into the relief groove of the backing plate. When the joint prohibits using a backing plate, you can direct a series of hydrogen flames on the joint's underside to exclude contamination from the weld.

NOTE: Set the high frequency switch to the start position for steel and to the continuous position for aluminum.

Welding stainless steel edge joints

The edge joint is easy to weld and is used primarily on light-gauge metal. Do not use it if direct tension or bending stresses are to be applied to it, because it is not a strong joint and may fail at the root under relatively low stress loads

Edge joint preparation is simple. Clean the joint edges thoroughly to remove all foreign material. Make sure that the edges fit together evenly and that you remove all burrs. A very close fit up is necessary for the edges to fuse together without filler rod.

Machine setting and equipment adjustment

For metal thickness from .030- to .051-inch, you may alter the setting slightly to fit the metal thickness. Set the current for 15 to 30 amps DCSP/DCEN. Adjust the flow meter to allow 8 to 10 liters of gas flow per minute. Use a tungsten electrode with a diameter from .040- to $^{3}/_{32}$-inch. Adjust the electrode to extend $^{1}/_{8}$- to $^{3}/_{16}$-inches beyond the gas-shielding cup edge. With a water-cooled torch, the water flow should be approximately 1 pint per minute.

Welding application

At the weld starting point, strike and hold an arc until a molten pool develops. Hold the electrode as nearly vertical to the joint as possible and regulate the travel speed to produce a uniform bead. A slow welding speed causes the molten metal to roll off the metal edge. Irregular or rapid travel speed produces a rough or an uneven surface. To terminate the weld, remove your foot from the foot control to stop the arc. The shielding gas will continue to flow over the weld area until it cools to a black heat.

When you must weld in the vertical, horizontal, or overhead position, there are some actions you can take to improve quality. When vertical welding on thin material, weld vertical down. This prevents your burning away too much of the edge. On thicker metal, weld vertical up to get better penetration. Whether you are welding up or down, add the filler rod to the puddle's leading edge.

To weld in the horizontal position, control your speed and arc length carefully. Make the arc length approximately the same as the electrode diameter and use a welding speed that permits adequate penetration without undercutting the weld's upper edge. Another technique that prevents undercutting is dipping the filler rod into the upper, leading edge of the puddle as needed.

To maintain better puddle control when overhead welding, reduce the welding current by 5 to 10 percent. This reduction in welding current gives you a smaller bead, which is less affected by gravity.

You can apply these techniques to edge, butt, lap, tee, and corner joints on aluminum or steel.

Stainless steel butt joints

When using gas shielded welding to make narrow beads on stainless steel butt joints, you may not need reinforcement. The reason is that the shielding gas results in a weld with high ductility and high tensile strength. Because the small electrode carries high amperage, you can make a narrow weld with a fusion quality that equals a wider weld made with oxyacetylene or shielded-metal arc welding processes.

The square-edge butt joint is easy to prepare and can be welded with or without filler metal, depending on the metal thickness being welded. When you weld thin gauge metal without adding filler metal, you need to be extremely careful to avoid low spots and burn through. The thicker metal generally requires filler metal to provide adequate reinforcement.

Metal preparation and setup

For all welding positions, you must perform proper cleaning of the metal to remove all oxidation, scale, oil, grease, dirt, and other foreign matter. You can do this either chemically or mechanically. The first step in preparing thin gauge sheet metal is to shear the metal to size. You must remove all burrs from the joint edges and thoroughly clean the joint area before welding. When you weld butt joints, align the joint edges parallel, allowing a space approximately equal to the metal thickness being welded, and then tack weld (fig. 2–12).

Figure 2–12. Tack welding stainless steel.

Machine settings and equipment adjustment

The electrode diameter and cup size varies with the metal that you want to weld. A general guide for welding metal from .030- to .051-inch thick is to adjust the TIG welding machine using the sequence in the table below.

TIG Welding Machine Adjustments	
Sequence	Action
1	Set the electric current to weld the selected metal thickness.
2	Set it to DCEN/DCSP at 15 to 30 amperes.
3	Use an argon shielding gas with a 5 to 6 liter per minute flow rate.
4	Use a tungsten electrode .040 to $^{3}/_{32}$-inches in diameter.
5	Adjust the electrode to extend slightly beyond the gas-shielding cup edge ($^{1}/_{8}$- to $^{3}/_{16}$-inch for flat welds and ¼- to $^{3}/_{8}$-inches for fillet welds).
6	If the torch is water cooled, adjust the water flow to approximately 1 pint per minute.

NOTE: Different welding applications affect how far the electrode extends. The basic idea is to keep the distance as short as possible and get a quality weld. We recommend following the manufacturer's guide.

Welding application

If the DC machine is equipped with a high frequency starter, the electrode does not have to touch the plate. If the machine is not, you must touch the electrode to the plate. You begin by striking an arc on a copper plate with the foot-control rheostat set in the high position. Immediately after getting an arc, swing the foot control toward the low position and back again toward high, fluctuating the current intensity to steady the arc characteristics. Move the arc to the joint edges and travel steadily along (forehand), holding the electrode as nearly vertical to the joint as possible. Add filler rod to the forward edge of the molten pool to prevent contaminating the tungsten electrode and to aid in weld control.

To terminate the weld, swing the foot control to the low position to break the arc. This permits the shielding gas to flow over the weld area until it cools to a black heat. To avoid overlap in restarting a weld, strike the arc ahead of the terminated weld (approximately ¼-inch) and then move the arc back to the end of the weld, bringing the weld to a molten state before adding filler rod.

The weld reinforcement (bead height) for thin-gauge stainless steel varies from 25 to 30 percent of base metal thickness. The bead width varies from two to three times the base metal thickness. The completed weld's surface appearance should be dark bronze or light purple.

Stainless steel lap, tee, and corner joints

You need to be familiar with how we use various joints in welding. Let's look at the three joints you most likely will use the lap, tee, and corner joints.

Lap joints

We use lap joints to join two overlapping stainless steel sheets so that one sheet is welded to the surface of the other. When the joint design does not permit welding from both sides, you can weld the joint from one side only. For some applications, such as tubular splices, a single-welded lap is satisfactory; however, a single-welded lap joint in sheet metal will not develop the full base metal strength. We use lap joints extensively to repair stainless steel parts because the joint is easy to prepare and easy to weld. You can use the gas-shielded welding process on stainless steel lap welds up to .0625-inch in thickness without having to use any filler rod. You can make the weld by directing the arc to melt the upper edge of the joint, which makes a smooth, slightly convex weld bead.

Making a Lap Joint	
Step	**Action**
Metal preparation and setup	Shear the pieces to be lap welded to leave a square edge that is free of burrs and warping. Clean the weld area thoroughly to remove all foreign materials. You may use steel wool for this purpose.
Machine setting and equipment adjustment	The machine and equipment settings for welding lap joints are similar to those used for butt welds. The difference is that you set the lap joint amperage 20 to 40 amperes higher.
Welding application	After the arc is struck and stabilized on a copper plate, move the arc to the joint edge and travel steadily along (forehand), melting back approximately one to two thickness of the top sheet. Failure to melt back the top sheet results in a concave undercut bead. Weaving the torch is not necessary to lap weld thin-gauge stainless steel sheets. Tilt the torch head slightly toward the root of the joint and in the weld travel direction. Take care to ensure that penetration at the root of the weld is 15 to 85 percent of T. The reinforcement should not extend above the upper sheet thickness. The bead contour should be slightly convex. The weld metal should taper smoothly into the base metal with no overlap, and the bead width should be from two to three times T. The surface appearance should be dark bronze or light purple.

Tee and corner joints

We use tee and corner joints to join two plates whose surfaces are at an approximate 90° angle to each other. You can do welding from one or both sides, depending on the position, joint type, and strength required.

Metal preparation and setup

To make a tee or corner weld, first shear the stainless steel sheet to a square edge that is free of burrs and warping. Thoroughly clean the joint edges. For metal up to .0625-inch in thickness, no edge preparation other than cleaning and square shearing is necessary. We sometimes prepare metal that is over .0625-inch thick for a double-bevel tee or a single-bevel tee when we can weld the joint only from one side or when maximum strength is necessary. Do not space tee or corner joints for inert-gas-shielded arc welding because the concentrated heat of the arc permits proper fusion and penetration without spacing the joint. We also recommend that you flux the backside of tee joints and the corner joint's undersides before you weld.

Machine setting and equipment adjustment

The machine and equipment settings for welding tee and corner joints are similar to the settings for butt welds. The difference for corner joints is that you adjust the argon flow to 8 to 10 liters per minute. The difference for tee joints is that the electrode usually extends ¼- to ⅜-inches beyond the edge of the gas-shielding cup.

Welding application

Strike and hold an arc on copper plate, using the foot control rheostat to establish a stable arc with the required heat. Tack weld the joint edges about 1½ inches apart. Hold the torch so that it bisects the included angle made by the two pieces being welded and so it is nearly perpendicular to the weld areas as practical. To weld sheets of unequal thickness, preheat the thicker sheet with a long arc and direct the heat on the thicker sheet during the actual welding operation. Add the filler rod at the root of the joint and the forward edge of the molten pool. Protect the molten pool and end of the filler rod with the shielding gas during the entire welding operation.

