I. The GTAW (TIG) Process

The necessary heat for Gas Tungsten Arc Welding (TIG) is produced by an electric arc maintained between a nonconsumable tungsten electrode and the part to be welded. The heat-affected zone, the molten metal, and the tungsten electrode are all shielded from the atmosphere by a blanket of inert gas fed through the GTAW torch. Inert gas is that which is inactive, or deficient in active chemical properties. The shielding gas serves to blanket the weld and exclude the active properties in the surrounding air. It does not burn, and adds nothing to or takes anything from the metal. Inert gases such as argon and helium do not chemically react or combine with other gases. They possess no odor and are transparent, permitting the welder maximum visibility of the arc. In some instances a small amount of reactive gas such as hydrogen can be added to enhance travel speeds.

The GTAW process can produce temperatures of up to 35,000° F/19,426° C. The torch contributes only heat to the workpiece. If filler metal is required to make the weld, it may be added manually in the same manner as it is added in the oxyacetylene welding process. There are also a number of filler metal feeding systems available to accomplish the task automatically. Figure 1.1 shows the essentials of the manual GTAW process.

Advantages of the GTAW Process

The greatest advantage of the GTAW process is that it will weld more kinds of metals and metal alloys than any other arc welding process. TIG can be used to weld most steels including stainless steel, nickel alloys such as Monel® and Inconel®, titanium, aluminum, magnesium, copper, brass, bronze, and even gold. GTAW can also weld dissimilar metals to one another such as copper to brass and stainless to mild steel.

Concentrated Arc

The concentrated nature of the GTAW arc permits pin point control of heat input to the workpiece resulting in a narrow heat-affected zone. A high concentration of heat is an advantage when welding metals with high heat conductivity such as aluminum and copper. A narrow heat-affected zone is an advantage because this is where the base metal has undergone a change due to the superheating of the arc and fast cooling rate. The heat-affected zone is where the welded joint is weakest and is the area along the edge of a properly made weld that would be expected to break under a destructive test.

