3

Processes

Objectives

Students will be able to:

- Define various welding cutting processes.
- List and explain the various terms specific to cutting processes and equipment.
- Compare and contrast the multiple welding cutting processes and equipment.
- Identify the safety considerations of each of the different cutting processes.
- Define various welding processes.
- List and explain the various terms specific to welding processes and equipment.
- Compare and contrast the multiple welding processes and equipment set up options.

Orienting Questions

- ✓ What are the most common welding cutting processes and explain each process?
- ✓ What are general safety issues within welding cutting processes?
- ✓ What are the most common welding processes and explain each process.
- ✓ How are the welding processes similar and different.

Keys for success

- ☐ Read and review required text along with this module
- ☐ Review key terms
- ☐ Do each and every activity in the module

Helpful Tips

- ✓ You can select the **BLUE TERMS** to learn more.
- ✓ If needed, there are **CLOSED CAPTION** buttons CC on the YouTube videos that will enable you to read along while you watch. The Closed Caption buttons are located bottom right of the video screen.
- ✓ Anytime you see **EXPLORE** click on link or image to learn about the subject.
- ✓ Anytime you see me  click my image and let me read the text to you!
- ✓ When you see this book icon  it is alerting you to a reading assignment. Information will be provided by your instructor on the reading materials.
- ✓ Anytime you see this icon, click on the  image to watch a video about the module subject.

INTRODUCTION

Module three will focus on different thermal cutting and welding processes. We will review the ins and outs of the equipment, functions to consider when evaluating and looking for purchase, and different technologies. A firm understanding of the different basic processes will allow us to use them to their fullest extent. With proper operation and use of the processes, we can best control the quality of cut and or weld put in place with minimal effect on the base metal from the heat introduced. Module three covers a number of different chapters from our text that you need to read.

3.1 THERMAL CUTTING PROCESSES

Thermal cutting is a very common practice throughout the metalworking industry. We find it to be very common even for the home hobbyist or farmer. The equipment is very common and can be fairly inexpensive if using the oxy-fuel process. On the other hand, if you desire a higher quality process, such as plasma arc cutting, then the cost increases significantly. This section will provide an overview of the most common processes, the safety required, and what equipment is needed.

3.1.1 OXY-FUEL CUTTING

Read Chapters 7, 30, 32 and 33 in *Welding Principles and Applications,* Larry Jeffus, 7th edition.

Oxy-fuel cutting is a very common process used throughout industry on a commercial industrial or home hobbyist level. It is considered oxy-fuel as multiple fuel gases could be used as you see in Figure 1 below. Each one of the possible fuel gases will be used in conjunction with oxygen. The fuel gas is the gas that is burned and consumed but by adding oxygen we intensify the flame in temperature that it burns at. Different gases burn at different temperatures and create different types of flames. Some flames, like with acetylene gas, keep the heat centralized where the flame is applied. For this reason, acetylene lends itself well to multiple processes such as cutting, heating, and welding. Most other gases do not provide a tight centralized point that is required to weld with. Therefore, these other gases work well with heating and cutting but not welding. So depending on the process cutting, heating, or welding will help to determine what gas needs to be used.

EXPLORE: Cutting Gases

Fuel Gas	Approximate Neutral Flame Temperature ° F
Propane	4579
Natural Gas	4600
Hydrogen	4820
Propylene	5193
MAPP	5301
Acetylene	5589

Figure 1. Types of Fuel Gases with Approximate Neutral Flame Temperatures (by Paul Phelps, CC BY 4.0)

There are some limitations to the oxy-fuel process. Materials that have the ability to rapidly oxidize or rust can be cut using the oxy-fuel process. These materials rely on a chemical reaction in the temperature range of 1600° to 1800°F, known as the **Kindling Temperature** or **Kindling Point**. At this temperature, when high-pressure oxygen is applied, rapid oxidation occurs in a controlled manner which separates the material into two pieces, with a cut taking place directly under the center orifice on the cutting tip where the high-pressure oxygen exits. Due to this requirement of this chemical reaction, not all materials are capable of being consistently and cleanly cut with the oxy-fuel process.

FLAMES

When igniting the gases, we can find different flame types depending on the mixture and concentration of gases. In Figure 2, to the right, you see an image of the different types of flames:

1. (far left) Pure acetylene or fuel gas is very orange and/or yellow in color, gives off a concentration of soot, and is not suitable for welding, heating, or cutting.
2. (second from left) When the concentration of oxygen is increased just slightly, you

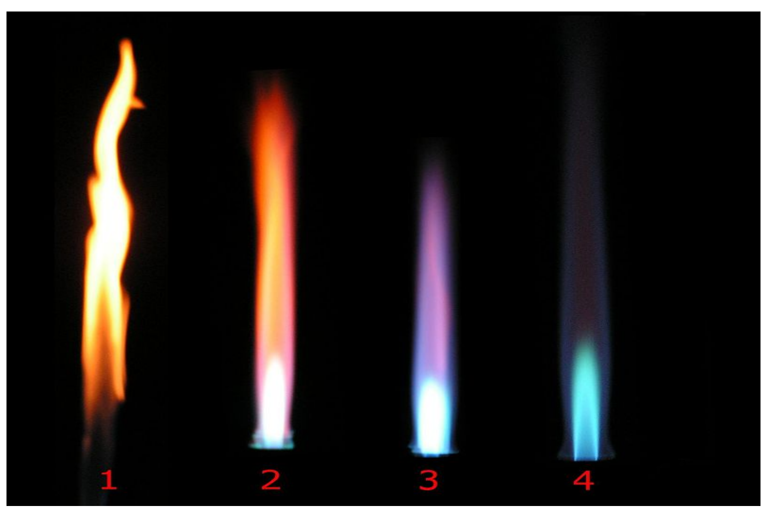


Figure 2. Types of Flames
(by Arthur Jan Fijalkowski, CC BY-SA 3.0)

have a carburizing flame. There is no focused inner-cone of the flame.

3. (second from right) With another increase in the concentration of oxygen, the inner cone comes into a focused point. This is known as a neutral flame. The neutral flame gives the best usable flame and concentration of heat.
4. (far right) Further increase in the oxygen content will enter into the range of an oxidizing flame which has little usefulness. If the level of oxygen continues to increase, the flame will be extinguished.

TECHNIQUE (GOOD CUTS VS. BAD CUTS)

Making good cuts with the oxy-fuel process relies on a number of factors. These factors include:

- proper setup of equipment
- correct cutting tip
- proper flame
- proper pressures for the tip size
- proper travel speed and a steady hand
- coupling distance (the distance between the inner cone of the flame and the work piece)
- torch angle

As the first four factors will be discussed in length elsewhere in the section, our focus here will be on torch angle, travel speed and coupling. First, the angle of cut on your work piece will follow the angle of the torch, so if your torch angle is wrong in relation to the desired angle, the angle of the cut will be wrong also.

Since this process relies on a chemical reaction of the base metal at temperature when high-pressure oxygen is applied, we have to ensure our travel speed allows the work piece to maintain the required temperature. If we traveled too fast, we can out run our heat and lose the cut. If we traveled to slow, it overheats the material, allowing **Slag** to form under the back edge holding the piece together rather than separating it into two pieces.

When cutting, the material removed during the process changes form and become slag. Slag can be either hard or soft. Hard slag is material that is only partially oxidized, but is mainly melted base metal. Hard slag is more difficult to remove and requires grinding or other mechanical means as it will stick to the base metal firmly. Soft slag is fully oxidize material and will resemble a lava rock in appearance. Soft slag is very brittle and easy to remove from the base metal with pliers or a chipping hammer requiring little mechanical touch up.

The **Coupling Distance** or the recommended distance between the inner cone of the flame and the surface of the plate is very important. You need to maintain a consistent distance for consistent heat to be applied to the work piece.

Since oxy-fuel cutting is a thermal process, there is a tremendous amount of heat introduced to the base metal. Large amounts of heat in metal create distortions also known as warping. There are techniques in which we can limit the effects of this heat.

Refer to pages 182-183 in *Welding Principles and Applications,* Larry Jeffus, 7th edition, Chapter 7, for diagrams of techniques to eliminate or minimize distortions/warping.

There are two common techniques that control distortions when cutting a plate;

1. When making a long cut, break that cut up into short pieces leaving material in between cuts to help hold the material in place, therefore allowing it to distort. After the material cools, return to finish the cuts of the tabs. This technique will go a long way to keeping the piece from warping.
2. For heavy industrial applications when making long cuts, it is recommended to double cut the material by running two torches parallel to one another, cutting each edge. The input of heat will cause stress from both directions and will offset the metals inclination to distort away from the heat.

When cutting pipe, you need to consider the diameter of the pipe;

1. Larger diameters - You must keep the torch pointed towards the center of the pipe allowing all of the energy from the flame to pierce through as we follow the radius of the pipe.
2. Smaller diameters such as 1 inch or smaller - You will find it easier to keep the torch vertical by applying heat to one edge while maintaining a vertical torch transition across the small laminar pipe to the opposite edge. The high-pressure oxygen will be able to pierce all the way through both sides.

SAFETY IN OXY-FUEL CUTTING

- **Eye Protection** - The light produced by this process is intense and does require protection of the eye. Protection can be provided the way of goggles, glasses, or face shields. The level of protection is indicated on the lens by a number. The higher the number, the darker the tint and the more protection provided. Normal practice is to use a number five level of protection.

- **Body Protection -** Heat generated from this process can be hazardous to the operator. Proper attire is required to protect the operator which includes materials the clothing is made out of. When working with thermal processes, such as oxy-fuel, clothing should be made of cotton, wool, or leather. We also want to ensure exposed areas are covered with use of a coat, cape, gloves, or apron depending on the protection level required in the amount of heat generated.

- **Safe Environment** - Due to the molten metal created through the process particular attention must be paid to directing of equipment away from the heat source. We must also pay particular attention to the surrounding environment to ensure combustible materials are a safe distance away from this process. General practice requires keeping combustible materials 35 feet or farther away from the flame source, as hot sparks can travel up to 35 feet.

- **Handling and Storage of Compressed Gas Cylinders** - The simple fact of them being filled with compressed gas where there is a lot of stored energy indicates they need to be handled and stored in a controlled secure manner. This energy is looking to exit the cylinder anyway possible, so the integrity of the cylinder must be closely managed to ensure we can control these gases as they leave the cylinder. Cylinders are to be routinely inspected and tested to ensure the integrity of the shell of the cylinder itself. The valve on top of the cylinder controls the release of these gases but if this valve was to become damaged the cylinder could become a projectile as the cylinder expels all of the trap gas. For this reason when not in use, a protective cap is to be placed over the valve for protection.

- **Transporting of Compressed Gas Cylinders -** The cylinders need to remain vertical. They are not to be thrown over your shoulder and carried from one place to the next, or laid on the ground and rolled to the destination. This is done most times through chaining or securing of the cylinder to a fixed structure. It is recommended to use a suitably designed bottle cart for transporting these gases. This is done to limit the chances of the cylinder following over and doing damage to the valve.

NOTE: Most people will put great emphasis on the safety and handling of the fuel gas and not pay attention as closely to the oxygen. The truth of the matter is that the oxygen is just as deadly if mishandled. We cannot discount the handling and use of the oxygen just because we breathe oxygen. The oxygen used for this process is 100%, where the air we breathe is a near 20%. So there is a large difference between what our bodies require and the concentration of oxygen used for this process.

OXY-FUEL EQUIPMENT

The oxy-fuel cutting process uses basic components (Figure 3). The components are:

- A regulator for the oxygen and for the fuel gas

- Hoses that are color-coded (green for oxygen with right-handed threads on the fittings, red hose for the fuel gas with left-handed threads indicated by a notch on the corner of each fitting)
- A torch handle
- Attachments for each process (welding, cutting, heating a.k.a. Rose Bud)
- Assorted tips depending on two factors (what gas will be used, and thickness of material to cut or weld)
- A striker to ignite the gas
- Tip cleaners (for maintenance of the tip in removing debris and allowing smooth flow of gas)
- A cart for transporting of gas bottles
- Eye protection, and heavy gloves

Figure 3. Typical Oxy-Fuel Components (by Paul Phelps, CC BY 4.0)

EXPLORE: How to Select and Set up an Oxy-Acetylene Welding Rig

In Figure 4 you see different tips for cutting. Notice the tip on the left has two pieces. Two-piece tips are used with alternative fuels, not acetylene. Cutting tips used for acetylene gas are solid copper. The tip in the center of Figure 4 has a slight bend and is known as a **Gouging** or **Washing** tip and it is used for removal of materials, such as from a bad weld, without fully piercing through the work piece.

Figure 4. Cutting Tips (by Paul Phelps, CC BY 4.0)

There are many different torch manufactures. One important piece of information for any welder to remember is that torch components ARE NOT interchangeable between different brands. It is very critical to make sure that all torch components are compatible with the brand and torch style. This is the only way to use the system safely.

This is also an issue with cutting tips. There is no industry standard when it comes to the numbering system for the cutting tip size. Each manufacturer has their own numbering system which relates to the thickness of material being cut. Welding cutting or heating tips are made specific to the brand and model. So we must know what brand of torch and model we are using and verify that the components are compatible. If not, you could encounter a gas leak and a very dangerous situation when working with combustible gases. So when selecting the proper tip size, we must refer to the manufacturer's recommended chart for the tip number because it can be very different from brand to brand.

With cutting tips, the one variable that changes is the diameter of the high-pressure oxygen hole in the center of the tip. The larger the hole, the more gas will flow so thicker material can be cut. In addition to choosing the correct tip size, we must set the proper gas pressures for the brand of torch. These values are established by the manufacturer. Therefore we must refer to manufactures data to ensure tip size and gas pressures for each and every torch that we use. This ensures we can operate the torch safely with high-quality cuts.

We have been focusing on manual hand cuts thus far, but for many years now, the oxyacetylene or oxy-fuel process has been automated for very consistent repetitive, or long cuts. Figure 5 is a picture of an oxy-fuel machine torch. Notice the straight body then imagine multiple torch heads placed on a gantry system cutting multiple parts out at once to increase productivity.

Figure 5. Oxy-fuel Machine Torch (by Paul Phelps, CC BY 4.0)

EXPLORE: [High Volume Oxy-torch Cutting]()

MODULE ACTIVITY 1

Choose the correct answer.

1. The two main processes in welding covered in this module are
    a. Cutting and welding
    b. Welding and gouging
    c. Gouging and washing
    d. Pre-flow and post-flow
2. Goggles or other suitable eye protection must be used for flame cutting. T/F
3. Oxy-fuel cutting is a very common process used throughout industry on a commercial industrial or home hobbyist level. T/F
4. Hydrogen is the main gas in the oxy-fuel process. T/F
5. The amount of oxygen content determines what kind of flame will be produced. T/F
6. The kindling temperature is the distance between the inner cone of the flame and the work piece. T/F
7. The oxidized material that has to be removed from a weld is
    a. Trash
    b. Slag
    c. Rock
    d. Pipe
8. Safety issues in oxy-fuel cutting involve
    a. Eye and body protection
    b. A safe environment
    c. Careful handling of the gas cylinders
    d. All of the above
9. Oxy-fuel torch components are interchangeable. T/F
10. _____ _____ (soft slag, hard slag) contains is fully oxidized material.
11. The most commonly used fuel gas in oxy-fuel is
    a. Propane
    b. Propylene
    c. Acetylene
    d. MAPP

3.1.2 PLASMA ARC CUTTING

Read Chapter 8 in *Welding Principles and Applications,* Larry Jeffus, 7th edition.

What is plasma? There are two definitions a plasma, one being the liquid portion of blood. As you can guess, this does not apply to welding or cutting. The second definition of **Plasma** is the state of matter that is found in the region of an electrical discharge. So we find plasma at any electrical arc. Through refinement and constriction of that arc we are able to create intense heat which is used to cut materials.

Plasma arc cutting has been around for quite some time. Like most technologies, in the beginning, it was very expensive and not for everyone. The machines were very large and required an external gas, most commonly nitrogen. Today, the machines are very portable and no longer require nitrogen, but use dried compressed air, making this option much more convenient and economical.

Within industry, there is an ongoing debate about which is better, plasma arc cutting or Oxy-fuel cutting. They both have their place depending on what is required. We will detail the equipment and different processes of plasma arc cutting in this section.