The torch angle, heat input, and weld travel speed must be exact in welding the tee joint to ensure adequate penetration at the root of the weld without burning through the lower sheet. To terminate the weld, swing the foot control to the low position to break the arc and permit the shielding gas to flow over the weld area until it cools to a black heat. The tee weld's upper and lower legs should equal 1½ T. The corner joint's upper and lower legs should equal T. The throat of the weld for both tee and corner welds should equal approximately the sheet thickness.

Tee welds should have a face contour varying from slightly concave to slightly convex. Corner welds should have a convex face to ensure the proper throat depth. The weld surfaces must be free of welding defects and excessive contamination. Refer to the discussion in Unit 1 for the procedures and techniques to use when welding these joints.

Welding carbon steel joints

Welding low carbon steel joints are easily done by the TIG process, but medium and high carbon steels require extensive preheating and post-welding heat treating to get satisfactory results.

When welding carbon steels with the TIG process, the best filler rods are made from low carbon steel with deoxidizers. Oxyacetylene welding rods don't contain the deoxidizers needed for the TIG process. Without deoxidizers your weld becomes porous (a welding defect). For this reason, do not use oxyacetylene welding rods.

The TIG welding process is particularly good for welding thin-gauge metals. It is not recommended and is not economically feasible for welding carbon steel joints on metal thicker than ¼-inch. Metal thicker than ¼-inch would require many passes to complete using TIG; it could be welded more efficiently by the shielded-metal arc or metallic inert gas methods.

Since this process is used on metals less than ¼-inch thick, there is usually no special edge preparation required other than cleaning the metal. Set up the butt, edge, tee, and lap joints in the same way you'd set them up for stainless steel joints. For welding procedures and techniques, review the welding stainless steel edge joints material we discussed earlier (Unit 1).

Aluminum joints

You can find aluminum joints in many Air Force facilities. The joints are part of such items as structural supports, doorframes, and windows. The trend to use aluminum will probably continue as new aluminum alloys are developed that are lightweight, strong, and corrosion resistant. Because you're in the structural career field, it is your job to repair them. In the following paragraphs we discuss how you prepare and weld joints to make effective repairs in aluminum and aluminum alloy.

Welding aluminum joints

Aluminum and aluminum alloys that can be welded by the TIG welding process include 1100, 3003, 3004, 5005, 5050, 5052, 5083, 5154, 6061, 6062, and 6063 alloys. Welding work-hardened, non-heat-treatable alloys reduces their strength. You can expect heat-treated alloys in the "as-welded condition" to develop 40 to 60 percent of their original strength.

Welding setup and application

Support the weld with a backup bar or plate when possible, except when welding from both sides. The backup bar can be copper, steel, or aluminum. Copper and steel backups should be removable. When you use an aluminum backup bar or plate, it should be compatible with the metal being welded. Backup plates are recommended to control heat for welding penetration and to permit faster welding speeds. Use inert gas backup when high-quality welding is necessary.

Figure 2–13 shows a tungsten electrode with grinding marks ending in a ball tip. The ball tip helps the electrode to have the best current carrying characteristics for welding aluminum. You can form this ball by arcing the electrode on a clean aluminum or copper strip.

Figure 2–13. Ball tipped electrode for welding aluminum.

Clamp the aluminum to be welded for alignment and spacing. Good joint fit up makes welding easier. Adjust the current setting and argon flow for the aluminum thickness. Start the arc by bringing the tungsten electrode close to the work surface. The electrode does not have to touch the work surface because the high-frequency current forms a path to the work plate. Adjust the arc distance to the plate to $^1/_8$- to $^3/_{16}$-inch. Hold the arc at the starting point until the metal liquefies and a molten pool is made. Add the filler rod manually to the front edge of the molten pool, melting a small amount and withdrawing the rod. Point the torch in the direction of travel at a 10° to 20° angle from the vertical position. Hold the filler rod fairly flat to the work surface between 5° to 30° from the horizontal position. Advance steadily along the line of weld, keeping a uniform bead with evenly spaced ripples. To terminate the weld, release the foot switch while keeping the torch directed onto the molten pool. Gas and water will continue to flow for a few seconds, cooling the weld and preventing contamination and cracking. You can minimize cracking during welding by using the steps shown in figure 2–14.

Figure 2–14. Minimizing cracking during welding.

Weld specifications

The weld specifications for aluminum can vary with its thickness and the alloy used. The bead width can be two to three times the base metal's thickness. The reinforcement can range from 25 to 30 percent T. The upper and lower legs should be equal to 1½ T and face slightly concave or convex. The following table is a guideline for work angle, travel angle, and drag/weave for flat, horizontal, vertical up, and vertical down welding positions

	Flat	Horizontal	Vertical down	Vertical up
	Butt Lap T	All joints	All joints	All joints
Work Angle	90°	15°		
Travel Angle	15° torch 15° filler	15° push	90° torch 15° filler	60° torch 45° filler
Drag/Weave	steady	Begin ½" from side	down	up

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

613. Job Preparation

1. When TIG welding with DCEN/DCSP and a small diameter electrode, what is the resulting bead contour?

2. What shielding gas do you use for TIG welding with alternating current?

3. What desirable features do thoriated tungsten electrodes have?

4. If the electrode becomes contaminated and erratic, what can you do to stabilize the arc?

5. How far should the electrode extend beyond the end of the gas-shielding cup for butt and fillet welding?

6. A number eight cup has what size cup opening?

614. TIG welding procedures

1. Why do we use inert gas shielded welding extensively for fabricating and repairing kitchen parts?

2. How does the coefficient of expansion for stainless steel compare with that of carbon steel?

3. How can you keep carbide precipitation to a minimum?

4. How do you back up a weld?

5. What purpose does backing up a weld serve?

6. Under what circumstances can you not use an edge joint?

7. Why is a very close joint fit up necessary when preparing an edge joint?

8. What amp setting do you use for welding .030-inch-thick stainless steel edge joints?

9. What type of edge joint surface does an irregular or rapid welding speed produce?

10. How do you terminate a weld?

11. How long do you make the arc when welding in the horizontal position?

12. Why do you add filler rod to the forward edge of the molten pool?

13. Why are welded lap joints used extensively to repair stainless steel parts?

14. Explain the edge preparation for TIG welding stainless steel corner joints.

15. What occurs if you do not melt back the top sheet (lap joint) approximately the thickness of one to two sheets?

16. Describe how you add filler rod to a stainless steel tee joint using TIG welding.

17. The TIG welding process can easily weld a low carbon steel type?

18. Why doesn't a low carbon steel oxyacetylene welding rod give good results when used in TIG welding?

19. What is the recommended maximum thickness for welding carbon steel by the TIG process?

20. What is the purpose of a backup bar?

21. What do you use when high quality aluminum welding is necessary?

22. What produces an arc without the electrode touching the metal?

23. Why do you allow the gas to continue to flow for a few seconds after you complete the welding?

24. What is the percentage range for reinforcement used in aluminum welding?

Answers to Self-Test Questions

611

1. A chemically inactive gas that will not combine with any other element.
2. TIG uses a non-consumable tungsten electrode, while MIG uses a consumable alloy wire with about the same composition as that of the metal being welded.
3. It prevents the oxygen, nitrogen, and carbon elements present in the air from coming in contact with the molten metal in your weld.
4. They're stronger, more ductile, and more corrosion resistant.

612

1. (1) An AC-DC engine-driven generator.
   (2) An AC-DC transformer-rectifier.
2. Starting the arc without contact between the electrode and the work.
3. For one, you can use a higher current, and for another, there is no danger of overheating as long as the water flows.
4. (1) Excessively high water pressure.
   (2) Mistreatment of equipment.
   (3) Improperly sealed hose connections.
   (4) Cracks in the torch body.
5. 10.6 cubic feet per hour (1 liter per minute is equivalent to 2.12 cubic feet per hour).
6. Leather sleeves or jacket, apron, gloves, safety glasses, and welding helmet with appropriate lens.

613

1. A narrow, deep weld.
2. Argon.
3. Better arc starting and stability, higher current-carrying capacity, and higher resistance to contamination.
4. Strike the arc on a copper plate.
5. A distance equal to its diameter for butt-welding and slightly farther for fillet welding.
6. ½-inch cup opening (The cup number indicates the cup opening diameter in multiples of $^{1}/_{16}$-inch).

614

1. Because it warps less, prevents oxidation, and maintains the maximum of corrosion resistance in the welded part.
2. The coefficient for stainless steel is approximately 60 percent greater than that for carbon steel.
3. By confining the arc to as small an area as possible while still obtaining proper fusion.
4. By positioning a metal strip on the joint underside.
5. It conducts excess heat away and prevents the weld from melting through.
6. If direct tension or bending stresses are to be applied to the finished product.
7. To allow the edges to fuse together without the use of a filler rod.
8. 15 to 30 amps DCEN/DCSP.