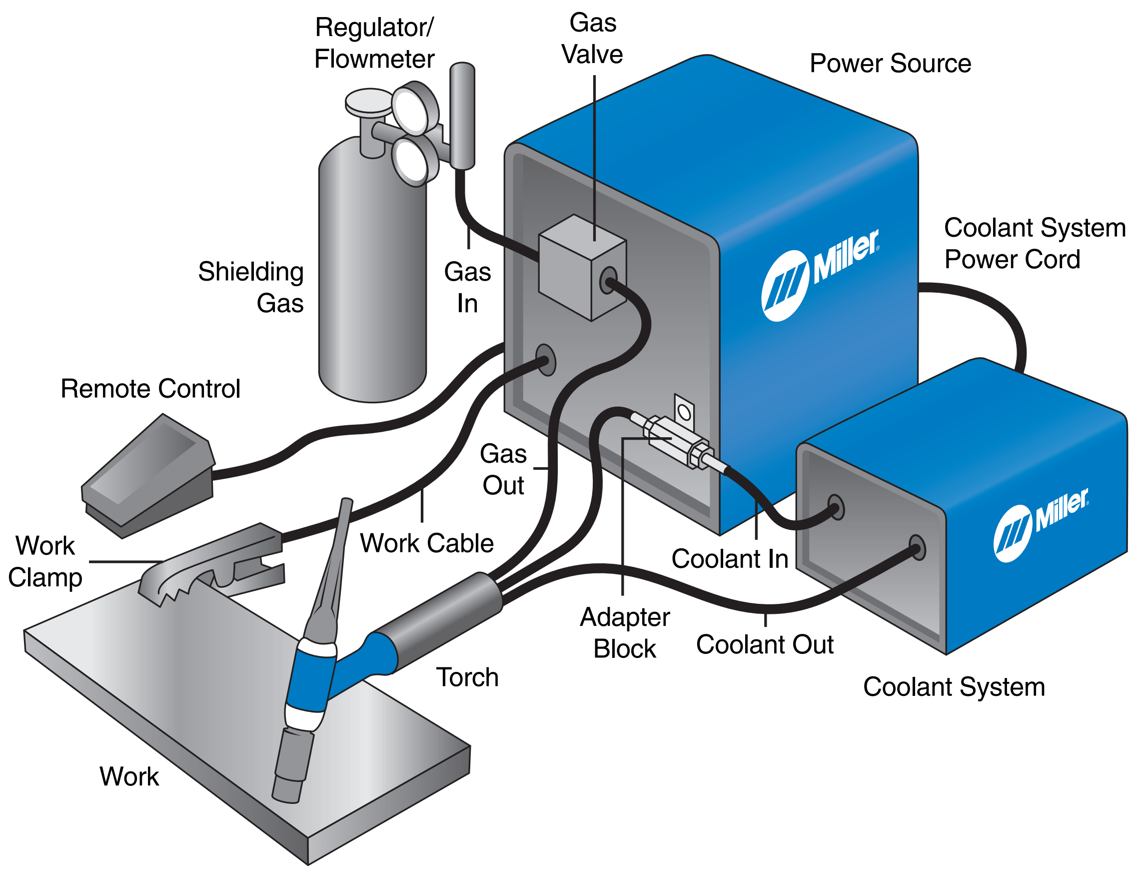


Figure 1.1 Essentials of the GTAW process (water cooled).

No Slag

There is no requirement for flux with this process; therefore, there is no slag to obscure the welder's vision of the molten weld pool. The finished weld will not have slag to remove between passes. Entrapment of slag in multiple pass welds is seldom seen. On occasion with materials like Inconel® this may present a concern.

No Sparks or Spatter

In the GTAW process there is no transfer of metal across the arc. There are no molten globules of spatter to contend with and no sparks produced if the material being welded is free of contaminants. Also under normal conditions the GTAW arc is quiet without the usual cracks, pops, and buzzing of Shielded Metal Arc Welding (SMAW or Stick) and Gas Metal Arc Welding (GMAW or MIG). Generally, the only time noise will be a factor is when a pulsed arc, or AC welding mode is being used.

No Smoke or Fumes

The process itself does not produce smoke or injurious fumes. If the base metal contains coatings or elements such as lead, zinc, nickel or copper that produce fumes, these must be contended with as in any fusion welding process on these materials. If the base metal contains oil, grease, paint or other contaminants, smoke and fumes will definitely be produced as the heat of the arc burns them away. The base material should be cleaned to make the conditions most desirable.

GTAW Disadvantages

The main disadvantage of the GTAW process is the low filler metal deposition rate. Another disadvantage is that the hand-eye coordination necessary to accomplish the weld is difficult to learn, and requires a great deal of practice to become proficient. The arc rays produced by the process tend to be brighter than those produced by SMAW and GMAW. This is primarily due to the absence of visible fumes and smoke. The increased amounts of ultraviolet rays from the arc also cause the formation of ozone and nitrous oxides. Care should be taken to protect skin with the proper clothing and protect eyes with the correct shade lens in the welding hood. When welding in confined areas, concentrations of shielding gas may build up and displace oxygen. Make sure that these areas are ventilated properly.

Process Summary

GTAW is a clean process. It is desirable from an operator point of view because of the reasons outlined. The welder must maintain good welding conditions by properly cleaning material, using clean filler metal and clean welding gloves, and by keeping oil, dirt and other contaminants away from the weld area. Cleanliness cannot be overemphasized, particularly on aluminum and magnesium. These metals are more susceptible to contaminants than are ferrous metals. Porosity in aluminum welds has been shown to be caused by hydrogen. Consequently, it is most important to eliminate all sources of hydrogen contamination such as moisture and hydrocarbons in the form of oils and paint.

II. GTAW Fundamentals

If you've ever had the experience of hooking up a car battery backwards, you were no doubt surprised at the amount of sparks and heat that can be generated by a 12 volt battery. In actual fact, a GTAW torch could be hooked directly to a battery and be used for welding.

When welding was first discovered in the early 1880s it was done with batteries. (Some batteries used in early welding experiments reached room size proportions.) The first welding machine, seen in Figure 2.1, was developed by N. Benardos and S. Olszewski of Great Britain and was issued a British patent in 1885. It used a carbon electrode and was powered by batteries, which were in turn charged with a dynamo, a machine that produces electric current by mechanical means.

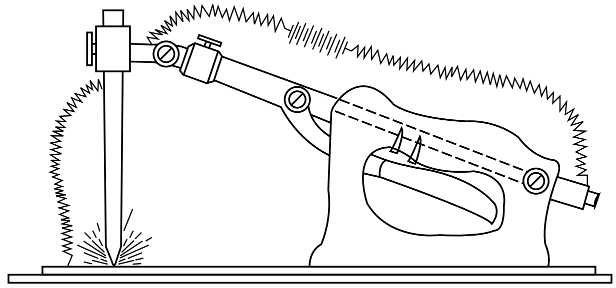


Figure 2.1 Original carbon electrode welding apparatus — 1885.