PLASMA ARC CUTTING BENEFITS VS. LIMITATIONS

Benefits:

1. High heat and speed
    - Allows cutting of any material that is electrically conductive not just materials that rapidly oxidize as with Oxy-fuel cutting. This means plasma arc cutting can cut many more materials than Oxy-fuel cutting.
    - Gives better quality and precision of cut and the ability to make fast cuts along the broken edges of the material. With Oxy-fuel cutting, each individual section has to be reheated to the kindling temperature before being cut which slows that process when working with expanded metals.
    - Allows stack cutting or the stacking of multiple sheets of material on top of each other and making one cut which pierces through the multiple sheets and in turn produces multiple components with one cut. This is not possible with Oxy-fuel cutting as it relies on heating materials to the proper temperature range before cutting. With Oxy-fuel you may heat the top sheet with proper temperature range won't be reached on the lower sheets.
2. Modern plasma arc cutting processes/variations
    - Allows gouging, drag cutting, or extended standoff cutting. Oxy-fuel can be used for welding, gouging, and heating along with cutting.

Limitations:

1. Cost
    - Machines are much more costly in comparison to Oxy-fuel equipment, input power, and dried compressed air.

2. Process
    - Much more complicated compared to Oxy-fuel cutting when used in the field.
3. **Kerf**
    - Kerf plasma arc cutting is found to be wider. **Kerf** is the material that is removed during the cutting process, or the space left between the pieces when they were cut apart.
    - Kerf can be inconsistent and we have to monitor the many different variables for a consistent kerf and quality of cut. The variables to monitor are the:
        - **Standoff distance**, which is the distance between the torch and the work piece. The further we are from the work piece, the wider the plasma cone is at the work piece creating a wider kerf.
        - Increasing diameter of the orifice in the cutting tip as plasma exits through it with ionized gas. As a result, the kerf will widen and the quality of the cut deteriorates.
        - Condition of the electrode and other parts such as the swirl ring. These can contribute to the inconsistency of the arc and the quality of the cut.
        - Proper technique, such as improper power settings, improper travel speed, or torch angle.

SAFETY IN PLASMA ARC CUTTING

- **Eye Protection** - The cutting arc is very bright and focused and as intense as TIG welding. Due to this intensity of light, proper eye protection is required in order to prevent damage or burns to the eyes. Proper eye protection should be a welding face shields or helmet. Many times with very intricate cutting, face shields or a helmet make it difficult to see the pattern. In those situations, as a minimum protection, we should use number five cutting glasses or goggles and refrain from looking directly at the cutting arc.

- **Equipment Maintenance** - Since plasma arc cutting is electrical process, there is always the risk of electrical shock. We must routinely inspect equipment to make sure there are no open electrical connections were human contact can be made and risk electrical shock.

- **Hearing Protection** - Plasma arc cutting can be loud due to the compressed air. If we need to use plasma arc cutting for an extended period of time, it is recommended to use hearing protection in one form or another.

- **Proper Ventilation** - When plasma arc cutting, fumes will be created as part of the process. These fumes can be hazardous depending on the material, condition of material, or finishes on the material such as paint. As we cut over these materials with intense heat from plasma arc cutting, these materials become airborne in the form of fumes. It is highly recommended to use proper ventilation to pull the fumes away from the operator and out of the workspace. This can be done in a number of ways such as water tables or downdraft tables with other engineering controls.

Proper setup and Configuration of Workspace - Any cutting process creates molten metal that we must control to prevent the opportunity for fire and/or injury. So proper setup and configuration of the workspace is very important so that we can direct where the molten material goes and is captured. With plasma arc cutting, the molten material is known as **Dross**. In Oxy-fuel cutting, it is called slag. The main difference between the two is that dross is melted and redeposited material compared to Oxy-fuel slag that is material that has been oxidized creating a very porous texture as the oxygen is been forced into the molten material.

PLASMA ARC EQUIPMENT

Plasma arc cutting systems have a few major components. The major components are the power source, torch lead, ground cable, ground clamp, torch head, and consumable components of the torch head. They are considered consumable because they wear out and need to be replaced over time for consistent cutting. There are a variety of setups available based on the process you use.

In Figure 6, you will see a breakdown of those torch components:

- Part A is the nozzle tip (multiple types)
- Part B is the knot.
- Part C is the tip (type varies in shape and size of center orifice according to desired process.
- Part D is commonly considered the swirl ring which focuses the compressed air around the electrode.
- Part E is the electrode which has an embedded tungsten tip which conducts the electrical arc.

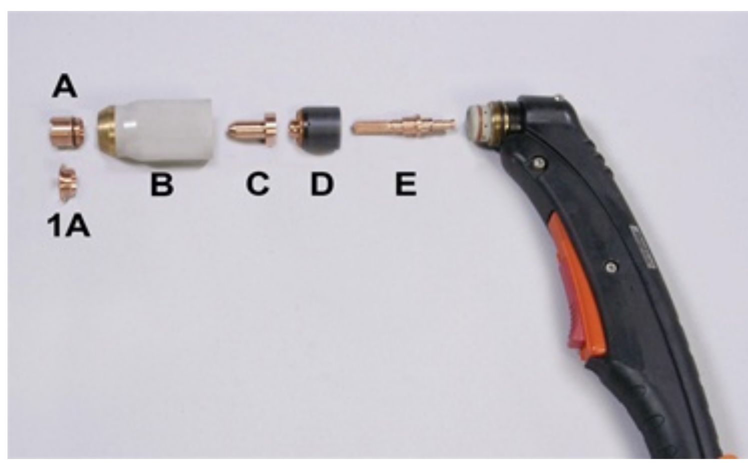


Figure 6. Plasma Arc Cutting Components (by unknown, Public Domain)

The compressed air is carried through the torch itself and pushed through the swirl ring which constricts the air around the electrode. The arc, when making contact with the compressed air, will ionize the gas and create the focused plasma arc which is then condensed and pushed through then out of the nozzle tip, to the work piece to be cut. The plasma arc closest to the electrode tip is estimated to be near 43,000°F. As it extends out to the work piece, the working end can be close to 25,000°F far exceeding the melting point of most materials. These high temperatures are why plasma arc is so flexible in working with multiple materials such as carbon steel, stainless steel, aluminum, copper, and many other exotic materials. This is the reason you will find this equipment in most shops today.

Modern plasma cutting has continued to evolve and be refined. It is not uncommon to find the use of water tables where the torch cutting actually takes place below the water surface which further limits distortion. We also find water injected torches such as the one on the left in Figure 7 which helps to further focus the plasma arc for very precise cutting and limiting heat input into the base metal. The diagram on the right of Figure 7 shows the standard handheld torch which we find in most common everyday shops. We also see a new push for high definition plasma cutting where the plasma cone is further refined and higher travel speeds are accomplished. This is becoming the new standard and very comparable to laser cutting but at a lower cost. As you can imagine, this is very attractive choice for most manufacturing facilities (Figure 8).

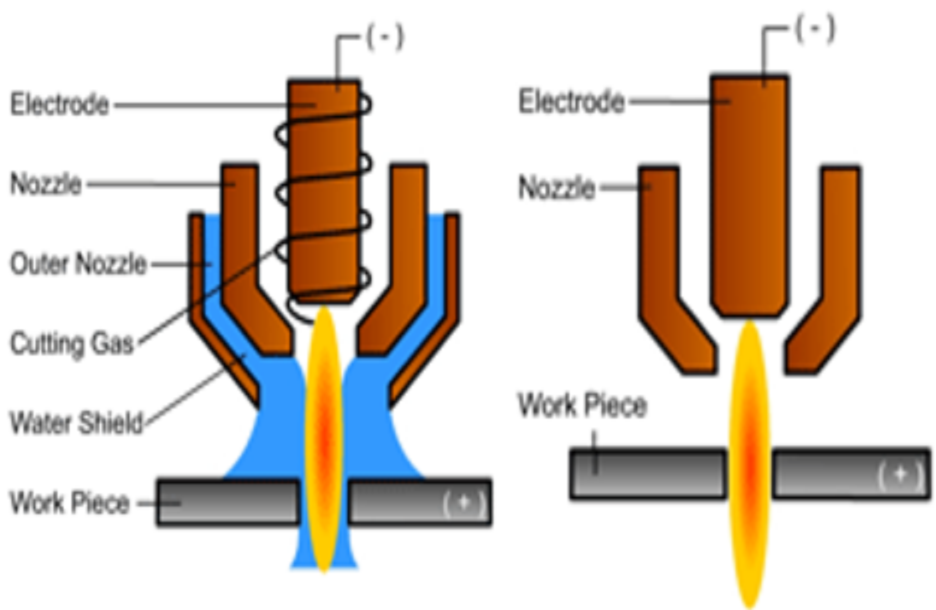


Figure 7. Plasma Cutting Systems, (by Unknown, Public Domain)

Figure 8. Plasma Cutting with a CNC Machine, (by Devaes, CC BY-SA 3.0)

Outside of the machine itself, the plasma cutting system has a couple of requirements, input power and a dried compressed air source. Input power DC current can be either single phase or three-phase depending on the power source requirements and its rated output. The higher the output of the power source the thicker the materials that it can cut.

The compressed air required for the process must run through a dryer to remove all the humidity. If the air is not dried, the life of the consumables on the torch, such as the electrode, tip, and swirl ring will be severely limited therefore increasing the cost of the system by requiring a more frequent replacement of these parts. The pressure requirements for the compressed air is usually around 90 psi.

As previously mentioned, the main components are the power source, torch lead, ground cable, ground clamp, torch head, and consumable components of the torch head. In Figure 9, you will see different configurations according to the desired process. The top configuration is for what's known as drag cutting. Drag cutting allows the copper nozzle tip to be drug along the surface of the material to be cut making contact with the material. This is very common for making the long straight cuts as it allows us to use a straight edge guide that we make contact with and follow. The middle configuration is for extended cutting. Extended cutting allows us to hover over the material to be cut and is used when making very intricate precise cuts or with an automated system which is computer-controlled. The very bottom configuration of torch components is for gouging. Gouging is a process where we remove material from the surface without piercing all the way through like a cut. Gouging is commonly used in repairs to remove bad welds, cracks, or to smooth the surface for being rebuilt.

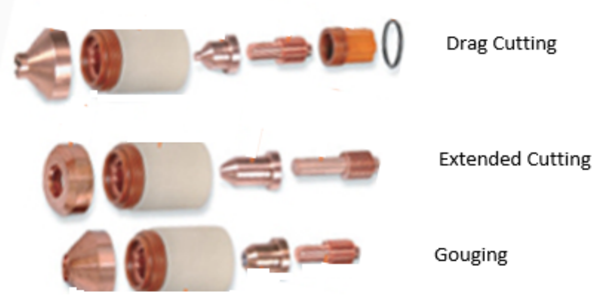


Figure 9. Different Torch Head Configurations (by Unknown, Public Domain)

There are a number of manufacturers of plasma arc cutting systems. For each they are typically rated according to the thickness material to be cut. It is very possible to cut up to 7 inches in thickness, which is not commonly used. The most commonly thickness is one inch or less.

There are number of different torch designs. Each design focuses typically on the application and or ergonomics for the user. For the manual user, torches angles will be 90°, 45°, 30° or others as desired. This will be based on what is required for the application or what is the best for the ergonomics of the user, to create less fatigue on the joints when using the torch for long periods of time. In automated applications, you will find a straight torch design in a gantry system where it is completely computer-controlled and ergonomics are not a factor.

EXPLORE: Large Industrial Plasma Arc Cutting Systems

MODULE ACTIVITY 2

Choose the correct answer.

1. Plasma is the state of matter that is found in the region of an electrical discharge. T/F
2. Kerf is the material to be removed during the cutting process. T/F
3. Plasma arc cutting may use water in the process. T/F
4. In plasma arc cutting, the molten material to be removed is called _______ (slag, dross).
5. There is only one torch design in plasma arc cutting. T/F

3.1.3 AIR CARBON ARC CUTTING

Read Chapter 9, beginning on page 219, in *Welding Principles and Applications,* Larry Jeffus, 7th edition.

Air carbon arc cutting is a process that goes all way back to the 1940s. In the beginning, it was very crude and dangerous. Prior to the addition of using compressed air, it was just known as carbon arc cutting. Early on, the carbon arc cutting process used a carbon electrode to superheat the material and basically melt it off. It was done in the vertical and overhead positions to use gravity to take the melted material and pulled it off. One disadvantage was that the intense heat could cause a material to weld itself together. This made it a partially ineffective process and difficult to work with. Later, it was determined that adding a compressed air source to direct the molten material way made it a much more effective process. The process name changed to air carbon arc cutting and it is still widely used in the repair industry today.

The repair industry commonly uses air carbon arc gouging. This gouging process allows for the removal of damaged material and then replacing it with new sound weld metal. Figure 10 below shows a cracked weld. With air carbon arc gouging, we can cut a U-groove, as shown in the Figure 11, removing the damaged material and then replacing it with a new weld.

It is also a common practice to use what is known as washing. Washing allows us to remove a wider section, much shallower so that we can go back and rebuild a surface. We find washing commonly used in the grading or earthmoving industry. Pieces of heavy equipment used to move dirt, such as bulldozers or track hoes, will wear over time and thin out. Washing will be used to smooth out that worn surface. The welder will then use hard facing electrodes to rebuild that surface and thicken the part, creating a new surface comprised of solely welded material. Hard facing electrodes are specialty electrodes designed for abrasion resistance and lengthen the life of the one piece of equipment.

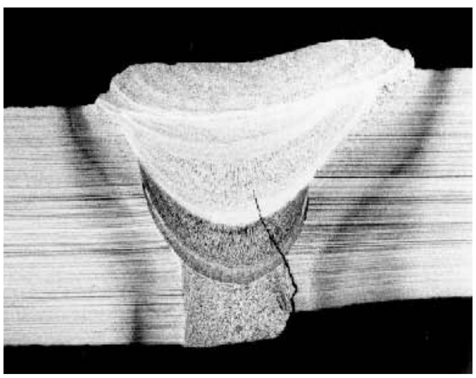


Figure 10. Cracked Weld
(by P H M Hart, "Courtesy of TWI Ltd")

Figure 11. Single U Groove
(by Benrunge, Public Domain)

SAFETY IN AIR CARBON ARC CUTTING

Air carbon arc cutting can be a very dangerous process even though very simple. Due to the amount of heat, sparks, noise, and spread of molten material we must be very careful in how we use this process.

- **Personal protective equipment** – This should include, a welding helmet eye protection, heavyweight welding gloves for proper protection from the high heat, and covering of loose clothing and clothing of cotton or leather so not to risk catching fire or melting.

- **Hearing Protection** - The decibel level created can be very high and if used for a prolonged period of time, without protection, can damage hearing.
- **Proper Ventilation** – Since this is a cutting process, there are a large amount of fumes so proper ventilation or engineering controls must be employed to pull away or capture of the fumes.
- **Proper setup in a safe environment** - The major concern is the spraying of molten material off of the base metal as we cut, wash, or gouge. This includes anything that may be considered flammable or combustible in any sort of proximity to work area. Routing of air hoses and work leads away from the area were molten metal will be sprayed is a major requirement.

AIR CARBON ARC EQUIPMENT

Air carbon arc cutting equipment is fairly simple and inexpensive. It is mainly comprised of a special electrode holder shown in Figure 12.

Figure 12. Air Carbon Electrodes and Electrode Holders (by Moya034, Public Domain)

The specialty electrode holder has two special parts. One is the air valve built into the handle where the compressed air can be turned on or off directly at the electrode holder. The second is the bottom jaw of the electrode holder which has airports that focus the compressed air down the electrode and behind the electrode. This specialty bottom jaw also pivots so that the angle can be adjustable according to what is needed for the application. It is important, when setting up, to ensure that bottom jaw focuses the air under and behind the electrode.

The other main component is the power lead cable which goes to a junction block. At the junction block, we find the power connection and the compressed air connection. The requirement is a welding power source able of providing adequate amperage and a compressed air source able to produce the required PSI, which is typically 90 to 100 psi.

The only other requirement are specialty electrodes. These electrodes are primarily pure carbon in the form of compressed graphite with an external copper coating. The compressed graphite of the electrode is very brittle and not a good conductor of electricity. The exterior copper coat provides two purposes, structure for the compressed graphite and aiding in conducting electricity. We find these electrodes will come in a variety of shapes and sizes. The type needed depends on how much material is to be removed, whether gouging or washing is to be used, and the thickness of material. Like with most arc welding processes, the larger the electrode the greater the required amperage for running the given electrode.