9. A rough or an uneven surface.
10. Remove your foot from the control to permit the shielding gas to flow over the weld area until it cools to a black heat.
11. Approximately the same as the electrode diameter.
12. To prevent contaminating the tungsten electrode and to aid in weld control.
13. Because lap joints are easy to prepare and weld.
14. Shear the stainless steel sheet to leave a square edge that is warp and burr free.
15. It will result in a concave undercut bead.
16. It is added at the root of the joint and the forward edge of the molten pool.
17. Low carbon steel.
18. It does not contain deoxidizers.
19. ¼-inch.
20. To support the weld, control heat for welding penetration, and permit faster welding speeds.
21. Inert gas backup.
22. High-frequency current.
23. To prevent contamination and cracking of the weld.
24. 25 to 30 percent.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the best answer to each question, and circle the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

58. (611) What characteristic of helium makes it undesirable for welding thin material?
    a. Low heat per ampere.
    b. High heat per ampere.
    c. Decreased penetration depth.
    d. Presence of weld contaminates.

59. (611) Which welding process uses a consumable alloy wire with approximately the same chemical composition of the base metal?
    a. Nonshielded gas.
    b. Metallic inert gas.
    c. Oxyacetylene gas.
    d. Tungsten inert gas.

60. (612) What is the minimum number of amperes recommended for using a water cooled inert gas welding torch?
    a. 100.
    b. 150.
    c. 200.
    d. 250.

61. (612) What is indicated if the molten pool becomes cloudy or the tungsten electrode turns blue when cooling?
    a. A leak in the hose or hose connection.
    b. Wrong shielding gas being used.
    c. Amperage setting is incorrect.
    d. Polarity setting is incorrect.

62. (612) What do you use to make slight changes in the current setting when tungsten inert gas (TIG) welding?
    a. Foot control.
    b. Current meter.
    c. Fine adjustment knob.
    d. Hand-operated rheostat.

63. (613) For any given current setting, DCEP/DCRP requires an electrode approximately how many times larger in diameter than would be used for DCEN/DCSP.
    a. 1.
    b. 2.
    c. 3.
    d. 4.

64. (613) What machine setting produces a tungsten inert gas weld with deep penetration and a narrow bead?
    a. Alternating current.
    b. Direct current, reverse polarity.
    c. Direct current, straight polarity
    d. Alternating current, high frequency.

65. (613) What size opening does a number 6 cup have?
   a. $\frac{1}{4}$-inch.
   b. $^{3}/_{16}$-inch.
   c. $^{3}/_{8}$-inch.
   d. $^{5}/_{16}$-inch.

66. (614) You must closely follow procedures to align, space, and tack weld stainless steel joints because stainless steel in comparison to carbon steel has a metal expansion coefficient that is
   a. 30 percent less.
   b. 60 percent less.
   c. 60 percent greater.
   d. 30 percent greater.

67. (614) Confining the arc to as small an area as possible and still allowing proper fusion when welding austenitic stainless steel
   a. decreases tack welds.
   b. increases gas shielding.
   c. increases electrode size.
   d. decreases carbide precipitation.

68. (614) Tungsten inert gas welding edge joint preparation on stainless steel includes cleaning, deburring, and
   a. polishing the edges.
   b. rounding the edges.
   c. fitting the edges evenly.
   d. fitting one edge slightly higher.

69. (614) Approximately how many pints per minute should the water flow be for a water-cooled torch?
   a. 1.
   b. 2.
   c. 3.
   d. 4.

70. (614) How do you prepare a stainless steel lap joint using the tungsten inert gas welding process?
   a. V-groove the top edge only.
   b. Square the edges and remove burrs.
   c. Square top edge only and remove burrs.
   d. V-groove the edges for better penetration.

71. (614) What color should a stainless steel joint have after welding?
   a. Dull silver or off white.
   b. Flat black or light blue.
   c. Dark blue or reddish purple.
   d. Dark bronze or light purple.

72. (614) When tungsten inert gas welding stainless steel tee joint or corner joint, the concentrated arc heat generated allows proper fusion with
   a. no shielding gas.
   b. no joint spacing.
   c. extra joint spacing.
   d. extra shielding gas.

73. (614) What do you do during the welding operation when you are tungsten inert gas welding stainless steel tee joints of unequal thickness?
    a. Use a short arc.
    b. Alternate the arc size.
    c. Direct most of the heat on the thinner sheet.
    d. Direct most of the heat on the thicker sheet.

74. (614) What filler rod type is best suited to weld carbon steel with the tungsten inert gas process?
    a. Low carbon steel with deoxidizers.
    b. High carbon steel with deoxidizers.
    c. Low carbon steel without deoxidizers.
    d. High carbon steel without deoxidizers.

75. (614) What is the arc adjustment distance from the arc to the plate when tungsten inert gas welding aluminum?
    a. $^{1}/_{16}$- to $^{1}/_{8}$-inch.
    b. $^{1}/_{8}$- to $^{3}/_{16}$-inch.
    c. $^{3}/_{16}$- to ¼-inch.
    d. ¼-to $^{5}/_{16}$-inch.

Please read the unit menu for unit 3 and continue ➔

Student Notes

Helium

Helium is a colorless, odorless, nontoxic, and tasteless inert gas. Much lighter than air, it is the second lightest of all gases. Helium is nonflammable and, like argon, its cylinder pressure is 2,000 to 2,500 psi. The cylinder's distinctive color markings are gray with a buff (light brown) top. The cylinder is considered empty when the pressure is reduced to 25 psi. Helium is also much cheaper than argon, but you use about one-third more helium because it is a lighter gas. Since helium is several times lighter, it does not settle down around the work as well as argon. The bead is wider with shallower penetration than it would be using argon, which is the opposite of TIG welding. Helium is used primarily for special tasks and for welding nonferrous metals such as aluminum, magnesium, and copper.

> NOTE: Make sure to follow all safety procedures for handling cylinders that you learned previously. If you are unsure, read the material safety data sheets (MSDS) or ask your supervisor.

Gas shielded welding methods

MIG (fig. 3–1) uses a consumable, continuously fed alloy wire (commonly referred to as filler wire) with approximately the same chemical composition as that of the metal being welded, while tungsten uses a non-consumable tungsten electrode. MIG is a fusion welding process that uses the heat produced by an electric arc between a metal electrode and the work. The filler metal electrode carries the current from the power supply unit to the base metal. An arc forms between the electrode and the base metal. The bead is produced by transfer of the filler metal to the base metal. The principles involve the arc, or heating source, and are the same as those for shielded metal arc welding. However, in the gas-shielded process, an inert gas (helium or argon) flows from the orifices in the torch head past the electrode to form a protective blanket over the weld area. The gas shield's primary purpose is to keep oxygen, nitrogen, and carbon elements that are present in the air from coming in contact with the molten metal and contaminating the weld

The time that you take to properly set up your inert gas welding equipment allows you to correct problems before you begin welding. By setting up your equipment to your welding task, you can make high quality welds.

Figure 3–1. Metallic inert gas shielded process .

MIG welding advantages

MIG welding has become an accepted process for joining all types of metals. You can easily mechanize production welding by using MIG welding, thereby substantially reducing manufacturing costs. Generally, the same type of equipment and welding techniques apply to all metals when welding with MIG.

There are several advantages to using MIG welding over other welding techniques. The weld cycle time is minimized due to lack of flux, slag, and very little spatter. MIG welding is a faster welding process compared to all other options and is easily learned by workers who are proficient in other welding techniques. MIG is equally effective and more economical than TIG when welding thin stock. Gas-shielded welding produces welds that are stronger, more ductile, and more corrosion-resistant than the welds made with shielded metal arc welding. The protective gas shield envelops the weld and makes the joint without flux which eliminates flux-caused corrosion and cleaning.

616. Selecting and maintaining metallic inert gas welding equipment

In order to make high quality welds, you must know what MIG welding equipment is needed and how it functions before you using the MIG welding process. In this lesson, we discuss the equipment needed for MIG welding along with its function.

Power source

The most efficient current for MIG welding is direct current reverse polarity (DCEP/DCRP or DC+.) This contributes to better melting, deeper penetration, and excellent cleaning action. The machine we use for MIG welding is a constant-potential machine, whereas the machine we use for TIG and shielded metal arc welding is a constant-current machine. The constant-current machine provides voltage that drops when the arc is struck and varies as the arc length changes. This is fine for stick and TIG welding, but with MIG welding, you've got a steady wire feed that requires steady voltage to maintain a uniform arc and bead. This need for steady voltage led to development of the constant-potential machine. This machine provides steady voltage when you strike the arc and maintains a steady voltage as the arc length varies. Although the constant-current machine can be adapted to MIG welding, you obtain the best welding results with constant-potential machines (therefore, constant-current machines are not recommended). You can also use a rectifier or motor generator. All machines used for MIG welding must also supply direct current with normal limits of 200 to 250 amps for all position welding.

There are only two basic controls that you use for MIG welding. The first is the voltage rheostat; it is located on the welding machine and regulates the voltage. The second is the wire feed rheostat, which is also located on the machine and controls the speed of the wire feed motor.