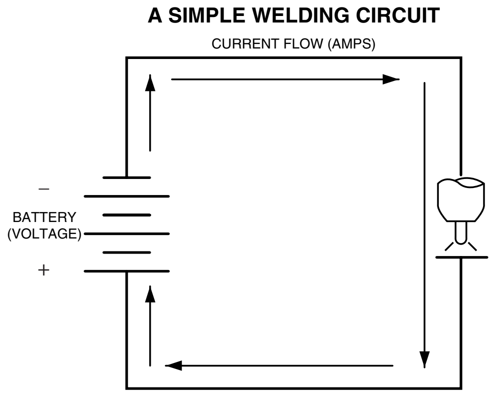


Figure 2.2 A simple welding circuit showing voltage source and current flow.

Figure 2.2 shows what a welding circuit using a battery as a power source would look like.

The two most basic parameters we deal with in welding are the amount of current in the circuit, and the amount of voltage pushing it. Current and voltage are further defined as follows:

Current — The number of electrons flowing past a given point in one second. Measured in amperes (amps).

Voltage — The amount of pressure induced in the circuit to produce current flow. Measured in voltage (volts).

Resistance in the welding circuit is represented mostly by the welding arc and to a lesser extent by the natural resistance of the cables, connections, and other internal components.

Chapters could be written on the theory of current flow in an electrical circuit, but for the sake of simplicity just remember that current flow is from negative to positive. Early researchers were surprised at the results obtained when the battery leads were switched. We'll examine these differences in more detail later in the section when we discuss welding with alternating current.

Even after alternating current (AC) became available for welding with the use of transformer power sources, welds produced were more difficult to accomplish and of lesser quality than those produced with direct current (DC). Although these AC transformer power sources greatly expanded the use of commercial power for SMAW (Stick), they could not be used for GTAW because as the current approached the zero value, the arc would go out. (see Figure 2.4). Motor generators followed quickly. These were machines that consisted of an AC motor, that turned a generator, that produced DC for welding. The output of these machines could be used for both SMAW and GTAW.

It was with a motor generator power source that GTAW was first accomplished in 1942 by V.H. Pavlecka and Russ Meredith while working for the Northrup Aviation Company. Pavlecka and Meredith were searching for a means to join magnesium, aluminum and nickel, which were coming into use in the military aircraft of that era.

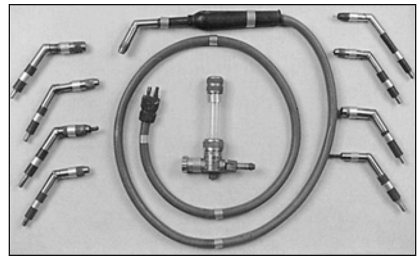


Figure 2.3 The original torch and some of the tips used by Pavlecka and Meredith to produce the first GTAW welds in 1942. *Note the torch still holds one of the original tungstens used in those experiments.*

Although the selenium rectifier had been around for some time, it was the early 1950s when rectifiers capable of handling current levels found in the welding circuit came about. The selenium rectifier had a profound effect on the welding industry. It allowed AC transformer power sources to produce DC. And it meant that an AC power source could now be used for GTAW welding as well as Stick welding.

The realization is that high frequency added to the weld circuit would make AC power usable for TIG welding. The addition of this voltage to the circuit keeps the arc established as the weld power passes through zero. Thus stabilizing the GTAW arc, it also aids in arc starting without the risk of contamination. The later addition of remote current control, remote contactor control, and gas solenoid control devices evolved into the modern GTAW power source. Further advances such as Squarewave, and Advanced Squarewave power sources have further refined the capabilities of this already versatile process.

Alternating Current

Alternating current (AC) is an electrical current that has both positive and negative half-cycles. These components do not occur simultaneously, but alternately, thus the term alternating current. Current flows in one direction during one half of the cycle and reverses direction for the other half cycle. The half cycles are called the positive half and the negative half of the complete AC cycle.

Frequency

The rate at which alternating current makes a complete cycle of reversals is termed frequency. Electrical power in the United States is delivered as 60 cycles per second frequency, or to use its proper term 60 hertz (Hz). This means there are 120 reversals of current flow directions per second. The power input to an AC welding machine and other electrical equipment in the United States today is 60 Hz power. Outside of North America and the United States, 50 Hz power is more commonly used. As this frequency goes up, the magnetic effects accelerate and become more efficient for use in transformers, motors and other electrical devices. This is the fundamental principal on how an "inverter power source works". Frequency has major effect on welding arc performance. As frequencies go up, the arc gets more stable, narrows, and becomes stiffer and more directional. Figure 2.4 represents some various frequencies.