The process as a whole involves an extreme amount of heat able to remove material by the electrode melting it, then converting the form into the molten material which the compressed air then blows away. If the air hits the electrode or molten puddle in the wrong position, it causes safety concerns for the operator as the molten material can blow back towards the operator and potentially cause a burn or fire.

EXPLORE: Electrodes

MODULE ACTIVITY 3

Choose the correct answer.

1. Air carbon arc cutting is a new process. T/F
2. Compressed air is important to air carbon arc cutting. T/F
3. What are two common practices in air carbon arc cutting?
    a. Sliding, climbing
    b. Gouging, washing
    c. Cutting, heating
    d. Melting, hardening
4. Common safety considerations in air carbon arc cutting are
    a. Personal protective equipment
    b. Proper ventilation
    c. Inadequate water flow
    d. Both a and b
5. Air carbon arc cutting uses a special electrode holder. T/F
6. Electrodes used in air carbon arc cutting are made of
    a. Carbon graphite

b. Iron ore
c. Stainless steel
d. Polycarbonate

3.1.4 ARC CUTTING

Read Chapter 9, beginning on page 227, in *Welding Principles and Applications,* Larry Jeffus, 7th edition.

Arc cutting is a very simple commonly used tool in the field. Most service rigs or trucks in the field will have a stick welder on the truck. It does not require anything additional for it to be used other than special electrodes (Figure 13) that are designed to cut or remove material rather than adding material as a typical welding electrode. So for demolition, repair, or rough fieldwork, arc cutting can be a very practical tool.

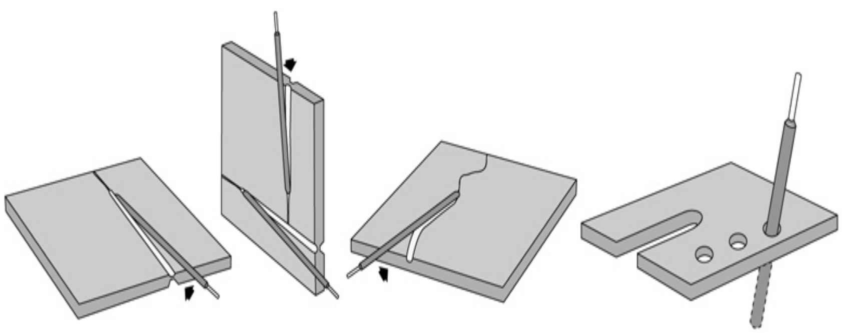


Figure 13. Examples of Gouging, Cutting and Piercing with Arc Cutting Electrodes
(by Unknown, Public Domain)

SAFETY IN ARC CUTTING

- **Personal Protective Equipment** - Welding hood, heavy gloves, and proper attire need to be used with arc cutting electrodes.
- **Safe Environment** - Slag will be produced and we need to be mindful of where that slag goes. Proper inspection of our workspace for combustible and flammable materials, and routing of power leads should be our main considerations for use of this process.

ARC CUTTING EQUIPMENT

With arc cutting, the main equipment requirements are a stick welding power source and the special electrodes (Figure 14). With a minimal investment in special electrodes, we can increase our functionality in the field.

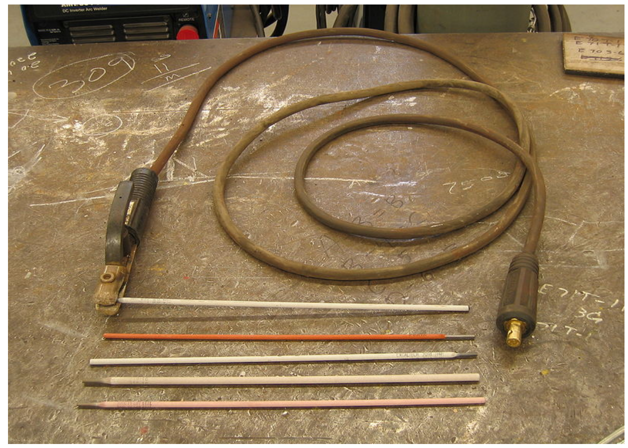


Figure 14. Arc Cutting Electrodes and Electrode Holder (Triddle, Public Domain)

MODULE ACTIVITY 4

Choose the correct answer.

1. Arc cutting is a very simple process. T/F
2. Common processes in arc cutting are
    a. Gouging
    b. Cutting
    c. Piercing
    d. All of the above
3. Special electrodes are not required for arc cutting, T/F
4. Arc cutting can be done easily in the field. T/F
5. A stick welding power source is required in arc cutting. T/F

3.2 WELDING PROCESSES

In this section, we will be focusing on different arc welding processes and MIG welding transfer modes. With each of these processes, we will be going through a brief overview of the equipment, options, and different set up for functions. Before delving into the welding processes, we need to discuss the heat distribution of welding currents.

3.2.1 HEAT DISTRIBUTION OF WELDING CURRENTS

Read pages 384-386, in *Welding Principles and Applications,* Larry Jeffus, 7th edition.

When it comes to the different welding processes, it is critical for us to understand the heat distribution and why it is so critical in teaching these welding processes. Electrical current and Polarity have a very distinctive effect on the heat distribution for each process.

Stick welding, also known as shielded metal arc welding (SMAW), requires heat to be generated on the tip of the electrode to melt the core wire and burn the flux which creates a shielding of gas around the molten weld puddle. For proper stick welding, we must use DC electrode positive polarity or DCEP, also known as reverse polarity or DCRP (bottom image in Figure 15). Reverse polarity generates two thirds (70%) of the overall heat on the end of the electrode. One third (30%) of the overall heat is applied to the work piece or base metal. It is possible to do stick welding with AC welding current and is very common for the home hobbyist or low-end usage but this does not produce high-quality welds equivalent to industrial commercial standards.

TIG welding, also known as GTAW, requires DC electrode negative polarity DCEN, also known as DC straight polarity (top image in Figure 15), when welding carbon steel or stainless steel. DCEN generates two thirds of the overall heat on the work piece or base metal. This is required to create the molten weld puddle in a controllable manner, to give us a finely controlled arc. We must limit the heat that is applied to the tungsten electrode. Excessive heat can cause accelerated tungsten electrode erosion. This will affect the overall weld quality by forcing tungsten particles into the weld which are only acceptable in very limited portions.

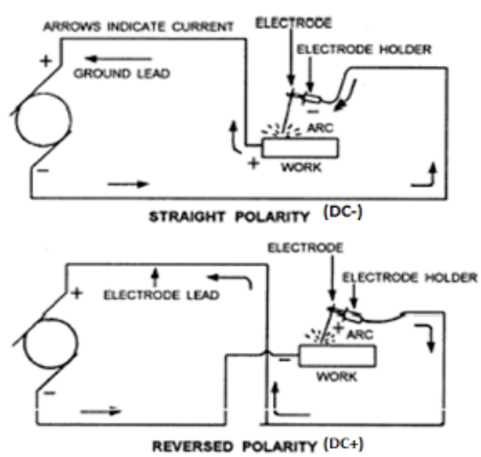


Figure 15. Polarity
(by AlthausenJ, Public Domain)

TIG welding of aluminum requires alternating current. Alternating current does not have polarity because it is both positive and negative (Figure 16). The heat distribution in an AC weld is evenly distributed between the tungsten electrode and the base metal. Advanced features on some machines allows us to throw it out of balance and gain cleaning action on the surface of the aluminum removing aluminum oxide that can limit penetration into the base metal. For a proper aluminum weld using the TIG process, the aluminum oxide must be fully removed.

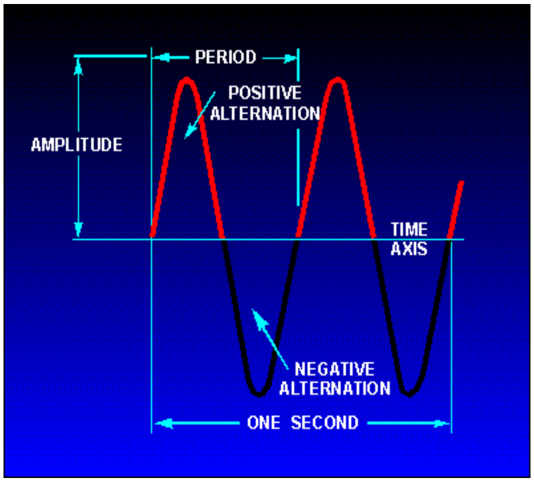


Figure 16. AC Polarity
(by NEETS, Public Domain)

MODULE ACTIVITY 5

Choose the correct answer.

1. It is important to understand that electrical current and polarity have a distinct effect on heat distribution in welding. T/F
2. Alternating current has polarity. T/F
3. DCEP is also known as reverse polarity. T/F

3.2.2 SMAW

Read Chapters 3 and 4 in *Welding Principles and Applications,* Larry Jeffus, 7th edition.

SMAW is the formal acronym that stands for shielded metal arc welding, also known as stick welding. Stick welding is the slang term that is commonly used when referring to this process.

Electrodes used for this process have an inner core wire with an external flux coating. As the core wire melts, it becomes the weld metal. The flux on the exterior of the electrode performs a number of different purposes. First, as it burns, it creates a gaseous envelope that surrounds the molten weld puddle, protecting it from contamination by normal atmospheric gases such as oxygen, nitrogen, hydrogen, carbon dioxide, and other trace gases. This protecting feature of the flux is very critical to the weld quality of this process. Second, the flux will change into a hard slag on the surface of the weld as it solidifies, continuing to protect the weld. The slag on the surface will be chipped off and removed after the weld cools. Finally, electrode manufactures add elements to flux that will strengthen the weld beyond just what is in the core wire of the electrode. In summary, the electrode flux performs three main functions; protecting the molten weld puddle from the atmosphere; changes to slag to continue to protect the weld as it cools; and adding elements to the weld deposit to strengthen it. Figure 17 is a diagram of the SMAW process.

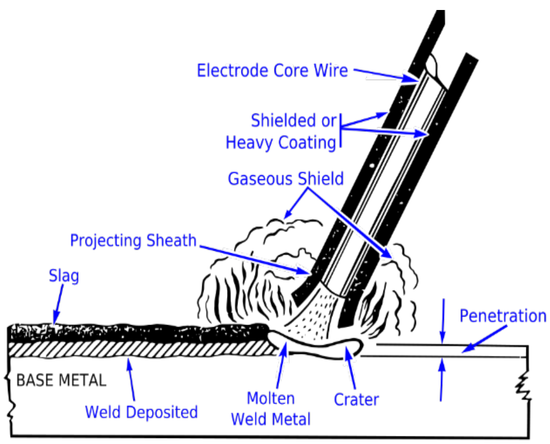


Figure 17. Diagram of the SMAW Process (by Amillar, Public Domain)

SMAW EQUIPMENT

This process has been around for quite some time and has fairly simple equipment requirements. SMAW machines can vary in type and size as you see in Figure 18 below. Stick welding power sources can also be used for TIG welding. Industrial commercial stick welding requires DC electrode positive power. On the far right in Figure 18, you will see a transformer rectifier type machine. The transformer type machines are the older technology and much larger in physical size and have much more copper in their construction. Newer technologies have allowed us to use inverters which are much smaller and efficient in consumption of input power (other two images in Figure 18).

Figure 18. Images of SMAW Equipment (by Paul Phelps, CC BY 4.0)

SMAW SET UP AND OPTIONS

Regardless of the type of machine, the basic components and their functions are very similar (Figure 19). There is one main dial that controls the amperage of the weld and another dial known as arc control or DIG. The arc control or dig function allows us to adjust the intensity of the arc according to type of electrode and aids us in the arc initiation. Other major components for the system are the power lead cables, electrode holder also known as the stinger (Figure 20 on the left), and the ground clamp (Figure 20 on the right).

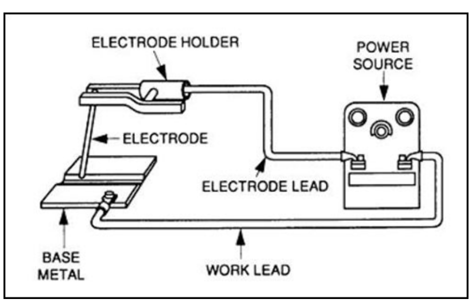


Figure 19. Basic SMAW Components (by Unknown, Public Domain)

Figure 20. Electrode Holder and Ground Clamp (by Paul Phelps, CC BY 4.0)

On the face of the machine, there will be a terminal for connection of the power lead cables and it is labeled positive and negative or ground/electrode and working lead. Modern machines have a quick connect feature which allow you to change set up between stick or TIG welding by changing the polarity from DCEP to DCEN (refer to Figure 15). Additional features on modern machines will be an input for a remote control, process mode selector, and advanced TIG welding features which will be covered in depth in the GTAW section of this module.

When discussing power sources we need to be familiar with the terms CV and CC. CV represents constant voltage and CC is constant current. With stick welding, we need a machine capable of CC. A CC capable power source is designed to give a consistent constant current which is critical for stick welding. At the electrode holder where the electrode connects, we have to manage the amperage that will we be working at. This is done by setting the amperage which controls the amount of heat generated at the electrode into the base metal. The amperage setting will be determined by the diameter of the electrode being used. With electricity in general, we find amperage and voltage at any given setting. In stick welding, we must manage the amperage or the flow of electrons for the intensity or what we refer to in the industry as heat.

Voltage is still a very important part of the process but it is not necessarily managed at a consistent rate. CV mode is used with the MIG or GMAW process. The CV mode is opposite from CC, in that it is a constant voltage setting. Constant voltage is critical for MIG welding and the machine will give a constant voltage that will be altered as needed. Voltage for stick welding is what maintains the arc. Some of the difficulties with stick welding are maintaining a consistent arc length or the space between the end of the electrode and the work piece. The arc length is critical to the quality of the weld and the penetration into the base metal by the weld. As previously stated, the voltage is what maintains the arc. It is what causes the jumping across the gap between the electrode and the work piece. As the arc length changes, the welding power source will vary the voltage when in the CC mode to maintain the arc. There are limits to this process. Some long arcs and pulls are too far away from the work piece for the electricity to will be able to jump across that gap. The machine cannot increase the voltage high enough to transition across that space.

Figure 21. SMAW Machine with CC and CV Capability
(by Paul Phelps, CC BY 4.0)

For a good consistent high-quality weld, the welder should try to maintain a consistent arc length which is usually equal to the diameter of the electrode or shorter.

Some of the modern machines have the capability of giving us CC or CV depending on the process to be used (Figure 21). So when using a multi-process capable machine, we need to ensure our set up is in constant current (CC) when stick welding. For some machines, you will need to flip a lever to change from CC to CV. With others, the machine may do it itself as you change weld process. We find this to be a nice feature in the more modern inverter type machines.

SMAW ADDITIONAL INFORMATION

When selecting a power source another important consideration will be the **Duty cycle**. Duty cycle refers to how long the welding power source can output welding current before it has to cool. The less expensive welding machines use less copper in the internal parts of the machine, smaller heat sinks and fans, so the machine will heat up more rapidly. Heavy industrial machines use larger concentrations of copper, oversized heat sinks, and on-demand fans and circuitry to keep the internals of welding power source cool, even at maximum output. As part of the machine specs, you will find the duty cycle as a percentage. This refers to the amount of time it can run before has to cool. For example, if machine specifies a 20% duty cycle, it is understood out of 10 minutes you can weld for two minutes and the remaining eight minutes will be required to cool. As you can imagine, a low duty cycle machine will not do well in high production work where it could be running 80+ percent of the time at high voltages or amperages. Considering how the machine will be used is very important in the selection of a welding power source. In a heavy industrial, non–robotic situation where the machine would be running nonstop, we will need a 100% duty cycle machine to keep up with demand from that power source. For home hobbyist, a much lower cycle time, such as a 20% or 50% duty cycle, would be adequate and can keep the cost down.

Additional considerations with our basic stick welding equipment will be the size and rating for the welding lead cables, electrode holder, and ground clamp. Each of these components are rated according to the amperage used at the maximum output of the machine. To prevent damage to the power source and operator, it is very important to obtain components with the correct rating for the process. When looking at welding lead cables, which are braided copper surrounded by a rubberized insulator coating, we must consider the amperage it will be running and how far away we will be working from the power source. With cables, we find a voltage drop will take place as current travels through the cable over a distance. The further we are away from the power source, we need to increase the diameter or size of cable to ensure the welding current and voltage can be carried all the way to the working end of the electrode holder in order to produce the required heat for that given weld. There are tables and charts which can help you determine the diameter or size of cable required for the application.