Wire drive

The MIG welding wire drive mechanism controls the welding wire speed. It has a rheostat which varies the speed at which the filler wire is supplied to the welding gun and normally contains the controls for the welding current flow and shielding gas. If you have a water-cooled gun, a control for the water supply will also be in the wire drive.

The wire drive can be located on the welding machine or at another location to allow more efficient equipment use. You must change the rollers in the wire drive or torch for different wire types and diameters. The rollers used include the "V" grooved, "U" grooved, "V" knurled, and "U" cogged. Refer to your machine's owner's manual to determine which rollers to use. The wire straightener is an accessory to the wire drive which is installed between the filler wire roll and the wire drive. The wire straightener removes the wire's curvature as it comes off of the wire roll. The wire straightener also prolongs the life of the wire drive and welding gun.

Welding gun

The welding gun is literally where everything comes together during MIG welding. The gun can be water-cooled or air-cooled. The air-cooled gun is used on light-gauge metals requiring less than 200 amps. The water-cooled gun is designed for use on jobs requiring up to 200 amps or more. Both gun types are shown in figure 3–2. Whether you use the straight or curved nozzle depends on your access to the joint. You can change the nozzles for welding different materials. Some nozzle types include copper, ceramics, glass, and glass-coated metals. The glass nozzle gives you a good view of the welding operation, but for all-around use, the copper nozzle performs best.

Figure 3–2. MIG welding guns.

Squeezing the welding gun's trigger starts the electric current, the shielding gas flow, the wire drive, and the cooling water flow (for the water-cooled gun). Since the welding wire is the power lead for MIG welding, squeezing the trigger charges it (causes it to become hot). Do not touch the welding wire at the gun or the welding wire spool when you are handling the ground lead or are in contact with the grounded work. If the welding wire is hot and you come in contact with the ground lead or work and wire at the same time, you might get an electric shock.

You'll find that MIG welding guns are either push or pull guns. The pull gun has drive rollers in it to pull the wire from the wire drive. Use it for small-diameter and soft wires such as aluminum. Pulling these types of wire prevents them from binding or kinking between the gun and the wire drive. The push gun has the wire pushed to it by drive rollers in the wire drive. Use it for large-diameter and hard wires such as carbon and stainless steel. These wires are less likely to be bent before they reach the gun, making the push gun more suitable. You also use the push gun to weld with hard wires and where currents often exceed 250 amps. Both guns have a trigger switch that controls the wire feed and arc as well as the shielding gas. Wire feed, arc, and gas stop immediately when you release the trigger. Some equipment has a timer that permits the shielding gas to flow for a predetermined time to protect the weld until it solidifies.

Hose

The hose used for MIG welding is very much like the TIG welding hose. It is a series of rubber or plastic hoses that carry the shielding gas, welding wire, and the supply and return water (if your gun is water-cooled). The conduit (hose), which guides the electrode wire, is interchangeable to match the wire that you use. A standard conduit is used for hard wire, such as steel, and a nylon-lined conduit is used for soft wire, like aluminum.

Shielding gas

Earlier, we discussed two shielding gasses that can be used for MIG welding—argon and helium. There's another inert shielding gas—carbon dioxide—that can be used alone or mixed with other shielding gasses. When carbon dioxide is used as a shielding gas, the arc heat causes the carbon dioxide to separate into its two elements—carbon monoxide and oxygen. Since oxygen is present in carbon dioxide, there is a problem since the purpose of a shielding gas is to keep certain elements such as oxygen away from the molten pool during welding. To overcome this problem, you must use a welding wire that has a deoxidizer in it. This deoxidizer combines with the oxygen and keeps it out of your weld puddle. Some common deoxidizers we use are manganese, silicon, aluminum, and titanium. Gas purity may also have considerable effect on welding, depending on the extent to which the metal is affected by contaminates. Stainless steel, as a rule, is not significantly affected by the small percentages of contaminates in the shielding gas. In contrast, nonferrous metals, such as aluminum, are sensitive to impurities, so you must weld them with high-purity inert gas. The commercially available argon and helium gases average well over 99.95 percent purity.

As a shielding gas, carbon dioxide and carbon dioxide mixtures are a good choice for industry and one you may want to consider. It is relatively inexpensive, possesses good penetration characteristics, and provides a good bead contour when welding carbon steel. Make sure that your welding wire has a deoxidizer in it when you use carbon dioxide.

Gas-control equipment

We use a combination regulator and flow meter (fig. 3–3) for MIG welding. This is the same flow meter we use for TIG welding. Gas flow rate should be approximately 35 cubic feet per hour (cfh) for most welding conditions. The correct settings are governed by the type and thickness of the metal, position of the joint, the kind of shielding gas used, diameter of the electrode, and the type of joint. With the proper gas flow, the arc produces a rapidly crackling or sizzling sound. Inadequate gas flow makes the arc produce a popping sound with resultant weld discoloration, porosity, and spatter. This may also occur with high weld speed or from unusually drafty or windy conditions in the weld area. You must place the gas nozzle no further than 2 inches from the work. Too much space reduces the effectiveness of the gas shield. Too little space may result in excessive spatter, which collects on the nozzle and shortens its life.

Figure 3–3. Argon gas flow regulator/meter.

Protective equipment

When you are MIG welding, wear full protective clothing and gloves to keep hot metal spatter from burning you. The arc produced by MIG welding is more intense than the arc produced by TIG welding. To protect your eyes while MIG welding, use a lens in your welding hood that is two to four shades darker than that you use for TIG welding.

Equipment maintenance

The maintenance that you do on MIG welding machines is the same as the welding machine maintenance we discussed for TIG welding. You can clean the welding leads and hoses by reversing the cooling water flow through the hoses and by using compressed air to blow dust and dirt out of the welding wire lead. Repair or replace damaged hoses to prevent gas and water leakage and possible short circuits in the welding wire.

Check all electrical circuit connections and tighten any that are loose. Check all equipment for any loose nuts and bolts and tighten any that are loose.

Welding gun maintenance includes visually inspecting the gun, hoses, and cables. Clean any slag from the gun and replace the welding tip and gun nozzle when they become worn or damaged. Check the gun for broken or cracked insulation and parts. Check the hoses and cables for cuts and frays. Inspect the flow meter for cracks or leaks and replace it if it is not working properly or if you find it is damaged. For more extensive repairs, follow procedures in your gun manufacturer's handbook. If you cannot make the repairs, contact your supervisor for contract repair or replacement.

> NOTE: Disconnect the power to the welding machine before performing any maintenance procedures.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

615. Metallic inert gas welding principles

1. Explain the term inert gas.

2. What is a significant difference between TIG and MIG welding?

3. How does inert gas prevent weld contamination?

4. How do welds produced by gas-shielded welding compare with those made with ordinary metal arc welding?

616. Selecting and maintaining metallic inert gas welding equipment

1. What type of power source do you use for MIG welding?

2. What piece of MIG welding equipment controls the wire speed?

3. What occurs when you squeeze the trigger on the MIG welding gun?

4. What MIG welding shielding gas requires a deoxidizer in the filler wire?

5. If a number 10 lens is safe for TIG welding, what shade would you use for MIG welding?

3–2. Application procedures

This section covers the techniques used in MIG welding. The MIG welding is being increasingly used for maintenance and repair applications. If you are proficient in shielded metallic arc or TIG welding, then learning the MIG welding process should be easy for you. The MIG welding process allows you to complete a joint without stopping, thereby overcoming such problems as, slag inclusions, cold laps, poor penetration, crater cracking, and poor fusion. In the first lesson we'll concentrate on job preparation and follow in the second lesson with the actual MIG welding procedures.

617. Job preparation

The MIG welding principles involve welding metal together with an electrical arc, a continuous consumable welding wire, a wire-dispensing gun, and shielding. Before you begin welding with the MIG outfit, you need to know how to apply these principles. First, we give you information about welding current, filler-wire selection and gun setup; and then we cover the different metal transfers you can use when MIG welding.

Welding current

The welding current for almost all MIG welding should be DCEP/DCRP (or DC+). It gives better penetration than DCEN/DCSP (or DC-), and you can use it to weld all metals. Figure 3–4 shows the bead contour obtained with DCEP/DCRP and DCEN/DCSP. We sometimes use DCEN/DCSP when minimum penetration is required. When you compare these bead contours with those in Figure 3–5, you can see that they are opposite.

Figure 3–4. MIG weld contour comparison.

Figure 3–5. TIG weld contour comparison.

The difference between TIG and MIG welding beads is the difference in metal transfer. When you are MIG welding with DCEP/DCRP (or DC+), the metal transfers from the weld wire to the work in a fine spray, which penetrates easily into the work. When you are MIG welding with DCEN/DCSP (or DC-), the metal transfer is globular, which results in poor penetration. MIG welding with AC current gives you very poor results because the current flow direction is constantly changing. This change causes the weld wire to burn unequally, resulting in an erratic arc. You can use a wide range of current values with each wire diameter; this allows various thicknesses of metal to be welded without having to change the wire. It takes some trial-and-error to determine the correct current to use for a particular joint in order to achieve the correct specifications.