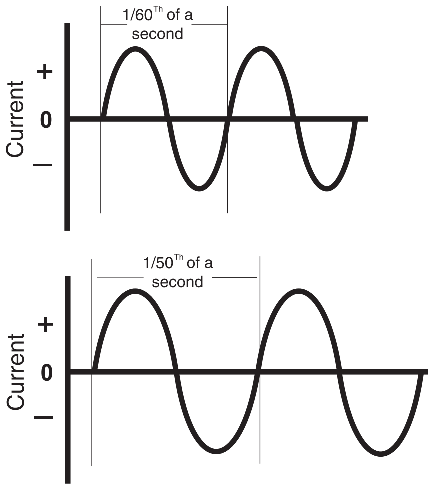


Figure 2.4 An oscilloscope representation of normal 50 and 60 Hz in relation to increased frequency rate.

The AC Sine Wave

In some of the following sections we will be seeing alternating current waveforms which represent the current flow in a circuit. The drawing in the first part of Figure 2.5 is what would be seen on an oscilloscope connected to a wall receptacle and shows the AC waveform known as a sine wave. The other two types of waveforms that will be discussed are Squarewave and Advanced Squarewave. Figure 2.5 shows a comparison of these three waveforms. These waveforms represent the current flow as it builds in amount and time in the positive direction and then decreases in value and finally reaches zero. Then current changes direction and polarity reaching a maximum negative value before rising to the zero value. This "hill" (positive half) and "valley" (negative half) together represent one cycle of alternating current. This is true no matter what the waveform is. Note however, the amount of time at each half cycle is not adjustable on the sine wave power sources. Also notice the reduced current high points with either of Squarewave type power sources.

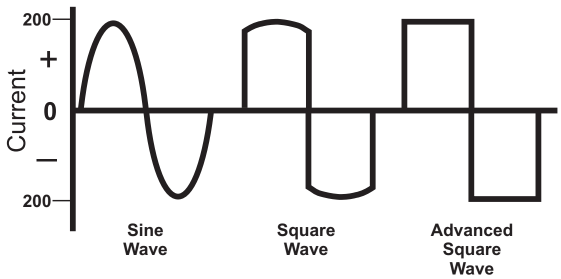


Figure 2.5 Comparison of the three different AC waveforms all representing a time balanced condition and operating at 200 amperes.

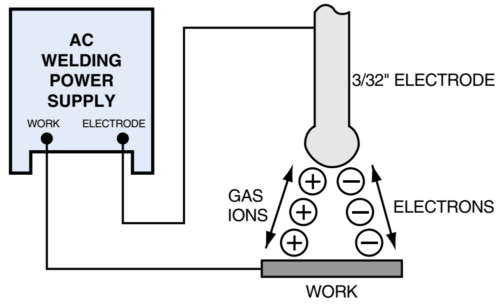


Figure 2.6 AC welding machine connection.

Squarewave AC

Some GTAW power sources, due to refinements of electronics, have the ability to rapidly make the transition between the positive and negative half cycles of alternating current. It is obvious that when welding with AC, the faster you could transition between the two polarities (EN and EP), and the more time you spent at their maximum values, the more effective the machine could be. Electronic circuitry makes it possible to make this transition almost instantaneously. Plus the effective use of the energy stored in magnetic fields results in waveforms that are relatively square. They are not truly square due to electrical inefficiencies in the Squarewave power source. However, the Advanced Squarewave GTAW power source has improved efficiencies and can produce a nearly square wave as compared in Figure 2.5.

Advanced Squarewave

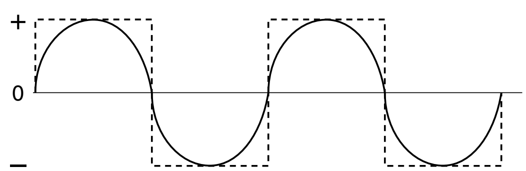


Figure 2.7 Advanced Squarewave superimposed over a sine wave.

Advanced Squarewave allows additional control over the alternating current waveforms. Figure 2.7 shows an AC sine wave and an Advanced Squarewave superimposed over it. Squarewave machines allow us to change the amount of time within each cycle that the machine is outputting electrode positive or electrode negative current flow. This is known as balance control. They also reduce arc rectification and resultant tungsten spitting. With Advanced Squarewave technology, AC power sources incorporate fast switching electronics capable of switching current up to 50,000 times per second, thus allowing the inverter type power source to be much more responsive to the needs of the welding arc. These electronic switches allow for the switching of the direction the output welding current will be traveling. The output frequency of Squarewave or sine wave power sources is limited to 60 cycles per second, the same as the input power from the power company. With this technology and advancements in design, the positive and negative amplitude of the waveform can be controlled independently as well as the ability to change the number of cycles per second. Alternating current is made up of direct current electrode negative (DCEN) and direct current electrode positive (DCEP). To better understand all the implications this has on AC TIG welding, let's take a closer look at DCEN and DCEP.