Maintenance of the system is fairly simple. The lead cables must be inspected routinely for cuts or breaks in the insulation and possible dry rot of that insulation. We want to ensure the inner braided copper wire is never exposed putting the operator risk of electrical shock. The electrode holder, or Stinger, is nothing more than a spring-loaded piece of copper that clamps onto the electrode but the electrode holder does have insulators on the outside to keep the operator from inadvertently making contact with ground. These insulators become worn and cracked over time and need to be replaced. The other issue with the electrode holder is to make sure the contact points on the jaws are kept clean and that the grooves cut into the jaws can grip the electrode firmly. With the ground clamp, the spring can wear out keeping the jaws from making consistent contact with the work piece or worktable. We must ensure a good solid connection for smooth transition of the electrical current.

SMAW TECHNIQUES AND EFFECTS

Proper technique for stick welding is very important. When done properly, stick welds are very strong and deep penetrating into the base metal. Proper technique begins at the very beginning when we initiate the arc. We must be careful about the initiation of the arc. If the operator is careless with the initiation of the arc, it will leave burn marks on the surface of the material that are prone to cracking. We must always initiate the arc in the weld zone so we can fuse back over the initiation spot thus leaving no risk of cracks. There are two basic techniques for initiation of the arc; striking like a match; or bouncing the electrode on the work piece (Figure 22). With each of these, we must make quick contact and break that contact to establish the arc length quickly.

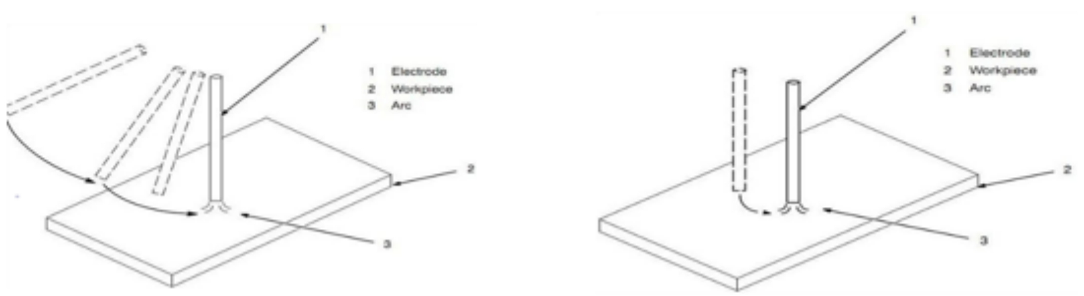


Figure 22. Two Basic SMAW Techniques (by Unknown, Public Domain)

The desired technique in stick welding, known as a drag or backend technique, is where we pull the weld along with us. In Figure 23, you will see the travel angle showing this backend technique or dragging. This allows the new molten material to be deposited at the forward edge of the weld crater where the new weld metal and melted base metal join. The dragging technique is also very important so the flux can provide the shielding of the molten puddle and for the slag formation to take place on the surface of the completed weld and not be introduced into the weld itself. Without proper angle, we risk forcing the slag into the weld creating an inclusion or a defect within the weld.

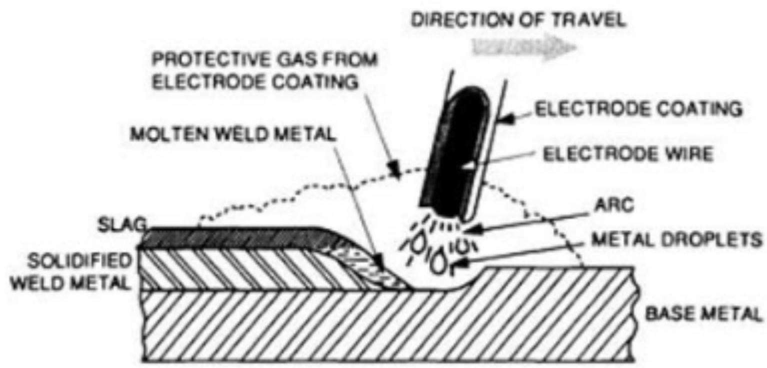


Figure 23. Diagram of the SMAW Drag or Backend Technique (by Unknown, Public Domain)

The work angle will depend on the joint configuration or your welding position. The main thing to remember is that more heat is focused in the direction we point the electrode. Therefore, point the electrode where you want to focus the heat in order to create good fusion of the weld into the base metal.

It is a very common technique to use a weaving motion which is represented in Figure 24 below. There are number of different techniques for this weaving pattern. In general we want to make sure that the tip the electrode is staying on the forward edge of the weld crater as we move forward, technique allows us to move the molten puddle aiding in fusion of the base metal and weld.

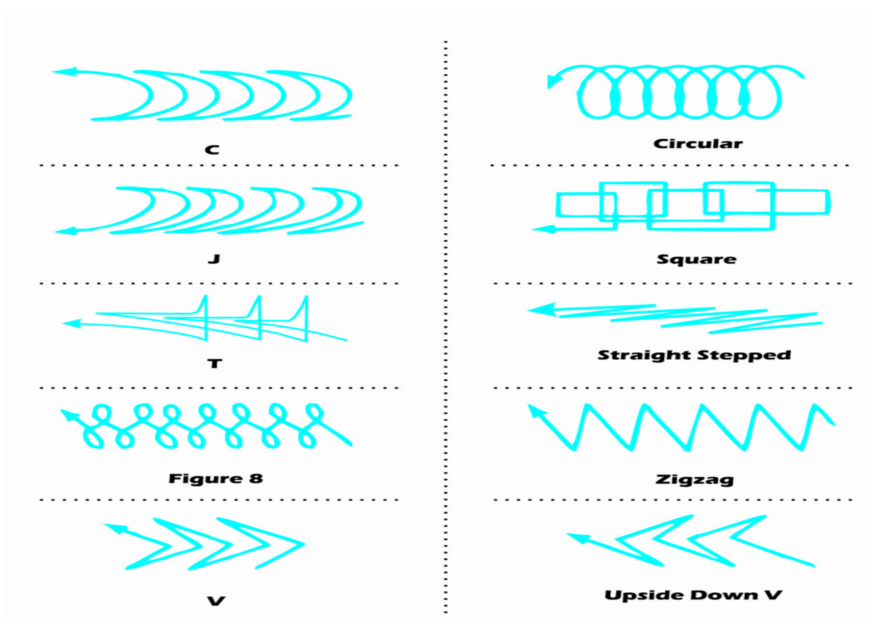


Figure 24. Various SMAW Weaving Patterns (by unknown, Public Domain)

Earlier in this section we talked about proper amperage. The effect of improper amperage will be seen in the completed weld quality. Amperage that is too high will cause what is known as spatter or splashing of the molten weld puddle, where small droplets of weld metal will surround the area of the weld. It can also lead to other weld quality issues such as undercut or where material has been burned away and weld metal is not placed back to completely fill the weld. If amperage is too low, a cold weld with the weld metal sitting on top of the surface of the base metal and not being fused into the base metal, might happen. A proper weld will be fairly flat with a slight convexity of the additional metal on the surface of the base metal. The fusion of the weld metal and the base metal should be clearly visible.

EXPLORE: SMAW

MODULE ACTIVITY 6

Choose the correct answer.

1. SMAW is the acronym for shielded metal arc welding. T/F
2. SMAW is also known as ________ (slack, stick) welding.
3. The electrodes used in SMAW have an inner core wire with an external flux coating. T/F
4. The SMAW molten weld puddle is not protected from the atmosphere. T/F
5. The flux on the exterior of the electrode performs two important functions:
    a. It evaporates leaving the weld puddle unprotected.
    b. It creates a gaseous sheath that protects the weld puddle
    c. It changes into hard slag on the surface of the weld which protects the weld
    d. Both b and c
6. The electrode holder in the SMAW process is also known as a stinger. T/F
7. SMAW machines always have CC and CV capabilities. T/F
8. CC stands for constant current. T/F
9. CV stands for
    a. Constant velocity
    b. Constant viscosity
    c. Constant voltage
    d. Consistent voltage
10. When selecting a power source for the SMAW process, _____ _____ (duty cycle, durable current) needs to be considered.

3.2.3 GMAW

Read Chapters 10 and 11 in *Welding Principles and Applications,* Larry Jeffus, 7th edition.

GMAW is an acronym for gas metal arc welding, also known as MIG welding. MIG welding is the slang term and stands for metal inert gas welding. GMAW is a wire fed process with gas shielding rather than the chemical flux with SMAW. It is a very common process and widely used in fabrication due to its speed, simplicity, and ease-of-use. GMAW can be done manually or automated such as in manufacturing with the use of robotics. This section will be focusing on what is known as short arc MIG welding.
The acronym MIG references Inert gas. Inert, by definition, is a material that will not chemically combine with any other. Our most common inert welding gases are argon and helium. Helium was the first gas used but it is expensive and ionizes at a very high temperature therefore over time it was determined that an argon mix was much more stable and cost effective.

It may seem confusing to refer to MIG welding when you are not truly using an inert gas but a gas mix, which makes it an Active gas. This is a prime example where slang can be misleading. It would be better to refer to Short arc MIG welding as MAG welding or metal active gas welding. Therefore, even though we commonly refer to MIG welding, it would be better and more accurate if we referred to MAG welding due to the argon, carbon dioxide mix. There are varying mixtures but the common gases in the mixture is argon and carbon dioxide. There is one time we are truly MIG welding. When welding aluminum using the GMAW process, we use 100% argon.

The gas metal-arc welding process (GMAW) in Figure 25 has revolutionized arc welding. In this process, a consumable electrode (in the form of wire) is fed from a spool through the torch (welding gun) at a preset controlled speed. As the wire passes through the contact tube of the gun, it picks up the welding current. The consumable wire electrode serves two functions: it maintains the arc and provides filler metal to the joint. The method of delivery of the filler metal allows GMAW welding to be basically a one-handed operation.

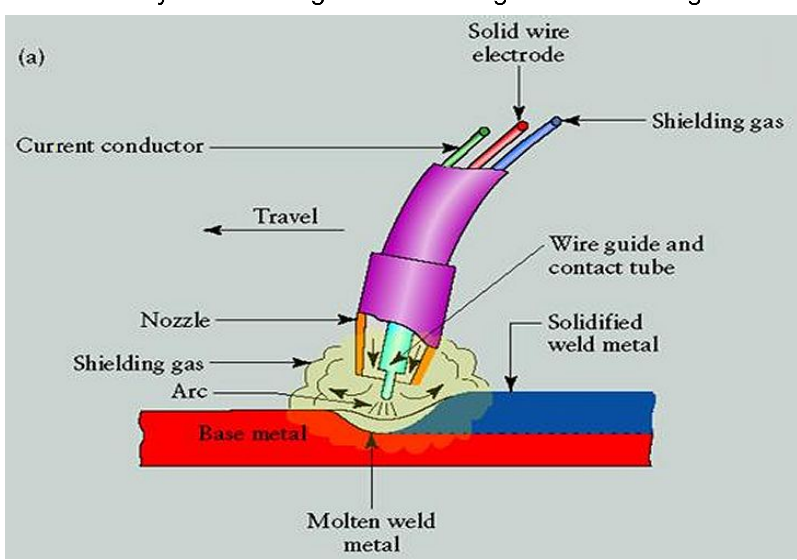


Figure 25. GMAW or MIG Welding Diagram
(by Ed Schmidt, Public Domain)

Gas metal-arc welding uses a shielding gas to protect the weld zone during welding. The inert gas is fed through the gun into the weld zone and prevents atmospheric contamination. With MIG welding, the electrode (wire) is not coated with flux. To concentrate the heat in the weld zone, inert gas (usually argon or helium) flows through the stinger and blankets the area. A gas cylinder and regulator are required to supply this gas, and the cylinder must be periodically refilled. Since the argon is heavier than air, it blankets the weld from contamination. Due to the absence of flux, GMA welds are clean and there is no slag to remove. GMAW enables you to produce sound welds in all positions quickly. Now let us take a look at the equipment you will use for GMA welding.

GMAW EQUIPMENT

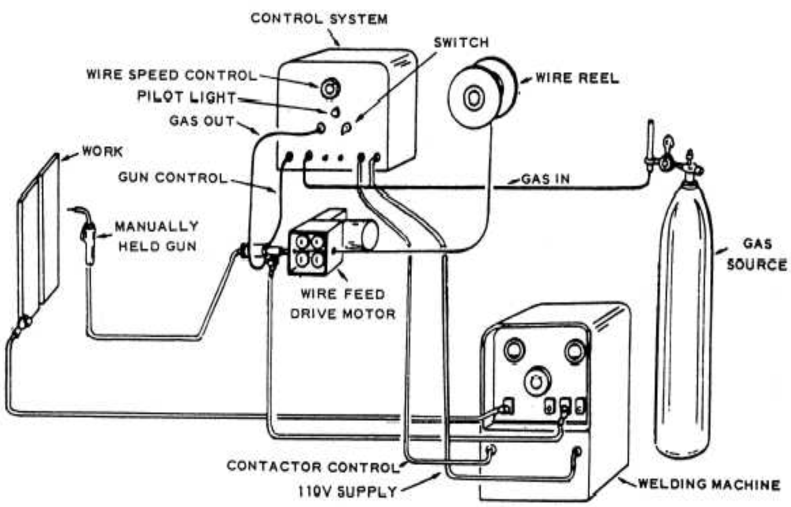


Figure 26. Common GMAW Equipment Setup (by ADMIN, Public Domain)

The basic equipment to execute a MIG welding process is a welding gun, electrode wire, welding power supply, a wire feed unit, ground clamp and a shielding gas supply. Figure 26 above is an example of a common set up. Figure 27 below is an example of a welding gun and some fittings. The other components may vary according to the manufacturer in the way they connect.

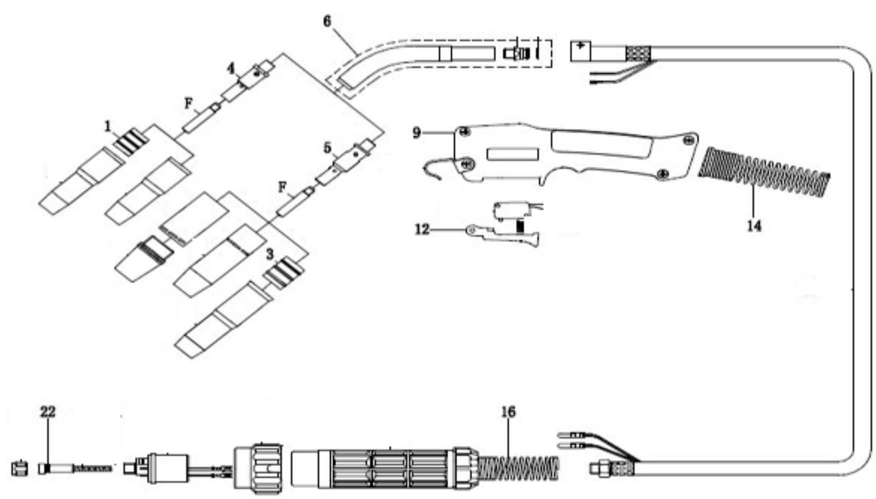


Figure 27. Common GMAW Equipment Components (by Unknown, Public Domain)

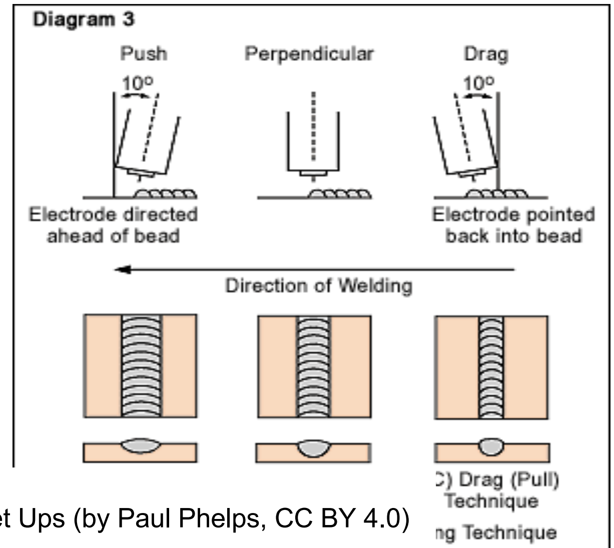
<u>Common GMAW Equipment Components</u>

1, 3 – Insulators (some insulators are built into the nozzle)
4, 5 - Gas Diffusers (disperses gas and focus it out the end of the nozzle)
F - Contact Tip or Tube
6 - Neck Assembly
9 - Gun Body
12 - Trigger Assembly
14, 16 - Gun Lead Stiffener (keep lead from binding and damaging connection)
22 - Gun Liner (coiled steel cable which allows gun lead to flex and smooth feed the spooled wire from

GMAW SET UP AN OPTIONS

When looking at set up of a system, we need to start at the shielding gas. You need to be sure that there are flow meters/regulators controlling the flow of gas that are measured in cubic feet per hour. Next, there is a hose between the flow meter and the welding machine. This hose will connect directly to the wire feeder or, in a self-contained unit that has a built-in wire feeder, the rear of the machine. On either assembly, the next part you would find is the gas solenoid, which controls the flow of gas when the trigger assembly is depressed. Finally, there is the input power source. This power source can vary depending on the size of machine. Some can hook up to single phase or three-phase. On the face of the machine, we will find the connection for the gun lead and ground clamp lead.