Welding-wire selection and gun setup

The welding wire and gun are unique MIG welding features. Learning how to select the wire and use it in the gun is a critical step for you to understand. Let's start with the welding wire.

Welding wire

In MIG welding, the welding wire serves the same purpose as a welding rod does in oxyacetylene welding. There are many welding wire types and sizes available for specific purposes. They are purchased in spools to provide a continuous feed of filler metal. You must make sure that the wire is compatible with the base metal for fusion to take place. Fusion must take place to have a proper weld. Base your selection of wire size (diameter) on the type of metal, metal thickness and the position in which you are to do the welding. There are tables available that you can use to determine the type of filler wire needed. Vertical and overhead welding require smaller diameter wires. Basic wire diameters are 0.020-, 0.030-, and 0.035-inch. These are best used for welding thin metals of low and medium carbon steel. We normally use 0.045- and $^{1}/_{16}$- inch diameter wires on medium thickness metals and $^{1}/_{8}$- inch diameter wires on thicker metals. Be sure that the wire feed rollers are the size required for a particular wire. For example: the .030-inch wire requires .030-inch rollers (wire feed rollers have the size stamped on their side). Check the gun for the correct size nozzle.

Solid welding wires

Filler wires have identifying numbers assigned by the American Welding Society (AWS). Figure 3–6 lists some electrodes along with their recommended usage. The “E” in the number indicates that it is an electrode. The first two digits of the mild steel electrodes indicate their tensile strength in thousands of psi, and the “S” indicates a solid bare wire. The final numbers or letters specify the chemical composition. The numbers for the aluminum and stainless steel wires indicate the composition; use them on base metals of similar composition.

Figure 3–6. MIG welding electrodes.

Flux-cored welding wire

Flux-cored arc welding wire is a MIG welding method in which you use a hollow wire electrode with a flux material core. Flux-cored welding forms a coating over the completed weld. Consequently, you must do more post weld cleaning, especially when you weld multiple passes. Like any arc welding wire, these wires must be compatible with the base metal. The two flux-cored welding wire types are described in the following table.

Flux-cored Welding Wire	Requirements/Example
Self-shielded	x Does not require an inert gas to protect the molten pool. x Generally used for applications that otherwise would be done by the shielded metal arc welding method. Example: Welding mild steel.
Gas-shielded	x Requires a shielding gas. x Generally used for applications that would otherwise be done by MIG welding with a solid wire. x Provides a higher quality weld than does self-shielded. Example: Welding stainless steel or aluminum.

Wire extension

The term extension refers to the distance the welding wire extends beyond the welding gun nozzle. The recommended extension for most welding operations is ⅜ to ¾ inch (fig. 3–7). As wire extension increases, your ability to control the wire decreases. If the wire extension is too long, the wire tends to preheat, become soft, and whip around. If the wire extension is too short, the wire tends to fuse to the welding tip, which shortens tip life. To attain the correct extension, keep the welding tip even with or slightly recessed inside the welding gun nozzle. Do not let the welding tip extend beyond the gun nozzle.

Figure 3–7. Welding wire extension.

Metal transfer

In an earlier lesson, we discussed advantages of direct current reverse polarity. You'll recall that penetration is greater and there is also a good surface-cleaning action on metals that have heavy surface oxides, such as aluminum. For these reasons, DCEP/DCRP (DC+) helps transfer metal the best when you are MIG welding. There are two metal transfer methods that we use in MIG welding: spray arc transfer and short-circuiting transfer.

NOTE: During all welding, you must protect the leads of the welding machine from sparks or damage. Make sure to remove any flammable material from the welding area.

Spray arc transfer

The spray arc transfer is very good for welding on thick metal. In this metal transfer (fig. 3–8), you use high amperage with an argon shielding gas. Argon has a pinching affect on small molten metal pieces, and with high current, the small molten particles pass from the electrode (welding wire) to the work with a spraying effect

Figure 3–8. Spray arc transfer.

Short-circuiting transfer

The short-circuiting transfer is very good for welding thin materials. It gives you better puddle control than the spray arc transfer. This feature makes short-circuit transfer better for welding in the flat position.

The short-circuiting transfer (fig. 3–9) uses current below 200 amps and welding wire less than .045-inch in diameter to keep the weld puddles more controllable. In this metal transfer, the molten metal does not break off the weld wire before it contacts the weld puddle. This forms a continuous path (fig. 3–9, view B) for the weld current to follow, which short-circuits the arc. As the molten metal separates from the weld wire (fig. 3–9, view C), the arc starts again. This short-circuiting and arc restarting occurs between 20 and 200 times per second, depending on machine settings. The starting and stopping of the arc gives you a cooler weld puddle, making this metal transfer the most suitable for welding thin metal.

Figure 3–9. Short-circuiting transfer.

618. MIG welding procedures

There are certain welding practices that you must follow to make good welds with the MIG welding process. In this lesson, we explain the techniques that you can use to weld various metals.

Before you begin welding, follow the steps listed below for setting up MIG welding equipment.

Setting Up MIG Welding Equipment	
Step	Action
1	Select and install the filler wire.
2	Select the shielding gas according to the type of material to be welded.

Setting Up MIG Welding Equipment	
Step	Action
3	Set the machine to the correct voltage according to the material's thickness.
4	Set the wire feed speed.
5	Set the flow meter to the correct cfh.

Welding techniques

The techniques that you use are partially determined by the way that you prepare the joints for welding. You can prepare butt, edge, tee, and lap joints the same as you do in other welding types. On metals that are $^{1}/_{8}$-inch thick or less, no special edge preparation is required, but on metals that are greater than $^{1}/_{8}$-inch, V-grooving is necessary for good penetration because grooves have smaller root faces and root openings since the arc used is narrower than the one we use for SMAW. The flat position is the best for MIG welding, but you can obtain good results in all positions. Use weld backing to obtain a sound weld at the root when welding butt joints. Materials that you can use for backing include copper blocks, strips and bars, carbon block, or fired clay. Some of these materials draw the heat away from the joint. Copper is the most commonly used backing material.

Flat butt and edge joints

When you are welding butt and edge joints, center the gun on the joint. To begin welding the butt joint in the flat position, you must start by depositing the root pass; use a smooth, steady drag motion. You can use a slight weave instead of the drag. Do not let the wire leave the leading edge of the puddle. Maintain a work angle of 90° and a drag travel angle of 5° to 15°. Make your penetration for the root pass flush to slightly convex. The finished weld should equal leg dimension and fuse smoothly into both plates with no overlap or undercut. When you weld the cover pass, you must maintain a steady weaving motion with a work angle 90° to the surface of the plates and a travel angle of 5°–15° drag. Weld reinforcement should be flush to slightly convex to the surface of the base metal. The finished weld should have equal leg dimension and should fuse smoothly into both plates with no overlap or undercut.

If you use the forehand technique (push), angle the gun 5° to 10° in the weld's travel direction. If you use the backhand technique (drag), angle the gun 5° to 15° away from the weld's travel direction. The bead penetration is greater with the backhand technique than the forehand technique. The backhand technique also gives the welder a better molten metal puddle view, which usually results in a better weld. For these reasons, the backhand technique is preferred.

Flat lap and tee joints

The lap and tee joints are fillet welds. Center the gun angle on the joint angle, then incline it 5° to 10° in the weld travel direction when using the forehand technique. If you are using the backhand technique, angle the gun 5° to 15° away from the weld's travel direction. It may be necessary or advantageous to incline the material 10° to 20° when welding in the flat position to help flatten the bead and increase the travel speed. When welding flat position lap joints, you must use a slight weave motion, with a work angle of 45° to the joint and a travel angle of 5° to 15° drag. Travel smoothly and evenly to ensure complete and proper penetration into both plates. Make your bead face flat to slightly convex and the finished weld should have equal leg dimension and no overlap or undercut.

When welding the flat position T-joint, you must deposit the first pass using a slight weaving motion. Maintain a 45° work angle and smoothly maintain a 5° to 15° drag travel angle. Ensure the weld bead has equal leg dimensions. The second pass work angle is 55°, and the drag travel angle is 5° to 15°. Make the second pass overlap the first pass by $^{1}/_{3}$ to ½. On the third pass, make your work angle 35° and the drag travel angle 5° to 15°. Make the third pass overlap the second pass by $^{1}/_{3}$ to ½, slightly convex, and have equal leg dimensions with smooth fusion into both plates and no overlap or undercut.

Horizontal butt joint

Follow the procedures you learned earlier for setting up the machine and preparing the metal to be welded. For the root and cover pass follow the same procedures as welding in the flat position Deposit the weld using a steady weaving motion. Make sure to pause at the tip of each weave to help fight the effects of gravity. Do not let the wire leave the leading edge of the puddle. You must maintain a work angle of 80° to 85° and a drag travel angle of 5° to 15°. Make your penetration for the finished weld pass flush to slightly convex and make sure it fuses smoothly into both plates with no overlap or undercut.

Horizontal lap and tee joints

Use a slight weaving motion pausing at the tip of each weave. The work angle must be 45° to the joint and the travel drag angle 5° to 15°. Travel smoothly and evenly to ensure complete and proper penetration into both plates. Make your bead face flat to slightly convex and have equal leg dimension, with smooth fusion into both plates with no overlap or undercut. When welding a horizontal t-joint, you must deposit the first pass using a slight weaving motion, pausing at the top of each weave. Maintain a 45° work angle, and 5° to 15° drag travel angle. Ensure the weld bead has equal leg dimensions. Make the second pass work angle 55° and the drag travel angle 5° to 15°. Have the second pass overlap the first pass ⅓ to ½. The third pass work angle is 35° and the drag travel angle is 5° to 15°. Have the third pass overlap the second pass ⅓ to ½, and have equal leg dimensions, with smooth fusion into both plates with no overlap or undercut.

Vertical down butt joint

Deposit the root pass using a steady drag motion. Stay on the leading edge of the puddle. You must maintain a work angle of 90°, with a drag travel angle of 10° to 20°. Root penetration must be flush to the underside of the plate's surface to slightly convex. Make sure the finished weld has equal leg dimensions and smooth fusion into both plates, with no overlap or undercut. For the cover pass, the work angle is 90° to the surface of the plates, with a drag travel angle of 10° to 20°. Use a Z weave pattern to evenly deposit the cover pass onto both plates. Keep the wire located on the leading edge of the puddle as you move down the joint. Be sure the finished weld has equal leg dimensions with smooth fusion into both plates with no overlap or undercut.

Vertical down lap and tee joints

Use a downward Z weaving motion to maintain even fusion into both plates. The work angle must be 45° to the joint, with a drag travel angle of 10° to 20°. Make sure the finished weld has equal leg dimensions and smooth fusion into both plates with no overlap or undercut.

When welding a t-joint, you must use a downward Z weaving motion to maintain even fusion into both plates. Maintain a 45° work angle and a 10° to 20° drag travel angle. Ensure the weld bead has equal dimensions. For the second pass, the work angle must be 45° to the joint, with a 10° to 20° drag travel angle. Use a wider weaving motion than on the previous pass. Make sure the finished weld has equal leg dimensions with smooth fusion into both plates, with no overlap or undercut.

Vertical up butt joint

When welding the vertical up butt joint, you must move evenly up the joint with no side to side motion. Stay on the leading edge of the puddle, while maintaining a work angle of 90° and a push travel angle of 5° to 10°. Travel at a speed that penetrates the joint completely and produces a finished bead that is slightly convex to the surface of the plates. Make sure the finished weld has equal leg dimensions and smooth fusion into both plates with no overlap or undercut.

Vertical up lap and tee joints

Weld the vertical up lap joint upward using a slight weaving motion to maintain even fusion into both plates. The work angle must be 45° to the joint and maintain a push travel angle of 5° to 10°. Make sure the finished weld has equal leg dimensions and smooth fusion into both plates with no overlap or undercut.

When welding the t-joint, you must start at the bottom of the joint and weld upward using a slight weaving motion. The work angle must be 45°, with a 5° to 10° push travel angle. Keep the wire in the leading edge of the puddle. For the second pass, the work angle must be 45° to the joint, with a 5° to 10° push travel angle. Use a wider weaving motion than on the previous pass. The finished weld must have equal leg dimensions, with smooth fusion into both plates with no overlap or undercut.

Overhead butt joint

Follow the procedures we described earlier for setting up the machine, preparing the metal, and starting the arc. Deposit the weld pass using a smooth, steady drag motion. Do not let the wire leave the leading edge of the puddle. You must maintain a work angle of 90°, with a drag travel angle of 5° to 10°. The finished weld must have equal leg dimensions and smooth fusion into both plates with no overlap or undercut.

Overhead lap and tee joints

When welding the overhead lap joint, use a slight weaving motion with a work angle of 45° to the joint and a 5° to 10° drag travel angle. Travel smoothly and evenly to ensure complete and proper penetration into both plates. The finished weld must have equal leg dimensions, with smooth fusion into both plates with no overlap or undercut. Accomplish the t-joint by depositing the first pass using a slight weaving motion, a work angle of 45°, and a 5° to 10° drag travel angle. Ensure the weld bead has equal leg dimensions. Make the second pass work angle 55°, with a 5° to 10° drag travel angle Make the second pass overlap the first pass by ⅓ to ½. The third pass work angle is 35°, with a 5° to 10° drag travel angle. Make the third pass overlap the second pass by ⅓ to ½. The finished weld must have equal leg dimensions and smooth fusion into both plates with no overlap or undercut.

Beginning to weld

To begin welding, squeeze the trigger to start the arc. Keep the gun at the proper travel and work angles. If the arc is not started properly, the filler wire may stick to the work or freeze to the tip of the gun (shut off the machine and free the wire if this happens). Use a pulling or pushing motion. Keep the wire at the leading edge of the puddle and keep the wire centered in the middle of the gas pattern to insure adequate shielding. You can use a slight weaving motion to ensure complete penetration. Release the trigger when you reach the end of the weld, this stops the wire feed and welding current. Keep the gun over the weld until the gas stops flowing to protect the puddle until it solidifies. When you must stop a weld midway through the joint, make sure to leave the crater unfilled. To restart, position the wire approximately ½ inch in front of the crater of the existing weld. Pull the trigger to restart the arc As you pull the trigger, move back toward the crater. Trace the outline of the crater with the wire. Resume the weaving motion and travel speed.

Welding carbon steel, stainless steel, and aluminum

The techniques that you use to weld different metals include metal transfer and gas shielding. Let's see how you can use them to MIG weld.

Carbon steel

When welding carbon steel, you'll find the spray arc transfer is the best for heavy material and the short-circuiting transfer is the best for thin material. Argon is the preferred shielding gas for either transfer method, but carbon dioxide also gives good results

When welding in the horizontal, overhead, or vertical position, you need to control your molten metal puddle very carefully. You can do this by using the short-circuiting transfer to keep the weld cool. Another way to control the puddle size is by changing your travel speed. For a small puddle, make your travel speed fast. For a large puddle, make your travel speed slow.

Stainless steel

Welding stainless steel by the spray arc transfer method with an argon shielding gas gives you the best results. Using a different shielding gas lowers the corrosion resistance in your weld area.

The welding techniques you used on carbon steel joints also apply to stainless steel joints. The forehand technique is recommended for welding stainless steel. This gives you a little less penetration, but keeps the base metal cooler. By keeping the base metal cooler, you can keep corrosion resistance loss to a minimum.

When welding in the overhead, horizontal, or vertical position, you can control your bead by increasing or decreasing weld travel speed. You can use the short circuiting transfer method when welding thin materials in the flat position to give maximum puddle control.

Aluminum

Welding aluminum with the MIG process requires you to use lower amperage settings than you use on carbon or stainless steels. The lower amperage settings are required due to the molten aluminum's flow characteristics. Argon is the best shielding gas to use when welding aluminum. The spray arc transfer method is best for welding thick aluminum in the flat position. The short-circuiting transfer method is best for welding thin aluminum in the horizontal, vertical, and overhead position where the molten metal puddle control is a factor.

The gun angles for welding aluminum are the same as those for carbon and stainless steel. The following table is a guideline for work angle, travel angle, and drag/weave for flat, horizontal, vertical down, vertical up, and overhead welding positions.

	Flat			Horizontal			Vertical down			Vertical up		
	Butt	Lap	T	Butt	Lap	T	Butt	Lap	T	Butt	Lap	T
Work Angle	Root		(1) 45°		45°	(1) 45°	Root		(1)		(1)	(1)
	90°	45°	(2) 55°	80-85°		(2) 55°	90°	45°	45°	90°	45°	45°
	Cover		(3) 35°			(3) 35°	Cover		(2)		(2)	(2)
Travel Angle	5°-15°			5°-15°			10°-20°			5°-10°		
	Drag			Drag			Drag			Push		
	(all three positions)			(all three positions)			(all three positions)			(all three positions)		
Drag/ Weave	Slight weave			Slight weave			Drag Downward			Push	slight weave	
	(all three positions)			(all three positions)			z weave			slight weave		
							z weave			slight weave		

	Overhead		
	Butt	Lap	T
Work Angle	45°		(1)
	90°	45°	(2) 50°
	40°		(3)
Travel Angle	5°-10°		
	Drag		
	(all three positions)		
Drag/ Weave	Slight weave		
	(all three positions)		

Common MIG welding defects

You must control MIG welding properly to produce consistently high quality welds. Let’s discuss some of the common defects you may encounter while MIG welding.

Common MIG Welding Defects	
Defect	Description
Cold lap (overlap)	Cold lap occurs when the arc does not melt the base metal sufficiently and the molten puddle flows onto the un-melted base metal. Often this happens when the puddle is allowed to become too large. You must keep the arc at the leading edge of the puddle for proper fusion.
Surface porosity	Surface porosity is caused by having the shielding gas set too high or too low. If the gas is too low, the air in the arc area is not fully displaced. If the gas is set too high, air turbulence is generated; this prevents complete shielding. Occasionally this occurs when you weld in a windy area.
Crater porosity and cracks	The chief cause is from removing the gun and shielding gas before the puddle solidifies. The other possible cause is moisture in the gas, dirt, rust, oil or paint on the base metal, or excessive tip-to-work distance.
Insufficient penetration	Insufficient penetration is caused by low heat input in the weld are. It can also be caused by failing to keep the arc properly located on the leading edge of the puddle.
Excessive penetration (burn through)	Excessive penetration can be caused by having excessive heat in the weld zone, wire speed too fast, travel speed too slow, or improper joint design (such as the root opening being too wide).
Whiskers	Whiskers are short lengths of wire sticking out through the joint. These can be caused by pushing the wire past the leading edge of the puddle. To prevent whiskers, you must reduce the travel speed, increase the tip-to-work distance, or reduce the wire feed speed.