On the heavy duty industrial systems which have individual components, the wire feeder will have a power cable that needs to connect directly to the positive terminal on the face of the welding power source. There will be a remote control cable the needs to connect directly to the face of the welding power source. On the face of the wire feeder, you will see the connection for the MIG welding gun lead. The ground lead will connect directly to the welding power source. Several advanced features are available on some machines such as pulsar controls, hot start, burned back, inductance, and various others settings. Figure 28 shows examples of two different GMAW set ups.



GMAW TECHNIQUES AND EFFECTS

In Figure 29, you see the illustration of 2 basic techniques. One is to push, the other to pull. There will be different results in a weld contour, deposition, and profile according to which technique is used. Both are acceptable but the welder must choose the correct technique according to the job. With the push, or forehand technique, there is shallower penetration, a wider weld, and a flatter profile. When working on thinner materials, the push technique will be the desired tech through the materi profile. With a drag technique or pull, also known as a backhand technique, there will be deeper penetration but a narrower weld with higher deposition and bead profile. This technique will be beneficial when working with thicker materials where penetration is critical.

Figure 28. Examples of GMAW Set Ups (by Paul Phelps, CC BY 4.0)

EXPLORE: How to MIG Weld

GMAW TRANSFER MODES

Read pages 236-243 in *Welding Principles and Applications,* Larry Jeffus, 7th edition.

In GMAW, there are a number of different modes of transferring the filler metal from the wire to the weld. This process basically involves how the welding electrode or spooled wire is consumed and become the weld. These transfer modes are affected by the gas mixture and the weld parameters of amperage and voltage. Each transfer mode will give different weld characteristics in the way of penetration, deposition, and heat input. Selecting the mode of transfer depends on the welding power source, the wire electrode size, type and thickness of material, type of shielding gas used, and the best welding position for the job. In this module, we will examine short-circuiting transfer (GMAW-S), axial spray metal transfer, globular transfer, and pulse-arc metal transfer modes.

SHORT-CIRCUITING OR SHORT ARC TRANSFER MODE

Short-circuiting transfer mode (GMAW-S), more commonly known as the short arc transfer mode, is most common with the home hobbyist and in light industrial use. It easily set up and used, but does have limitations. The main limitation is the penetration into the base metal. The GMAW-S process is normally recommended for materials only up to one quarter of an inch thick. This process is not automatically accepted by AWS D1 .1 structural steel welding code. If it is to be used in production, it must be proven to work prior to being used. This is done through very stringent controls of welding out a sample and sending it to a testing laboratory to verify the weld strengths that are created.

With the short arc transfer mode, the common gas mixture is 75% argon and 25% carbon dioxide. You may find other mixtures used to gain additional heat for greater penetration, but they tend to be close to this particular mixture such as 80% argon and 20% percent carbon dioxide.

The short arc transfer mode begins with the depression of the trigger assembly on the MIG gun. This will activate the gas solenoid allowing shielding gas to flow towards the end of the nozzle and it advances the wire from the wire feeder at the end of the contact tip, and energizes the contactors sending electric current forward. The wire is energized as it travels through the contact tip. The friction of the wire passing through the contact tip is where it gains its electrical charge.

The wire is carrying the positive charge and the work piece is grounded with the negative charge. The wire will contact the work piece or the molten weld puddle and short-circuit. This generates heat, which melts the core wire causing a droplet to form, and the arc force pushes the droplet to the weld puddle. This process repeats over and over up to 200 times a second.

Video 1 and 2 are slow motion videos of this process. You will notice the pinching effect of the arc force at the end of the wire which forces the droplet across the arc gap pinching off the droplet from the end of the wire.

Video 1 – Click on the video icon to watch a slow motion video about the Short Arc Transfer Mode

Video 2 – Click on the video icon to watch a slow video showing a Short Arc Fillet Weld.

AXIAL SPRAY METAL OR SPRAY ARC TRANSFER MODE

Axial spray metal transfer or Spray arc metal transfer mode is the formal name for this process but it is typically referred to as spray arc for short or slang. This transfer mode creates high heat and high deposition which means it produces a deep penetrating weld with a large amount of weld metal deposited. The limitations of this process is it is only good with thick materials. Also, it requires a fairly clean base metal. Contaminants on the surface can lead to porosity and other defects within the weld. Due to the high heat in high deposition, this process is typically limited to fly or horizontal welding positions.

This transfer mode requires a gas mixture with high argon content. The typical gas mix will be 90% argon and a minimum of 10% carbon dioxide to achieve the spray arc transfer. Without this high argon content, a true spray transfer is not possible because there will not be enough argon to achieve the required transitional current. A common misconception is that just running higher voltage and wire speeds is all that is needed to achieve spray transfer. The proper gas mixture with the required argon content is required to truly reach the spray transfer.

The different chemistries of weld wire produced by different manufacturers may cause the required gas mixture to vary. Most manufactures have datasheets available online that provide this information. In applications where adherence to code requirements is necessary, we must adhere to the manufacturer's recommended gas mixture. So the welder must know the product they are using in order to make sure they are using the proper mixture.

The higher argon content creates the required heat to achieve the transitional current. This transfer mode differs greatly from the short arc. It does not pinch off large droplets of molten wire but creates hundreds of small droplets that shoot across the gap into the weld puddle creating the deep penetrating weld with high deposition. The spray arc transfer mode is considered a prequalified weld process in the AWS D1 .1 structural steel welding code due to these high heat, deep penetration characteristics of the weld produced. This prequalification saves us from having to send a weldment to a test lab and prove that the process works and what this process can achieve.

Video 3 – Click on the video icon to watch a video about a Spray Arc Molten Metal Transfer Fillet Weld

GLOBULAR METAL TRANSFER MODE

Globular metal transfer mode is a formal transfer mode but it is not typically used in the field. It usually results from a mistake in trying to set our parameters for short-circuit or spray. You would get this transfer mode as an in-between setting when adjusting voltage and wire feed speeds in achieving one of the other two transfer modes. Normally, due to running wire feed speeds that are too low, it allows a large droplet to form on the end of the wire that grows in size as the wire is consumed until surface tension can no longer hold on. The large droplet of molten wire then transitions across to the weld puddle, but due to its large size it loses energy. The droplet splashes as it enters and adds to the weld puddle, but lacks penetration into the base metal. It is a fairly dirty process due to the heavy spatter it creates surrounding the weld. The spatter has to be removed which causes more time to be spent on the weld and ultimately more project costs.

Video 4 – Click on the video icon to watch a video about the Globular Transfer.

PULSE TRANSFER MODE

The **Pulse transfer mode** requires built in or external pulsing units/advanced controls for this transfer mode. Not all machines are capable of pulse transfer. It must be a machine that works very well on thin materials which allows us to minimize heat input. The pulse transfer mode allows us to create a primary voltage and a background voltage, and then the number of pulses per second. By doing this, we do not run at the peak voltage for the duration of weld. It gives a pulse of the main voltage followed by a pulse of the background voltage. The main voltage gains the penetration into the base but the background drops off to a lower voltage to limit heat input. The pulses per second will be dialed in for the desired penetration and bead appearance required.

The pulse transfer mode, when properly set up, can give the appearance of a TIG weld. It can also aid in consistency of weld appearance as it is not reliant on the operator oscillating or manipulating the weld puddle to gain the same pattern. The reduced heat input will aid in less distortion and spatter surrounding the weld. Even though the transfer mode has many benefits, it does require welder skill and ability/knowledge to properly set up this transfer mode.

EXPLORE: GMAW and Transfer Modes

MODULE ACTIVITY 7

Choose the correct answer.

1. GMAW is an acronym for gas metal arc welding. T/F
2. The slang term for GMAW is
   a. TIG welding
   b. MIG welding
   c. Stick welding
   d. DCEP welding
3. GMAW includes short arc MIG welding. T/F
4. What type of gas is used in GMAW?
   a. Active
   b. Inert

c. Gas mix
d. No gas is used

5. When welding aluminum using the GMAW process, you use
   a. 100% oxygen
   b. 50% argon
   c. 100% argon
   d. 50/50 argon, oxygen mix
6. The gas metal arc process has revolutionized arc welding. T/F
7. GMAW does not use a shielding gas to protect the weld zone. T/F
8. The GMAW process is a clean process and has no slag because:
   a. It is a cold process
   b. It uses an inert gas
   c. It only takes one hand to complete
   d. The electrode is not coated with flux
9. The GMAW process has ____ (2, 4) transfer modes.
10. Selecting the mode of transfer needed depends on
    a. The welding power source
    b. The wire electrode size
    c. The type of shielding gas used
    d. All the above
11. The common gas mixture in short arc transfer is 75% argon and 25% carbon dioxide. T/F
12. Which answer below is not a GMAW transfer mode?
    a. Globular metal
    b. Axial spray
    c. Pulse
    d. Puddle

3.2.4 FCAW

Read Chapter 13 in *Welding Principles and Applications*, Larry Jeffus, 7th edition

FCAW is an acronym for flux cored arc welding and is commonly known as flux cored welding. FCAW is a wire fed process similar to GMAW. There are two major types of flux cored arc welding, self-shielded and dual shielded. In GMAW, we use a solid wire but in FCAW we use a tubular wire where the inside of that wire is a flux. With self-shielded FCAW, the melting of the wire creates the protective barrier like that with

SMAW/stick welding. The dual shielded FCAW process ads on an external shielding gas along with the flux cored wire. With the addition of the shielding gas we gain better surface appearance and deeper penetration. With FCAW we find two common gases used either 100% CO_2 or a 75/25 argon/CO_2. This is another difference from GMAW. Figure 30 below shows both of the FCAW options.

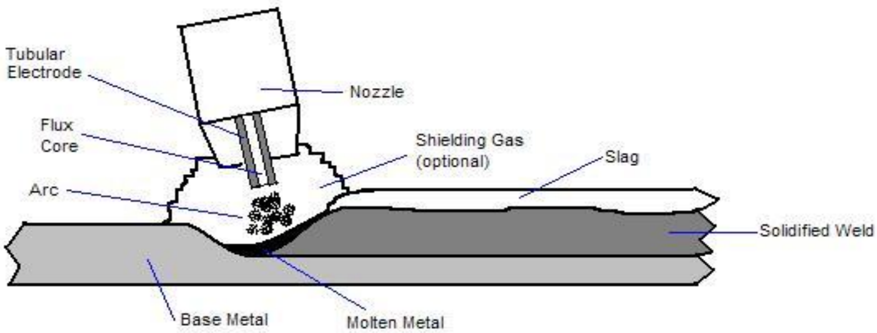


Figure 30. Diagram of FCAW Process (by Mowens57, Public Domain)

Due to the inte npleted weld. This slag, just like with SMAW/stick welding, must be removed and cleaned away from the completed weld before additional work continues.

Self-shielded FCAW is a low level, low cost option for the home hobbyist or it can be used for heavy industrial processes. The small GMAW machines that can be purchased at local home improvement stores already have a set up for self-shielded FCAW. These low-end machines require low voltage power input, such as 110 V wall outlets, but they are very limited in their usage. They are best on thin materials in light-duty usage.

On the heavy industrial side, we find machines with much higher power input which give us much higher outputs. Heavy industrial users prefer this process due to its deep penetration and ability to work through surface contaminants. With the self-shielded process, it is also easier to set up and move around without having to keep an external gas source. This process is commonly used in work with structural steel and piping.

Actually, the dual shielded FCAW process is more commonly in the heavy industrial use and fabrication. It works well with thick materials and it will burn through surface contaminants without affecting weld quality. This minimizes cost by removing additional preparation time of the base metal. We find FCAW to be a good cross between SMAW/stick welding characteristics and the ease of GMAW/MIG welding.

FCAW EQUIPMENT

FCAW welding process equipment is very similar to that of GMAW/MIG welding (Figure 26). With dual shielded FCAW, the system as a whole is about the same. The welding power source, just as with GMAW, requires CV DC power which promotes input communication between the wire feeder and the power source.

In FCAW, there are two different components than in GMAW, the type of welding gun and drive rolls. There are dedicated guns for this process shown in Figure 31 and 32 below. Both of the guns incorporate a heat shield to protect the operator's hand from the intense heat that is created as part of the process.

Figure 31. Dual-shielded FCAW welding gun (by Unknown, Public Domain)

Figure 32. Self-shielded FCAW welding gun (by Unknown, Public Domain)

Another difference we find will be the drive rolls design. Typically with standard GMAW/MIG welding with solid wire, we find a V groove driver roll. The V groove driver roll can be used with FCAW but there is a risk of crushing the wire since it is tubular with an internal flux. It is not uncommon to see a V groove knurled driver roll used with FCAW to aid in grabbing the wire and pushing it toward the gun contact/tube. A U groove driver roll is recommended with aluminum welding GMAW.

EXPLORE: Driver Rolls

EXPLORE: FCAW

FCAW ADDITIONAL INFORMATION

There are a number of advantages to FCAW:

1. High deposition rates or the ability to put a large amount of weld metal down quickly.
2. Efficiency with minimal wasted electrode or the majority of product going directly into weld metal with little product been scrapped or wasted. With SMAW/stick welding, at least three or 4 inches of the electrode are unusable.
3. Ability to use a much narrower groove angle because of the deep penetration properties of the process. This means fewer required passes to complete a weld the joint which equates to a lower cost and shorter timeframe to completion.

4. Ability to weld over surface contamination of the base metal without sacrificing weld quality. This shortens the amount of time required for pre-cleaning of the material which in turn lowers cost of the overall weld joint.
5. Ability to weld out in a position unlike other processes. The one caution is to be sure to use the proper electrode designed for out of position welding.
6. Automatically acceptable process with many of the welding codes due to FCAW's deep penetration and weld quality.

Limitations to the process are few but very important in consideration when selecting a process:

1. Electrodes can be more costly. (Cost is usually recovered through lack of pre-cleaning time and the ability to complete the weldment faster).
2. Need for post cleanup time due to the slag on the surface of the weld, though only a minimal amount has to be fully removed.
3. Amount of smoke and fumes that are generated from the process. We must make sure that proper ventilation is in place to pull away the smoke and fumes from the operator and workspace. This can be as simple as fans but may require engineering controls such as a smoke extraction system to capture and filter the air depending on the size of facility and amount of welding taking place.
4. Improper technique at set up or during the process can lead to slag inclusions which can be considered a defect that undermines the strength of the weld.

FCAW TECHNIQUES AND EFFECTS

FCAW allows a forehand push technique or a backhand drag technique. For the best weld quality, it is recommended the angle be either perpendicular (90°) to the work piece, or be a backhand/drag technique, 10 to 20° off of a 90 degree angle, to the base. This is to ensure that the welding wire is adding to molten weld puddle and the forward edge of the crater, to limit the chances of slag being introduced into the weld and becoming inclusions.

MODULE ACTIVITY 8

Choose the correct answer.