Shut down procedures

To shut down the welding machine unit, use the sequence in the following table.

Welding Unit Shut Down Procedures	
Step	Action
1	Turn off the wire speed control.
2	Shut off the gas flow at the cylinders.
3	Squeeze the trigger on the welding gun to purge the gas lines.
4	Hang up the welding gun in its proper location.
5	Shut off the welding machine.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

617. Job preparation

1. Which welding current would you use for almost all MIG welding?

2. What do the first two digits of a carbon steel AWS electrode number indicate?

3. What does the AWS number for stainless steel and aluminum welding wire indicate?

4. What is the recommended welding wire extension for MIG welding?

5. When you are MIG welding what occurs if the welding wire extension is too long?

6. Which metal transfer has tiny molten metal pieces that pass from the welding wire to the work?

7. Which metal transfer has the arc start and stop 20 to 200 times per second?

618. MIG welding procedures

1. What difference in joint setup is required for MIG welding as compared to other welding types?

2. How do you align the welding gun with the joint when you are welding flat butt and edge joints?

3. How do you align the welding gun with the joint when you are welding flat lap and tee joints?

4. What two shielding gases give good results when welding carbon steels?

5. When you weld stainless steel what two factors could cause a corrosion resistance loss?

6. What is the best metal transfer to use when welding aluminum in the overhead position?

Answers to Self-Test Questions

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1. A chemically inactive gas that will not combine with any other element.
2. TIG uses a non-consumable tungsten electrode, while MIG uses a consumable alloy wire with approximately the same composition as that of the metal being welded.
3. It prevents the oxygen, nitrogen, and carbon elements that are present in the air from coming in contact with the molten metal in your weld.
4. They're stronger, more ductile, and more corrosion resistant.

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1. A constant-potential welding machine.
2. The wire drive mechanism.
3. The electric current starts, the flow of shielding gas starts, the wire drive starts, and, if the gun is water cooled, the cooling water starts flowing.
4. Carbon dioxide.
5. A number 12 or 14 shade lens (2 to 4 shades darker).

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1. DCEP/DCRP (DC+).
2. Tensile strength in thousands of psi.
3. The welding wire composition.
4. $^{3}/_{8}$ to ¾ inch.
5. The wire preheats, becomes soft, and whips around.
6. Spray arc transfer.
7. Short-circuiting transfer.

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1. The joint setup is the same.
2. Center the gun on the joint with a work angle of 90° and a drag travel angle of 5° to 15°.
3. Center the gun angle on the joint and angle it 5° to 10° in the weld direction for the forehand technique and 5° to 15° away from the weld travel direction for the backhand technique.
4. Argon and carbon dioxide.
5. (1) Using a shielding gas other than argon.
   (2) Overheating the base metal.
6. Short-circuiting transfer.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the best answer to each question, and circle the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

76. (615) What characteristic of helium makes it undesirable for welding thin material?
    a. Low heat per ampere.
    b. High heat per ampere.
    c. Weld contaminates present.
    d. Decreased penetration depth.

77. (615) What primary purpose does inert gas serve in the gas-shielded welding process?
    a. Cools the weld and fluxed area.
    b. Allows for higher current settings.
    c. Keeps contaminates out of the weld.
    d. Provides better fusion and penetration.

78. (616) The water-cooled metallic inert gas welding gun is designed for use on jobs requiring up to
    a. 50 to 100 amps.
    b. 100 to 150 amps.
    c. 150 to 200 amps.
    d. 200 amps or more.

79. (616) What is the difference in the welding lens requirement between metallic inert gas (MIG) and tungsten inert gas (TIG)?
    a. TIG's is 1 to 2 shades lighter.
    b. TIG's is 2 to 4 shades darker.
    c. MIG's is 1 to 2 shades lighter.
    d. MIG's is 2 to 4 shades darker.

80. (617) Which welding current can be used for almost all MIG welding, gives better penetration, and can be used to weld all metals?
    a. Direct current reverse polarity/DCEP (DC+).
    b. Direct current straight polarity/DCEN (DC–)
    c. Alternating current, high frequency (ACHF).
    d. Alternating current.

81. (617) When you are welding with metallic inert gas, what is the result of having a wire extension that is too short?
    a. The arc will not start.
    b. The arc length is doubled.
    c. The welding wire whips around.
    d. The welding wire fuses to the welding tip.

82. (618) When you weld fillet joints with the metallic inert gas process, how do you position the gun on the joint?
    a. Centered on the joint.
    b. Angled at 45 degrees.
    c. Pointed toward the upper piece.
    d. Pointed toward the lower piece.

83. (618) When you do metallic inert gas welding, which bead welding technique gives the best penetration?
   a. Backhand.
   b. Forehand.
   c. Overhand.
   d. Underhand.

Please read the unit menu for unit 4 and continue

Student Notes

Cooling water pumps are required for heavy-duty cutting. The pumps circulate water through the torch to prevent damage from the extremely high plasma arc temperatures.

Setting up for plasma arc cutting is simple. Start by making lines on the metal where you want to cut. You cannot alter or adjust all of the electronic controls on most machines. However, you usually have control and can adjust the flow for electric current and gas. These adjustments, along with gas selection, are the variables that you set to make smooth cuts. To start cutting, hold the torch ¼ inch above the base metal surface at the point where you want to begin the cut. Then press the switch on the torch to establish a high frequency pilot arc which makes a path for the plasma to follow. To stop cutting, simply release the torch switch and the current and plasma flow stop.

General machine maintenance

The general maintenance for plasma arc cutting machines is similar to what we covered for SMAW, TIG, and MIG welding machines. Like the other machines discussed, clean the plasma arc one as soon as you are done using it. While cleaning it, check it for wear and possible damage. Repair or replace damaged parts. Use compressed air to blow dust and dirt out of the welding machine. Check items like electrical cords and connections, hoses, machine gauges, machine operator controls, and the cutting torch. Check all electrical circuit connections and tighten any that are loose. Check all equipment for loose nuts and bolts and tighten any that are loose. For specific maintenance and schedules, follow the manufacturer's guide.

> NOTE: Disconnect the power to the welding machine before you perform any maintenance procedures.

Protective equipment

When you are plasma arc cutting, wear the same personal protective equipment you do for SMAW to keep hot metal spatter from burning you, that is, leather jacket, leg covers, gloves, and hood. The recommended lens shade number for plasma arc cutting is based on cutting current amperes. For u 300 amps, use a #9 lens. For 300–400 amps, use a #12 lens. For 400–800 amps, use a #14 lens. Wear earmuffs or earplugs since this is a very noisy process.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

619. Plasma arc cutting principles

1. Which cutting gases obtain the best results when cutting aluminum or stainless steel?

2. Name the two arc cutting processes.

3. What are the two operator adjustments you can make on most plasma arc cutting machines before cutting?

4. What lens shade number do you use when arc cutting using 300–400 amperes?

620. Arc cutting procedures

You must know what arc cutting equipment you need and how it functions before you use the arc cutting process. In this lesson, we explain the electric arc cutting processes of shielded metal arc, carbon arc, and oxygen arc, and cover the equipment needed along with its function. Let us begin with shielded metal arc cutting.

Shielded metal arc cutting

Shielded metal arc cutting is no longer in common use; however, it is still an acceptable option in an emergency when other, more efficient arc cutting methods are not available.

We do shielded metal arc cutting using the same equipment we use for SMAW. The shielded metal arc cutting (SMAC) process cuts metal using a thickly covered electrode with a slow burning cover. Once an arc is generated, the coating allows the electrode to be inserted into the molten puddle of the base metal, making contact, and starting the cut without being short-circuited. This electrode's coating also stabilizes and intensifies the arc's action. The force of the arc blows the molten metal away, creating a gouge or kerf. Figure 4–1 illustrates a groove cut using the shielded metal arc process.

Figure 4–1. Groove cutting with shielded metal arc.

The first step in the SMAC process is to determine the thickness and type of metal to be cut. This information determines the correct electrode and welding machine adjustment.

Some manufacturers sell special SMAC electrodes; however, those electrodes are not always available. If a SMAC electrode is not available, consider a common welding electrode with deep penetrating qualities, such as E 6010 or E 6011. The deep penetrating qualities allow the arc to dig deep into the base metal and melt it away instead of filling it in. The size of the electrode should be slightly smaller in diameter than the diameter you use to weld the same thickness of metal.

> NOTE: If you use regular mild steel SMAW electrodes for cutting, they will last a little longer if you soak them in water for a maximum of 10 minutes before you use them.

Regardless of the type of electrode used, always set the welding machine to Direct Current Straight Polarity (DCEN/DCSP, DC–). DCSP puts more heat on the base metal and less on the electrode. Increase the amperage to a point that generates heat that is hot enough to produce a large unmanageable molten metal pool.

Use standard electrode holders for SMAC. After clamping the electrode in the electrode holder, momentarily touch the electrode to the base metal. Then, pull the electrode a short distance away to create a gap that causes a high resistance to the electric current. As electricity jumps the gap, it forms an electrical arc that produces the intense heat required to melt the base metal.

Guide the electrode at a 70° angle to the metal surface and tip it backward at the top to ensure the molten metal is blown forward from the kerf.

Figure 4–2. Shielded metal arc cutting.

The arc length varies depending on the thickness of metal. For thin metals, hold an arc slightly shorter than the electrode diameter. Move the electrode down the line of cut with no up and down motion. For thick metals, move the electrode up and down with a sawing motion as you move down the line of cut. When you bring the electrode up and forward, it preheats the metal. When you push the electrode back down, it pushes the molten metal out of the kerf. The electrode's movement speeds up the job and reduces heat requirements. Figure 4–2 illustrates cutting with an electrode. Notice how the arc stream and gas jet blow the melted metal away.

NOTE: Remember the law of gravity—HOT LIQUID falls; make sure there is nothing under your cutting area.

Carbon arc cutting

Carbon arc cutting is a process of cutting metals with the heat of an arc between a carbon electrode and the work. The carbon electrode is used to melt the metal progressively by maintaining a steady arc length and a uniform cutting speed. Direct current straight polarity (DCEN/DCSP, DC–) is used because it develops a higher heat at the base metal (the positive pole). Direct current also permits a higher cutting rate and easier arc control than alternating current. Use air-cooled carbon electrode holders for currents up to 300 amperes. Water-cooled electrode holders are desirable for currents over 300 amperes.

Air carbon arc cutting

Air carbon arc cutting is another carbon electrode cutting process that is assisted with compressed air. An air jet nozzle in the electrode holder blows the molten metal out from the arc area (figure 4–3).

Figure 4–3. Air carbon arc cutting.

A carbon/air carbon arc is suitable for both ferrous and non-ferrous metal. However, it does not produce a cut of particularly good appearance. The electrodes are either carbon or graphite and are ground to a very sharp point. They are ground so that the length of the taper is equal to 6–8 times the electrode diameter. The pointed end reduces arc wandering and produces less erratic cuts. The cuts are still not satisfactory for welding and require further preparation by grinding or chiseling.

Oxygen arc cutting

Oxygen arc cutting is a progressive process where we use a tubular electrode in conjunction with a special oxygen arc-cutting torch. The tubular metal electrode maintains the arc and serves as a conduit through which oxygen flows into the cut. In this process, you strike the arc on the base metal then press the oxygen lever on the torch. In this process, base metal oxidizes and is blown away. The hollow electrode is consumed during this process. You can use both direct and alternating current welding machines.

General machine maintenance

The general maintenance for shielded metal arc, carbon arc, and oxygen arc machines is similar to those discussed with SMAW, TIG, and MIG welding machines. Follow the guidelines we mentioned earlier.

Protective equipment

When you are arc cutting, wear the same personal protective equipment as you would for SMAW to keep hot metal spatter from burning you. Again, that equipment consists of leather jacket, leg covers, gloves, and hood.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

620. Arc cutting procedures

1. What arc cutting process uses a thickly covered electrode with a slow burning cover to generate the cutting arc?

2. What polarity do we always use during the shielded metal arc cutting process?

3. Which arc cutting process uses carbon electrodes?

4. Which arc cutting process uses a tubular electrode?

Answers to Self -Test Questions

619

1. Argon-hydrogen or nitrogen-hydrogen mixtures.
2. Transfer and non-transfer.
3. Electrical current and gas flow.
4. #12.

620

1. Shielded metal arc cutting (SMAC).
2. Direct current straight polarity (DCEN/DCSP, DC-).
3. Carbon arc cutting.
4. Oxygen arc cutting.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the best answer to each question, and circle the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

84. (619) When compared to other arc cutting processes, the plasma arc makes the
    a. roughest and fastest cut.
    b. roughest and slowest cut.
    c. smoothest and fastest cut.
    d. smoothest and slowest cut.

85. (619) When cutting aluminum or stainless steel with the plasma arc process, what type of gas mixture gives the best results?
    a. Argon-helium or argon-nitrogen.
    b. Argon-hydrogen or argon-nitrogen.
    c. Argon-hydrogen or nitrogen-hydrogen.
    d. Nitrogen-helium or nitrogen-hydrogen.

86. (619) What plasma arc cutting method only uses the heat produced by the plasma changing to gas to melt the base metal?
    a. Direct arc.
    b. Indirect arc.
    c. Transfer arc.
    d. Non-transfer arc.

87. (619) What is the recommended lens shade number when using up to 300 amps for plasma arc cutting?
    a. #6.
    b. #9.
    c. #12.
    d. #14.

88. (620) The first step in the shielded metal arc cutting process is to determine the thickness and type of metal to be cut. This information determines the correct
    a. current and weld angle.
    b. amperage and work angle.
    c. electrode, work, and travel angle.
    d. electrode and welding machine adjustment

89. (620) Regardless of the type of electrode used during shielded metal arc cutting, the welding machine should always be set to
    a. direct current reverse polarity DCRP/DCEP (DC+).
    b. direct current straight polarity DCSP/DCEN (DC-).
    c. alternating current, high frequency (ACHF).
    d. alternating current.

90. (620) A low carbon electrode is used in a progressive cutting operation known as
   a. oxy arc cutting.
   b. carbon arc cutting.
   c. ferrous arc cutting.
   d. shielded metal arc cutting.

Hard surfacing—Also known as hard facing. It is a treatment accomplished by applying hard alloys to the surface of a softer metal to increase resistance to wear, abrasion, corrosion and impact. This process is not applicable to all metals and alloys.

Heat affected zone—Part of the base metal where the heat from welding, brazing, soldering, or thermal cutting has changed mechanical properties or grain structure.

Helium—A colorless, odorless, non-toxic and tasteless inert gas. Much lighter than air, it is the second lightest of all gases.

Included angle—An angle formed when two bevels are placed together. For example, two pipes with 22½-degree bevels are placed together forming a butt joint, the included angle is 45 degrees.

Inclusion—Entrapped foreign solid material, such as slag, flux, tungsten, or oxide.

Inert gas—A chemically inactive gas; it will not combine with any other element.

Joint—The junction of members or edges of members that are to be joined or have been joined.

Joint root—The joint portion to be welded where the two materials are closest to each other.

Lap joint • A joint between two overlapping members in parallel planes.

Laying surface—The mating surface of a member that is in contact with or in close proximity to another member to which it is being joined.

Leg—A term used in shielded metal arc welding of tee joints. It refers to the distance from the root of the joint to the toe of the fillet weld.

Padding—Welding a bead layer or layers to build up a metal surface.

Perpendicular—Forming a right angle (90 degrees).

Plasma—A highly ionized gas that is electrically neutral.

Plasma arc cutting—A process that uses a constricted plasma arc to quickly cut a smooth, small line through metal.

Porosity—Gas pockets formed in a weld.

Preheating—A process that heats metal to a certain temperature to prepare it for surfacing, welding, or cutting operation.

Quenching—A process to rapidly cool an item by contacting the item with fluids or gases. For example, use oil or water to cool hot metal.

Rectification—Converting alternating current into direct current.

Scarf—A chamfered joint surface.

Slag inclusion—Produced during welding. It is nonmetallic solid material that is trapped in the weld metal between the weld metal and the base metal.

Surface tension—The force that keeps the molten metal and slag globules in contact with the molten base metal or weld metal in the crater.

Tee joint—a joint between two members located approximately at right angles to each other in the form of a “T”.

Weldment—An assembly of components that are joined by welding.

Weld metal—The weld portion that has been melted during welding.

Weld Symbol—Shows the desired type of weld, whether it is localized or all around and if it is shop or field weld.

Abbreviations and Acronyms

AC	alternating current
AC-DC	alternating current-direct current
ACHF	alternating current high-frequency
AFOSH	Air Force Occupational Safety and Health
AWS	American Welding Society
CDC	career development course
CFETP	career field education and training plan
cfh	cubic feet per hour
DC	direct current
DC-	direct current negative
DC+	direct current positive
DCEN/DCSP (or DC-)	direct current electrode negative
DCEP/DCRP (or DC+)	direct current electrode positive
DC-RP	direct current-reverse polarity
DC-SP	direct current-straight polarity
E	electric
GTAW	gas tungsten arc welding
lpm	liters per minute
MIG	metallic inert gas (welding)
MSDS	material safety data sheet
ºF	ºFahrenheit
psi	pounds per square inch
SMAC	shielded metal arc cutting
SMAW	shielded metal arc welding
T	thickness
TIG	tungsten inert gas
TO	technical order

Student Notes

Student Notes

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