1. FCAW is an acronym for fluxed cored arc welding. T/F
2. The FCAW process is similar to GMAW. T/F
3. There are two common gases used in FCAW
    a. Oxygen, argon

b. Carbon dioxide, oxygen
c. Carbon dioxide, argon
d. Hydrogen, argon
4. The FCAW process does create slag on the surface of the completed weld. T/F
5. FCAW uses two types of welding guns. T/F
6. The two FCAW processes are
    a. Dual shielded
    b. Self-shielded
    c. Gas shielded
    d. Both a and b

3.2.5 GTAW

Read Chapters 15 and 16 in *Welding Principles and Applications,* Larry Jeffus, 7th edition.

GTAW is an acronym for gas tungsten arc welding, also known as TIG welding. TIG welding is an acronym for tungsten inert gas. TIG welding is a very clean, high-quality welding process that requires a high level of skill to consistently produce high-quality welds.

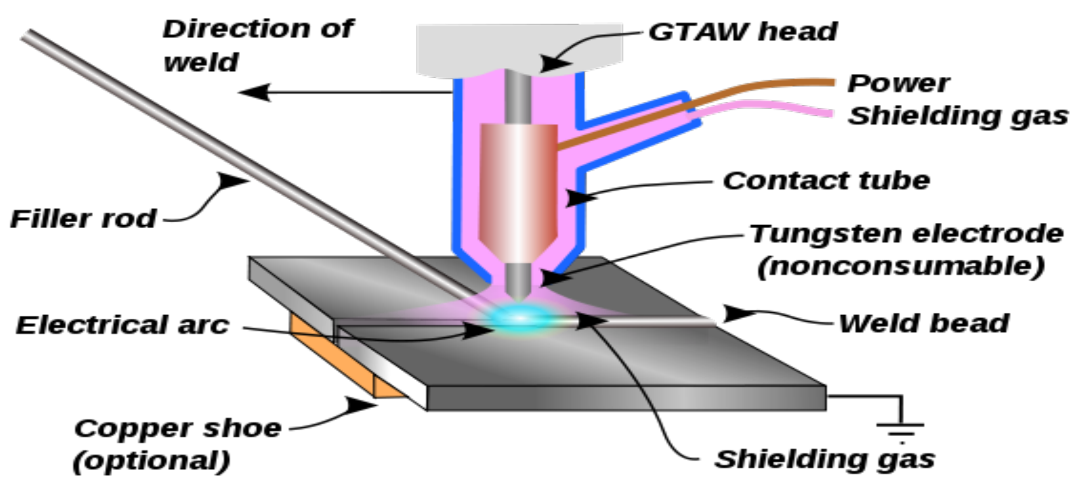


Figure 33. Diagram of GTAW Process (by Duk, CC BY-SA 3.0)

There are a number of variables that contribute to the quality and consistency of the weld. These variables are type and size of Tungsten , tungsten preparation, cleanliness of base material, fit up of base material, gas shielding, and possible purge of the weldment, amperage, heated base metal, and overall technique of applying the process. The GTAW process (Figure 33) is difficult due to the fact that the wire or filler rod, that is melted and becomes the weld metal, is added with the non-dominant hand while the TIG torch is controlled by the welders dominant hand. This two handed requirement takes time and practice to master. To further complicate things, we can add in a remote control which allows us to control the amperage while welding, so a two handed process can turn into a two handed and one foot process. The remote isn't required but gives an added level of control when working with thin materials and aluminum.

GTAW relies on proper shielding from the atmosphere through use of an inert gas. During an earlier period of time, helium shielding was used. Due to the fact that helium ionizes at a high temperature, is expensive and is not very stable, it was determined that argon shielding should be considered. Argon performed better than helium and was much more economical for the user. Older welders may refer to GTAW/TIG welding as Heliarc as they did in the early days when they used helium as the shielding gas. Most modern welders refer to it as TIG welding. Today, helium is still used when working on very thick weldments where increased heat is required, such as thick aluminum.

Tungsten, which is a very hard material with a high melting point and it is a very good conductor electrical current, is a major component for this welding process. For this reason, the GTAW electrodes are made of tungsten. A tungsten electrode allows focusing an electrical current into a precise fine point. Unlike most other electrodes, tungsten is a non-consumable electrode, meaning that it does not become part of the finished weld.

There are a number of different types of tungsten available and there are number of different factors to consider when choosing the type and size of a tungsten electrode. Typically there are color bands on the tungsten electrodes to represent the type of tungsten (Figure 34). We must choose a tungsten electrode that is compatible with the thickness of material, of adequate size for the weld we will create, and is capable of carrying the required amperage for the weld. For example, the green tungsten/pure works well on older transformer type power sources when working on aluminum with alternating current.

Figure 34. Image of Tungsten Electrodes with Color Bands (by Unknown, Public Domain)

As with most other electrodes, the larger the diameter the more heat or amperage it is designed to carry. The diameters of tungsten electrodes vary from 1/16 of an inch or smaller up to one quarter of an inch in diameter. The normal day-to-day manual welder will typically use a 3/32 or a 1/8 inch in diameter tungsten electrode. The thinner the materials, the smaller the electrode we will need to use to give the precise control needed.

The workhorse of the industry for many years has been the red tungsten, 2% thoriated. The red 2% tungsten has been the all-purpose tungsten when working on carbon steels, stainless steels, and even aluminum when using inverter power sources (Figure 35). There have been some major concerns with the 2% red tungsten in the last few years and new regulations have been put in place. The reason for the caution is the fact that the element thorium is mildly radioactive and require strict controls. This tungsten is still available in the market and widely used but more and more facilities are moving away from this tungsten and looking at other alloys that are not radioactive. When working with this particular tungsten, the dust from grinding it has to be captured and disposed of properly due to its radioactive nature. The operator must be ng or ingesting any of the particles.

Figure 35. Types of Tungsten (by Paul Phelps, CC BY 4.0)

Take a minute to read the safety related article below from the American Welding Society concerning red 2% thoriated tungsten.

EXPLORE: Safety Related article on 2% tungsten

GTAW EQUIPMENT

Equipment for the GTAW/TIG process (Figure 36), is very similar to SMAW/stick. The power source must have direct-current output. The main

Types of Tungsten					Recommended Uses	
Alloy	AWS Color	AWS Class	ISO Color	ISO Class	AC	DC
Pure	Green	EPW	Green	WP	Yes	No
2% Cerium Oxide	Orange	EWCe-2	Gray	WC 20	No high current	No
1% Lanthanum	Black	EWLa-1	Black	WL 10	Yes	Yes
1.5% Lanthanum	Gold	EWLa-1.5	Gold	WL 15	Yes	Yes
2% Lanthanum	Blue	EWLa-2	Sky-blue	WL 20	Yes	Yes
1% Thorium	Yellow	EWTh-1	Yellow	WT 10	W/inverters	Yes
2% Thorium	Red	EWTh-2	Red	WT 20	W/inverters	Yes
3% Thorium			Violet	WT 30	W/inverters	Yes
4% Thorium			Orange	WT 40	W/inverters	Yes
2% yttrium			Blue	WY 20	Yes	Yes
0.3% Zirconium	Brown	EWZr-1	Brown	WC 3	Yes	No
0.8% Zirconium				WC 8	Yes	No
Rare earth hybrid	Gray	EWG				Yes

difference is the external shielding in the form of 100% argon. Connection of the shielding gas can be done in a couple of ways depending on the system. A machine designed for stick or TIG welding will have a connection point on the rear of the machine with a gas solenoid inside that controls the flow of gas through the machine on demand and is controlled by the machine. On other simple machines, that do not have the gas solenoid, there will be a direct connection of the gas supply to the TIG torch itself. This is a common set up for what is known as a dry rig or as an air cooled torch. At the end of the power lead cable of the torch, you will find a junction block to connect the stick electrode holder which will carry the electrical current to the TIG torch. So, technically, we can TIG weld on any DC power stick welding machine, but for high-quality TIG welds, it is more desireable to have a higher level of amperage control beyond some of the low level, inexpensive power sources.

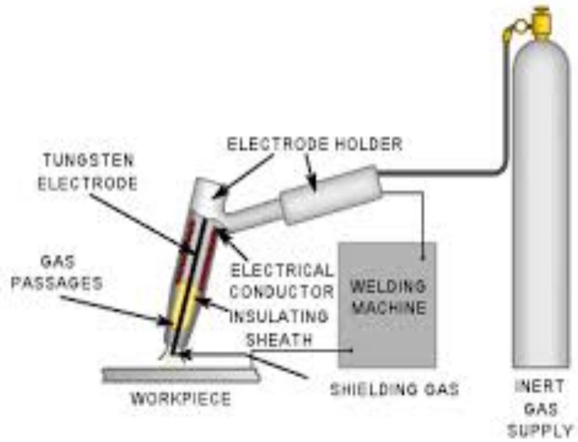


Figure 36. Common GTAW Equipment Setup (by Spanginee, Public Domain)

GTAW/TIG requires a DCEN polarity to keep heat off of the tungsten electrode. DCEN welding polority is required for welding steel and stainless steel. Alernating current is used for TIG welding aluminum. If the tungsten electrodes overheat, they can erode and push particles of tungsten into the weld. This is undesirable as tungsten is hard and will not be melted or consumed as part of the weld. Instead voids will be created within the weld itself.

There are a number of ways to limit tungsten erosion:

- Make sure all electrical connections are solid connections.
- Weld at the lowest amperage possible to prevent excessive heat.
- Use a watercooled torch when possible, to help pull heat away from the torch itself.
- Use the largest tungsten electrode size possible, as it will carry the electrical current with less chance of overheating.
- Use DCEN polarity so that the heat is focused on the work piece and not on the tungsten electrode.
- Use the shortest electrode stick as possible where the tungsten electrode extends past the nozzle to minimize the heat traveling through the tungsten electrode.
- Use the proper shape of tungsten electrode to obtain a focused, clean, consistent arc.
- Choose the proper tungsten electrode alloy to avoid overheating the tungsten electrode.

Another component of the system will be a remote control. This is an optional component but in certain applications it can be an added plus to gain control over the welding current. The remote control can act as an on-off switch for activating the contactor, sending electrical current to the tungsten electrode. It can also allow variable amperage, where we can adjust the amperage while welding. Remote amperage controls come in a few different designs as shown in Figure 37 below. Some are attached directly to the TIG torch and allow the operator to rotate a wheel or move a slide, while others are on a seperate foot pedal.

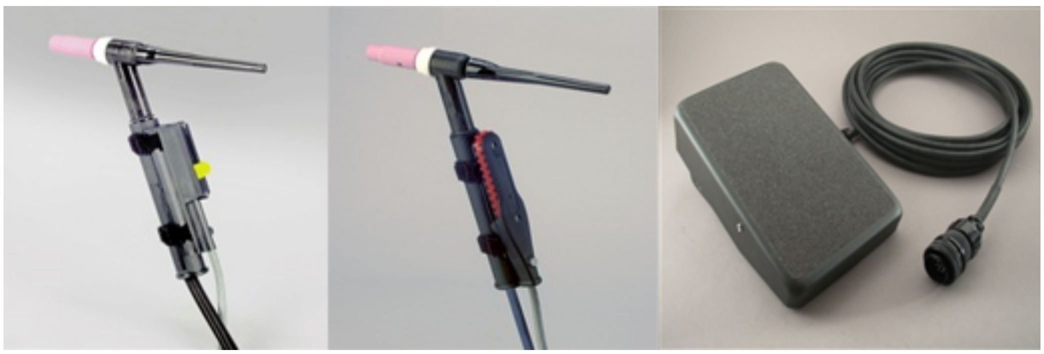


Figure 37. Remote control options for TIG welding (by Unknown, Public Domain)

There are two basic types of TIG torches available, air cooled or watercooled. Air cooled is also referred to as dry and watercooled as wet, if one is using slang terms. With a watercooled torch, you must have the addition of a radiator which circulates water to the torch, pulling heat away and returning the hot water to the radiator where it cools the water. These TIG torch water circulators/radiators can be a factory built in design (Figure 38) or purchased separately as an add-on to the system (Figure 39).

Figure 38. Factory Built-in TIG Torch Radiator
(by Paul Phelps, CC BY 4.0)

Figure 39. Add-on TIG Torch Water Cooler
(by Unknown, Public Domain)

In TIG torches, there are a number of different consumables. Figures 40 below, shows details of an air cooled torch and Figure 41 shows a watercooled torch details. The consumables are the same for the two types of TIG torches. There are number of different back cap designs that accommodate different lengths of tungsten. The cup seals will be different according to what type of Collet body or gas lenses are used along with the different size of ceramic cups. The cup seals are designed to ensure the gases are pushed through the Collet body or gas lens, out the end of the ceramic cup, to properly shield the molten weld puddle.

1. Cups, ceramic
2. Collet body, or gas lens
3. Collet
4. Cup seal
5. TIG torch, air cooled
6. Back cap, a.k.a. rooster tail
7. Short back, A.k.a. button

A. Remote button, acts as an on-off of the contactor

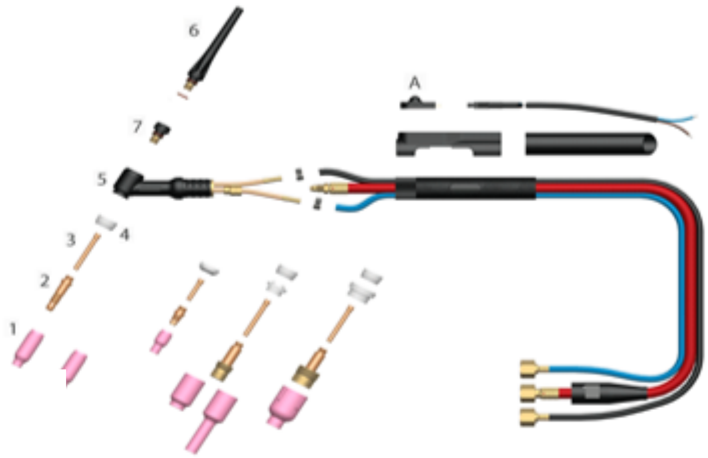


Figure 40. Air Cooled TIG torch parts
(by Unknown, Public Domain)

1. Cups, ceramic
2. Collet body, or gas lens
3. Collet
4. Cup seal
5. TIG torch, Water cooled, identifiable by the red and blue water lines
6. Back cap, a.k.a. rooster tail
7. Short back, A.k.a. button

A. Remote button, acts as an on-off of the contactor

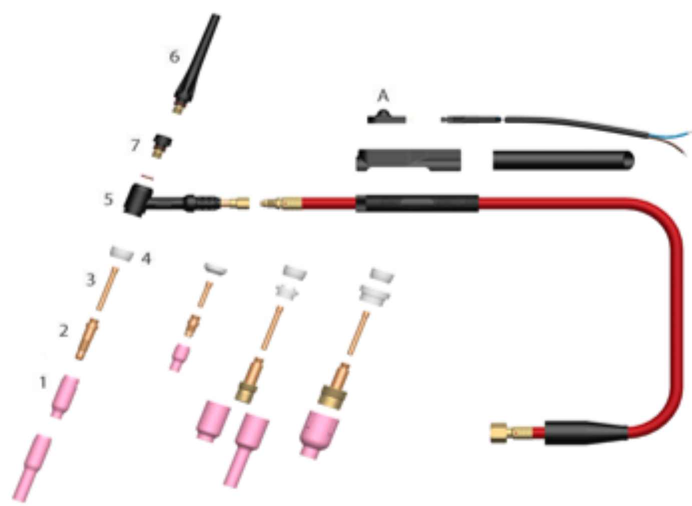


Figure 41. Water cooled TIG torch parts
(by Unknown, Public Domain)

The Collet body is the old, inexpensive design and has crosscut gas ports on the forward end where the shielding gas exits and is pushed out the end of the ceramic cup. The Collet body, with these crosscut holes, may not give you uniform coverage of the shielding gas and can lead to contamination at the weld by atmospheric gases leading to porosity. The gas lens has a screen on the forward end, which helps in breaking up the gases, giving a uniform coverage and resulting in higher weld quality. The gas lenses are a little more expensive but the difference in weld quality is well worth the added expense (Figure 42). We also find the shared component of the Collet, which is the component that clamps onto the tungsten and holds it in place while in the TIG torch. The Collet body, Collet, and gas lens all are sized according to the diameter of tungsten being used. Ceramic cups come in many different shapes and sizes according to whether they used with a Collet body or a gas lens and will have varying diameters of the open end according to the needs of the application. Figure 43 shows a common TIG torch design.

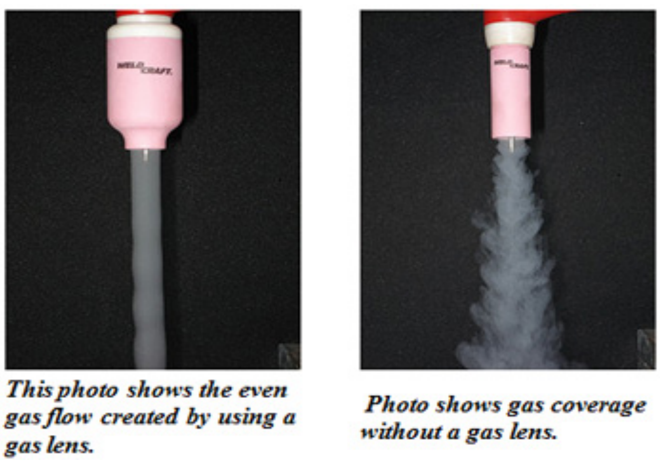


Figure 42. TIG Torches With and Without Gas Lenses (by Unknown, Public Domain)

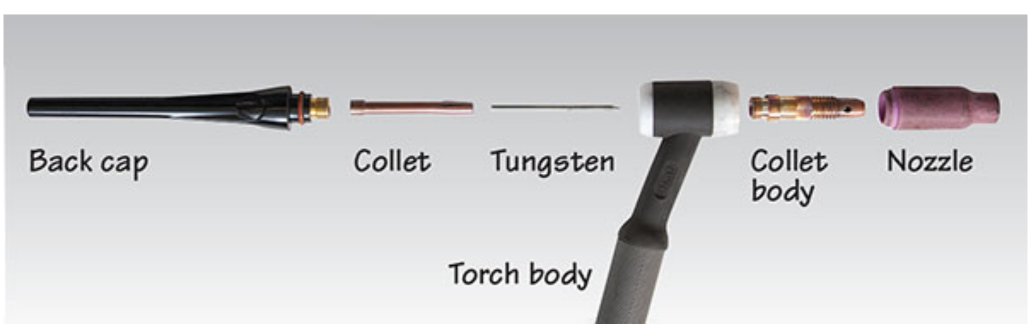


Figure 43. Common TIG Torch Design (by Mark Simpson, Public Domain)

There are variations of each of the two types of TIG torches, air cooled or water-cooled. These variations are specially designed for different applications and amperage ranges. There are very small torch designs to get into very limited access positions. Some torches are designed for different angles and for different amperage ranges. Finally, some torches have flex heads which allow the torch head to be bent according to the desired angle for access. Flex head torches are easily identified by the ribbed boot at the neck of the TIG torch head. Only these torches are meant to be bent. All other torch designs are at a fixed angle and are not meant to be bent. If fixed angle torches are bent the torch head may break as there is only a small copper tubing carrying gas and welding current to the working end of the TIG torch.

GTAW SET UP OPTIONS

As mentioned a number of times within this module, we can TIG weld or stick weld off of the same machine if it uses DC power. You will notice on the far left column on the machine face in Figure 44 below, that with the push of a button you can change between DC power and AC power.

DC power does have polarity but by going to the second column and choosing process, the machine internally will change polarity to electrode positive or electrode negative according to the process selected. Stick welding requires DC electrode positive polarity, and DC TIG welding requires electrode negative polarity. On this particular machine, there is no need to change the physical connection points of the welding leads at the face of the machine. You can just push a button to adjust polarity and process.

Another required advanced function is high-frequency impulse control when using AC welding current to TIG weld aluminum. The challenge with AC current not having polarity that changes between positive and negative is with the wavelength across the center line as it changes from one clarity to the other. At this point, the zero point, the arc will terminate without having the ability of high-frequency built into the machine. High-frequency does one of two things depending on whether you are using it with AC or DC. With AC, as the wavelength passes the center line changing polarity, the capacitors within machine will hold additional power to maintain the arc as it transitions from positive to negative and negative back to positive across that center line. This maintains the arc of AC current at that transitional point. With AC current, high-frequency stays on consistently throughout the weld as it is making this transition many times per second. With DC, we can still use the high-frequency feature. The main difference with DC TIG welding and using the high-frequency feature is that the high-frequency is only there to initiate the arc and once the arc is established for high-frequency function it will terminate. The reason for this is it allows the arc to jump across the gap between the electrode and the work piece without risking touching the electrode to the work piece thus keeping the electrode from sticking to the work piece. If this happens we contaminated the work piece and damage the tip of the tungsten affecting the arc quality. Therefore, use of the high-frequency function with DC TIG welding, allows us to initiate the arc and limit the opportunities for contaminating the work piece and damaging the tungsten. This ensures a high-quality and consistent weld.

The other feature noted in the column of processes is lift arc TIG. Lift arc TIG is a beneficial feature and will have similar benefits to that of the high-frequency DC TIG welding. When this feature is turned on, it allows the tungsten to make physical contact with the work piece connecting the circuit but then it will not give us electrical current until we break contact by lifting away from the work piece. When we first make contact with the work piece with the tungsten electrode, we will receive the free flow of shielding gas. Once we break contact, the electrical current will then flow, initiating the arc. This feature allows for a clean arc initiation and ensures proper shielding by the shielding gas.

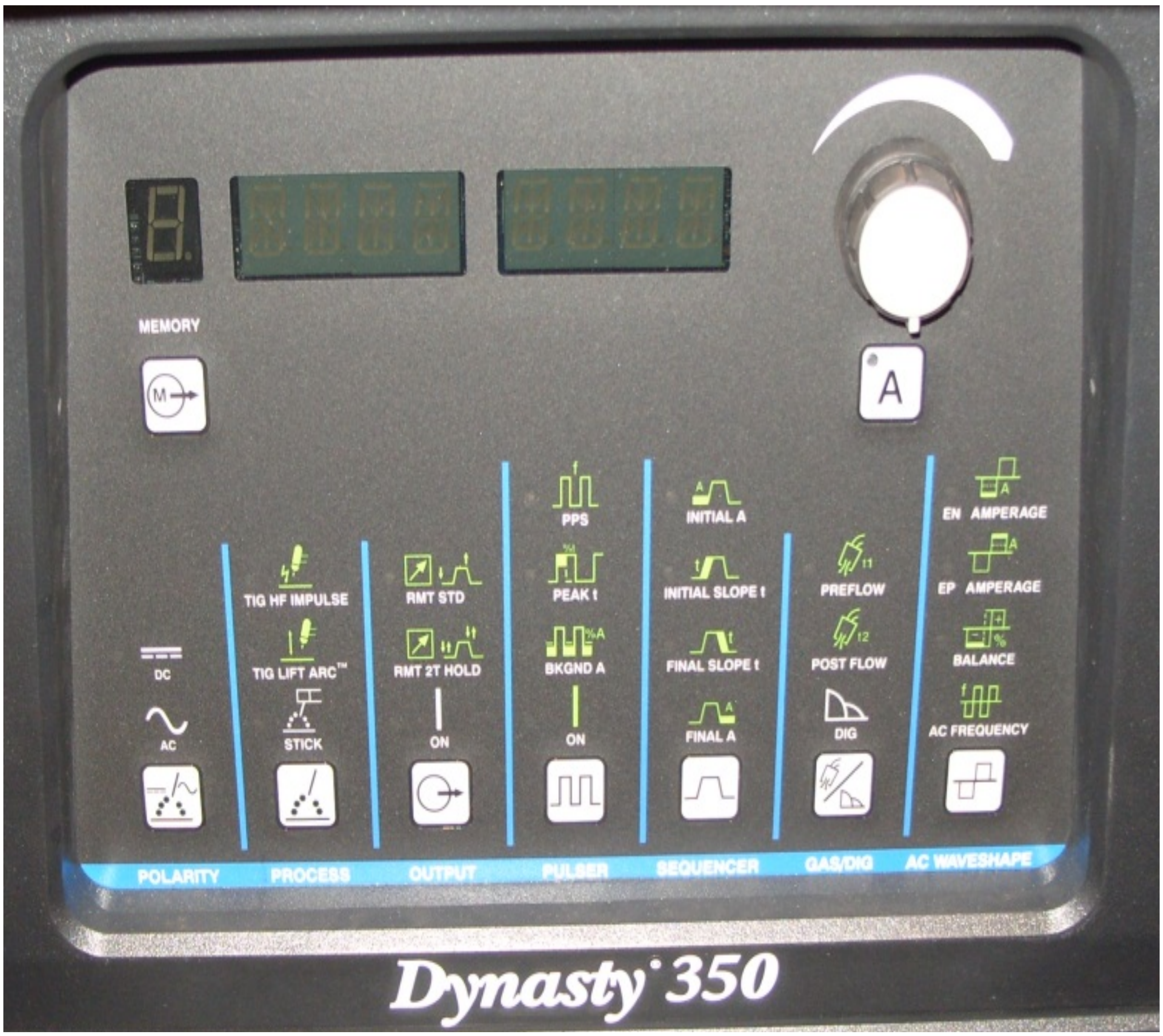


Figure 44. Example of TIG Machine Options, (by Paul Phelps, CC BY 4.0)

The third column from the left, the output option, allows us to select the function of the remote control. The choice is between variable amperage (Remote STD), on-off (remote hold), or constant on.

The next column over, the pulser controls, allows us to pulse a TIG weld as discussed with GMAW/MIG welding. With the pulser controls, we have the PPS or pulses per second, Peak amperage, background amperage, and the option to turn the function on.

In the next column, the sequencer option, we have the ability to alter the waveform to change the effect of the electrical current.

Continuing to move to the right, the next column is the gas controls. The gas controls allow us to control the gas solenoid with **Pre-flow** or **Post-flow**. Pre-flow is the flow of gas prior to the welding arc being established. Pre-flow is normally a half a second to a second prior to initiation of the arc. Pre-flow gives us gas shielding before the arc is initiated to ensure the absence of atmospheric gases and less likelihood of seeing a defect within the weld. With Post flow, we can set the duration of time gas flows after the arc is terminated. Post flow is important to continue shielding gas coverage as the molten weld puddle solidifies. Proper setup of pre-flow and post flow can save money by not wasting expensive shielding gas but providing the required coverage before and after the arc. The DIG function allows us to control the arc intensity at arc initiation mainly when stick welding.

In the far right column, you will see AC wavelength controls. This controls allow us to have very precise control over the alternating current when welding aluminum which leads to a very refined arc and a high-quality weld. The two main functions are balance and frequency. Earlier in this module, we overviewed different welding currents and the distribution of heat with these currents. AC or alternating current, does not have polarity since half of the time it is positive and half of the time it is negative. The **AC Balance control** function allows us to change the percentage of time that the tungsten electrode is carrying the positive charge. By doing this and throwing the AC wavelength out of balance, we gain certain benefits. The benefit from the base metal carrying the negative charge and the electrode carrying an extended positive charge is a cleaning action that removes aluminum oxide from the surface of the base metal.

AC frequency is how many cycles per second take place in the changing of clarity between positive. The **AC Frequency control** is measured by Hertz. AC frequency affects the arc itself by giving it a very tight focused arc or a broad arc. The higher the frequency, the more focused the arc, the deeper the penetration, and the better ability of the arc to push into corners. When working on flat materials, where we are not concerned necessarily about pushing into a corner, a lower frequency is desired to gain a flat weld bead profile. The range of AC frequency will be dependent on the capabilities of the particular welding power source. The machine, in Figure 44, has the ability of reaching 400 Hz where other lower amperage machines may be limited to 200 to 250 Hz.

GTAW TECHNIQUES AND EFFECTS

With TIG welding, we have discussed the different types of tungsten and now we need to discuss how to properly prepare the tungsten for welding. Shaping the working end of the tungsten can be done through a couple different methods. One method is chemical cleaning and pointing of the tungsten. There are products on the market, known as Chem dip, which allows you to dip the working end of the tungsten into the chemical for a designated amount of time and the chemical will form a point on the end of the tungsten. The more common method of shaping tungsten is use of a grinder. There are specially designed grinders for sharpening tungsten. These specialty grinders allow for a consistent angle and smooth preparation of the sharpened end. It is common for a welder to use an angle grinder (Figure 45) or a bench grinder (Figure 46) in preparation of the tungsten electrode. Regardless of the type of equipment used, the shape and angle of the tungsten tip will have an effect on the weld quality.

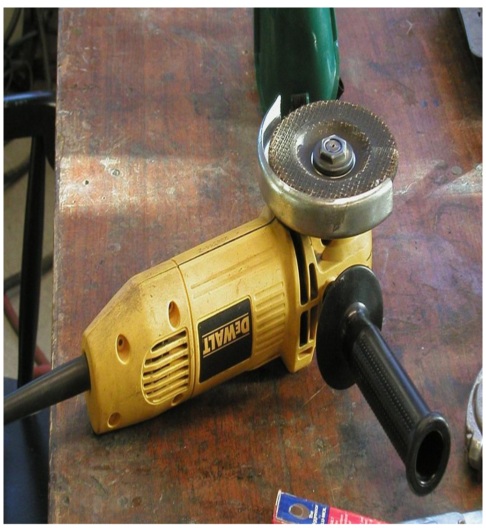


Figure 45. Angle grinder
(by Interiot, CC BY-SA 2.0)

Figure 46. Bench Grinder
(by Mark Simpson, Public Domain)

In Figure 47 below, you will see the characteristics of a properly prepared tungsten tip. The length of taper of the tip is normally two and a half to three times the diameter of the electrode. The grinding marks or grains left from the grinding process need to run the length of the tungsten to the tip and not swirl around the tip.

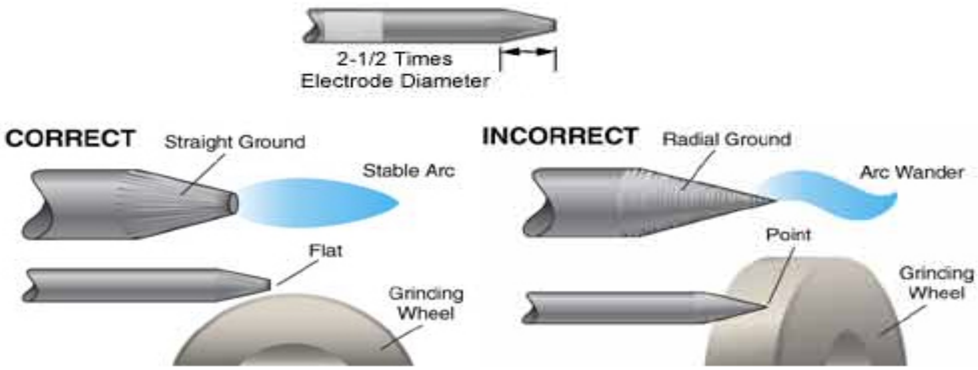


Figure 47. Preparing Tungsten Tips (by Unknown, Public Domain)

The grind marks running to the tip aid in focusing the electrons to a fine centralized point which allow us to produce very clean consistent welds. It is also important to flatten the very end. If we leave a very fine point, there is a risk of the arc force blowing a small piece off of the tip introducing it into the weld creating a defect. By grinding a slight blunt on the end, we remove the opportunities for this defect. The angle of the tungsten electrode tip will affect the weld penetration characteristics. Figure 48, below, depicts the weld penetration affect by different tip angles.

.

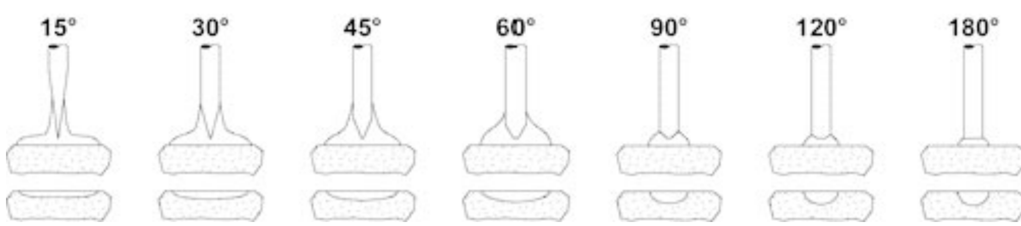


Figure 48. Effects of Different Angle Preparations of the Tungsten to the Weld Penetration Characteristics (by Unknown, Public Domain)

Working with different materials can require a very different preparation. This is mainly true when working with aluminum, using an older transformer type power source. When using this type of power source, it is recommended to use green pure tungsten which has a much lower melting point than the alloyed tungsten. When using pure tungsten to weld aluminum, we must ball the point. To accomplish this, you begin as usual by sharpening the point. Next, you change the machine over to DC electrode positive which focuses extra heat on the tungsten tip, thus melting the tip. As we initiate the arc, a ball will form on the end of the electrode as the tip is melted (Figure 49) . Once the ball has been formed, change back over to AC and weld accordingly with the balled tungsten electrode.

Figure 49. Balled Tungsten Electrode (by Unknown, Public Domain)

MODULE ACTIVITY 9

Choose the correct answer.

1. GTAW is an acronym for gas tungsten area welding. T/F
2. TIG is another name for GTAW. T/F
3. TIG welding is a low level skill process.
4. The electrodes in GTAW are made of
    a. Tin
    b. Titanium
    c. Tetracycline
    d. Tungsten
5. The GTAW process can be complicated because
    a. It is best to use a remote control
    b. It involves using a non-dominant hand
    c. It only welds aluminum
    d. Both a and b
6. TIG torches can air cooled or water-cooled. T/F
7. Gas lenses are found on all TIG torches. T/F
8. Electrodes for the GTAW process have to undergo a special preparation. T/F
9. When using pure tungsten to weld aluminum, the electrode must have a balled end. T/F
10. The ______ (angle, composition) of the tungsten tip effects the weld penetration.

3.2.6 ROBOTIC

Read Chapter 28 in *Welding Principles and Applications,* Larry Jeffus, 7th edition.

Robotics in welding has been used for a number of years. With the advancements in technology, robotics has become more affordable to even the lower end-user. Robotics is a computer-controlled method of using a robotic arm to apply a welding process that would normally be done manually. By using a robotic system, we remove inconsistencies and human error. A robot will do the same thing over and over by following its program. Today, welders must know more than just welding. We must now understand robotics, safety of a robotic environment, precision of components, and fixturing. Robotics require very precise and consistent parts to ensure that the robot goes to the same location and perform the same action time after time. If the parts are not consistent, the weld joint itself may not line up even if the robot was programmed to perform an accurate welding function. As a result, modern manufacturing is required to ensure the consistency of the raw components for the robot to weld accurately.

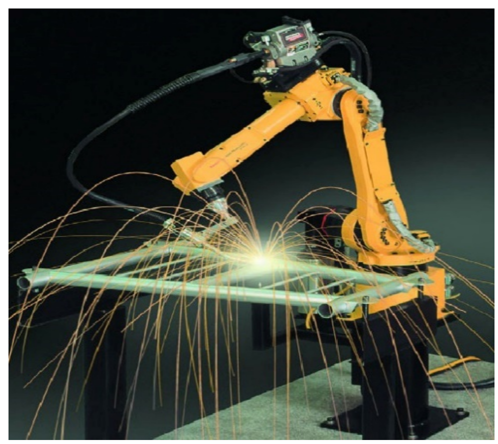


Figure 50. Robotic Welding
(by Orange Indus, CC BY 3.0)

ROBOTIC EQUIPMENT

Robotics are very flexible and can be used for many different applications. The applications are limited only by your imagination about how to use the robotic arm. Manufacturing uses robotics for such things as material handling, glue applicators, welding, spot welding, stud welding, inspection, and many others. The main components for a welding robotic work cell will be the arm, which are comprised of six axis's, the robot controller, a teach pendant or remote control, a physical enclosure with built-in safeties, a work table or positioner, status lighting, emergency stops, welding power source, wire feeder, MIG gun, and cleaning station. As with any type of welding, a variety of safety measures is required.

The main reason for looking towards robotics is quality and rate of work output. Robots are much faster in production compared to manual welding. It is well documented that a robotic work cell will produces much more work which in turns means more profit. We find robotics are a good fit in environments where multiple runs of a given component will be made. There is a large investment of time initially to configure the robot for the application but the investment is recovered by the increase in production. Modern improvements and advancements in technology have made robotics much more economical. As a result they are being more widely accepted and use of them is even spreading to smaller shops and facilities.

ROBOTIC OPTIONS

Welding robots have many software packages available today. The advanced options can include seam tracking. This feature allows the robot to keep track of whether it is in staying aligned with the weld joint by having inspection cameras to verify proper welds and self-adjustment features to correct for worn contact tips and other variables.

3.2.7 ORBITAL

Read pages 125 – 127 in *Welding Principles and Applications,* Larry Jeffus, 7^{th} edition.

Orbital welding is a very precise process used for welding of pipe and tube. There has been a large push in the industry for systems that are capable of making high quality welds quickly and less reliant on a welder's manual ability. Orbital welding is a viable option. Orbital welds are automated systems for TIG welding of a pipe. There are number of different manufacturers of these systems and the systems are costly. Modern systems have the ability to weld very small diameter up to very large ones. Orbital welding is very common in environments where food grade materials are used. On the wall tubing there are specialty heads the clamp onto the tube and are capable of making a high quality full penetrating weld in a single pass. This ability makes producing multiple welds of high-quality very quick.

Orbital welding has been used in heavy industrial applications where human access is limited such as within a nuclear reactor where any significant radioactive exposure cause grave health problems to a person. Teams of welders and technicians will set up a weld system where the welding takes place by remote control and viewing of the video feed outside of the radioactive environment. This allows the work to be done and not risk harm to the welders and technicians. This is very costly because the equipment will be exposed to radiation throughout the process and normally will

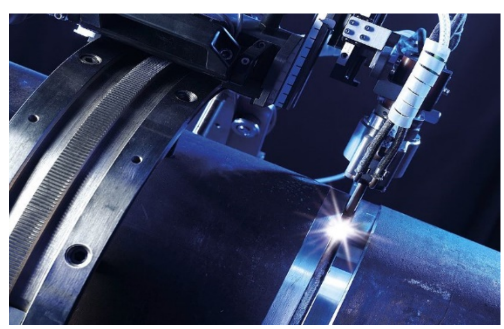


Figure 51. Orbital Welding
(by Polysoude, CC BY-SA 4.0)

be scrapped after the weld is made. This may seem wasteful but in certain instances is the only way to perform the work required.

ORBITAL EQUIPMENT

The equipment for an over the welding system includes the main controller or computer module, the clamp head that mounts to the piper tube to be welded, welding power source, TIG torch, and wire feeder.

MODULE ACTIVITY 10

Choose the correct answer.

1. Robotics has been used in welding for a number of years. T/F
2. The main advantage to using robotics in welding is to reduce inconsistencies and human error.
3. Small businesses use robotics in welding also. T/F
4. Orbital welding has become very useful in the
   a. Medical field
   b. Nuclear field
   c. Landscaping field
   d. Aerospace field

MAJOR CONCEPTS

KEY CONCEPTS

- It is important to understand the different types of welding cutting processes (oxy-fuel, plasma arc, air carbon arc, and arc cutting) as well as the benefits and limitations of each type.
- It is important to understand the different types of welding processes (SMAW, GMAW, FCAW, and GTAW) as well as the benefits and limitations of each type.
- Safety is the most important consideration when cutting or welding.
- The advanced welding processes found in robotic and orbital welding have made welding a viable option in manufacturing high quality products in a much shorter time frame for large factories and small businesses.

KEY TERMS

AC Balance control
AC Frequency control
Active gas
Coupling Distance
Dross
Duty cycle
FCAW
Globular transfer mode
GMAW
Gouging
GTAW
Inert gas
Kerf
Kindling Point
Kindling Temperature
Plasma
Polarity
Pre-flow
Post-flow
Pulse transfer mode
Short-circuiting transfer mode
Slag
SMAW
Spray arc metal transfer mode
Standoff distance
Tungsten
Washing

ASSESSMENT

MODULE REINFORCEMENT

True/False
Indicate whether the statement is true or false.

____ 1. SMAW is a rarely used welding process because of its cost and lack of flexibility.

____ 2. Goggles or other suitable eye protection must be used for flame cutting.

____ 3. A plasma is present in any electrical discharge.

____ 4. A high travel speed with plasma cutting will result in a heat input that is much higher than that of oxy-fuel cutting process.

____ 5. Helium is not considered to be an inert gas.

____ 6. The FCA welding power supply is the same type that is required for GMAW.

____ 7. DCEP has the lowest heat concentration on the electrode tip.

____ 8. As much as 20% of the heat generated by a GTA welding torch does not enter the weld.

____ 9. The shielding gas flow rate should be as high as possible.

____ 10. It is much easier to train a welder to operate the robot than it is to train a computer technician to make good welds.

____ 11. The combination welding and cutting torch offers more flexibility because a cutting head, welding tip, or heating tip can be attached quickly to the same torch body.

Multiple Choice
Identify the choice that best completes the statement or answers the question.

____ 1. Electrons flow through a conductor ____.
a. from negative to positive
b. from positive to negative
c. from negative to negative
d. from positive to positive

____ 2. A 60% duty cycle means that the machine can be used a total of ____ minutes out of every ten minutes at the maximum rated current.
a. two
b. six
c. eight
d. ten

____ 3. ____ contains little or no un-oxidized iron.
a. Soft slag
b. Hard slag
c. Magnesium
d. Zinc

____ 4. The plasma created by an arc ____.
a. is the fluid portion of blood
b. contains an ionized gas
c. is an ionized gas that contains both electrons and positive ions
d. cannot conduct electricity

____ 5. The temperature created when the arc is concentrated to form a plasma is about ____degrees Fahrenheit.
a. 1,000
b. 11,000
c. 43,000
d. 110,000

____ 6. Keeping the diameter of the nozzle orifice ____ will keep the kerf ____.
a. as small as possible, smoother
b. as small as possible, smaller
c. as large as possible, smoother
d. as large as possible, smaller

____ 7. Unlike the oxy-fuel process, the air carbon arc cutting process ____.
a. requires that the base metal be reactive with the cutting stream
b. can only be performed on metals that can be rapidly oxidized by the cutting stream
c. cannot be performed on metals that can be rapidly oxidized by the cutting stream
d. does not require that the base metal be reactive with the cutting stream

____ 8. Which of the following is a difference between an electrode holder and an air carbon arc torch?
a. The lower electrode jaw has a series of air holes.
b. The jaw has more than one electrode-locating groove.

c. The electrode jaw cannot pivot.
d. There is no air valve on the torch lead.

____ 9. In air carbon arc cutting, the air must be aimed ____ the electrode.
a. just under and behind
b. just above and behind
c. just under and ahead of
d. just above and ahead of

____ 10. MAG is short for ____.
a. metal arc gas welding
b. metal active gas welding
c. metal action gas welding
d. metal anion gas welding

____ 11. GMAW power supplies are ____ type machines.
a. constant-current, constant-voltage
b. constant-voltage constant-potential
c. drooping arc voltage, constant-current
d. constant-current, constant-potential

____ 12. Which of the following is true of backhand welding?
a. It has good joint visibility and makes welds with less joint penetration.
b. It works well on vertical up and overhead welds.
c. It has good bead visibility and makes welds with deeper joint penetration.
d. It has a good balance between penetration and reinforcement and is used on automated welding.

____ 13. The correct flow rate of a shielding gas can be set by ____.
a. checking the pressure of the gas
b. multiplying the nozzle size by the amperage
c. checking welding guides
d. checking the density of the gas

____ 14. Which of the following is true of FCAW?
a. When bevels are cut, the joint-included angle must be larger than 35 percent.
b. The addition of deoxidizers eliminates most of the precleaning required.
c. Welds cannot be made on plates with mill scale.
d. Edge-beveling preparation is required on all joints up to 1/2 inch.

____ 15. When the electrode provides all of the shielding, it is called ____.
a. protective
b. rutile
c. a shielding gas
d. Self-shielding

____ 16. Which of the following is true of DCEP?
a. With DCEP, the preferred electrode tip is pointed.
b. Because DCEP does not put much heat on the tip, it is relatively cool.
c. DCEP has the highest heat concentration on the electrode tip.
d. With DCEP, the point of the electrode tip is stable.

____ 17. DCEN concentrates about ____ of its welding heat on the work, and about ____ on the tungsten.
a. 1/3, 2/3
b. 1/4, 3/4
c. 1/2, 1/2
d. 2/3, 1/3

____ 18. AC concentrates about ____ of its welding heat on the work and ____ on the tungsten.
a. 1/3, 2/3
b. 1/4, 3/4
c. 1/2, 1/2
d. 2/3, 1/3

____ 19. Exceeding the maximum gas flow rates ____.
a. saves time and reduces the cost
b. decreases weld contamination
c. causes weld contamination
d. decreases rejection rate

Short Answer

1. Give an overview of the shielded metal arc welding process.

DISCUSSION PROMPTS

1. Discuss the common safety concerns in welding.

CRITICAL THINKING

1. Compare and contrast SMAW and GTAW using the table below.

	SMAW	GTAW
Define or explain each concept		
Explain how the concepts are similar		
Explain how each concept is different with respect to specific attributes		

ANSWER KEY FOR MODULE ACTIVITIES

ACTIVITY 1

1. a
2. T
3. T
4. F
5. T
6. F
7. b
8. d
9. F
10. Soft slag
11. c

ACTIVITY 2

1. T
2. T
3. T
4. Dross
5. F

ACTIVITY 3

1. F
2. T
3. b
4. d
5. T
6. a

ACTIVITY 4

1. T
2. d
3. F
4. T
5. T

ACTIVITY 5

1. T
2. F
3. T

ACTIVITY 6

1. T
2. Stick
3. T
4. F
5. d
6. T
7. F
8. T
9. c
10. Duty cycle

ACTIVITY 7

1. T
2. b
3. T
4. c
5. c
6. T
7. F
8. d
9. 4

10. d
11. T
12. d

ACTIVITY 8

1. T
2. T
3. c
4. T
5. T
6. d

ACTIVITY 9

1. F
2. T
3. F
4. d
5. d
6. T
7. F
8. T
9. T
10. angle

ACTIVITY 10

1. T
2. T
3. T
4. b

MODULE REINFORCEMENT ANSWER KEY

TRUE/FALSE **(textbook page reference)**

1.	ANS:	F	REF: 55
2.	ANS:	T	REF: 162
3.	ANS:	T	REF: 192
4.	ANS:	F	REF: 197
5.	ANS:	F	REF: 249
6.	ANS:	T	REF: 299
7.	ANS:	F	REF: 375
8.	ANS:	F	REF: 380
9.	ANS:	F	REF: 388
10.	ANS:	T	REF: 711
11.	ANS:	T	REF: 763

MULTIPLE CHOICE

1.	ANS:	A	REF: 55
2.	ANS:	B	REF: 66
3.	ANS:	A	REF: 178
4.	ANS:	C	REF: 192
5.	ANS:	C	REF: 192
6.	ANS:	B	REF: 200
7.	ANS:	D	REF: 219
8.	ANS:	A	REF: 220
9.	ANS:	A	REF: 220
10.	ANS:	B	REF: 235
11.	ANS:	B	REF: 245
12.	ANS:	C	REF: 251
13.	ANS:	C	REF: 268
14.	ANS:	B	REF: 300-301
15.	ANS:	D	REF: 308
16.	ANS:	C	REF: 375
17.	ANS:	D	REF: 384
18.	ANS:	C	REF: 385
19.	ANS:	C	REF: 403

SHORT ANSWER

1. ANS:
Shielded metal arc welding (SMAW) is a welding process that uses a flux-covered metal electrode to carry an electrical current. The current forms an arc across the gap between the end of the electrode and the work. The electric arc creates sufficient heat to melt both the electrode and the work. Molten metal from the electrode travels across the arc to the molten pool on the base metal, where they mix together. The end of the electrode and molten pool of metal is surrounded, purified, and protected by a gaseous cloud and a covering of molten flux produced as the flux coating of the electrode burns or vaporizes. As the arc moves away, the mixture of molten electrode and base metal solidifies and becomes one piece. At the same time, the molten flux solidifies forming a solid slag. Some electrode types produce heavier slag coverings than others.

REF: 55

ATTRIBUTION TABLE

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Benrunge	Figure 11. Single U Groove	http://en.wikipedia.org/wiki/Welding_joint#mediaviewer/File:Butt_Weld_Geometry.png	CC BY-SA 4.0
Moya034	Figure 12. Air Carbon Electrodes and Electrode Holders	http://www.alloyavenue.com/vb/showthread.php?4221-Air-Carbon-Arc-Cutting-amp-Gouging-HOWTO	Public Domain
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