Direct Current

Direct current (DC) is an electrical current that flows in one direction only. Direct current can be compared to water flowing through a pipe in one direction. Most welding power sources are capable of welding with direct current output. They accomplish this with internal circuitry that changes or rectifies the AC into DC.

Figure 2.8 shows what one cycle of AC sine wave power would look like and what it would look like after it has been rectified into DC power.

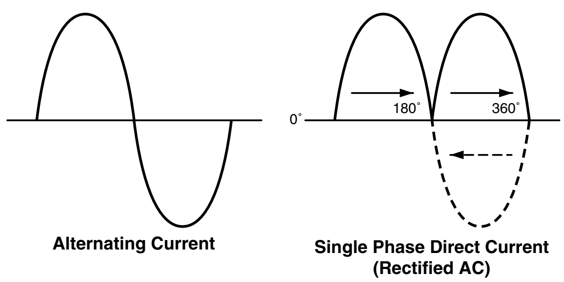


Figure 2.8 Single-phase AC — single-phase direct current (rectified AC).

Polarity

Earlier in this section it was stated how the earliest welders used batteries for their welding power sources. These early welders found there were profound differences in the welding arc and the resulting weld beads when they changed the battery connections. This polarity is best described by what electrical charge the electrode is connected for, such as direct current electrode negative (DCEN) or direct current electrode positive (DCEP). The workpiece would obviously be connected to the opposite electrical charge in order to complete the circuit. Review Figure 2.2.

When GTAW welding, the welder has three choices of welding current type and polarity. They are: direct current electrode negative, direct current electrode positive and alternating current. Alternating current, as we are beginning to understand, is actually a combination of both electrode negative and electrode positive polarity. Each of these current types has its applications, its advantages, and its disadvantages. A look at each type and its uses will help the welder select the best current type for the job. Figures 2.9 and 2.11 illustrate power supply connections for each current type in a typical 100 amp circuit.

Direct Current Electrode Negative (Nonstandard Term is Straight Polarity)

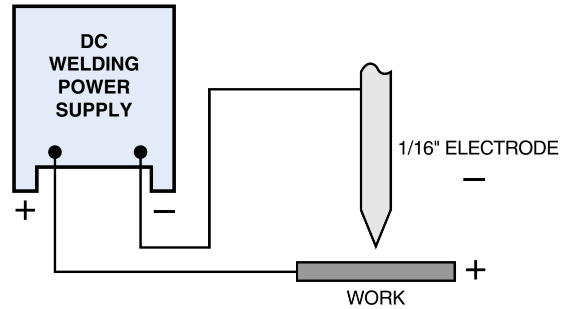


Figure 2.9 Direct current electrode negative.

Direct current electrode negative is used for TIG welding of practically all metals. The torch is connected to the negative terminal of the power source and the work lead is connected to the positive terminal. Power sources with polarity switches will have the output terminals marked electrode and work. Internally, when the polarity switch is set for DCEN, this will be the connection. When the arc is established, electron flow is from the negative electrode to the positive workpiece. In a DCEN arc, approximately 70% of the heat will be concentrated at the positive side of the arc and the greatest amount of heat is distributed into the workpiece. This accounts for the deep penetration obtained when using DCEN for GTAW. The electrode receives a smaller portion of the heat energy and will operate at a lower temperature than when using alternating current or direct current electrode positive polarity. This accounts for the higher current carrying capacity of a given size tungsten electrode with DCEN than with DCEP or AC. At the same time the electrons are striking the work, the positively charged gas ions are attracted toward the negative electrode.

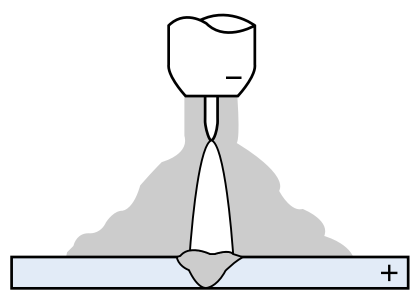


Figure 2.10 GTAW with DCEN produces deep penetration because it concentrates the heat in the joint area. No cleaning action occurs with this polarity. The heat generated by the arc using this polarity occurs in the workpiece, thus a smaller electrode can be used as well as a smaller gas cup and reduced gas flow. The more concentrated arc allows for faster travel speeds.

Direct Current Electrode Positive
(Nonstandard Term is Reverse Polarity)

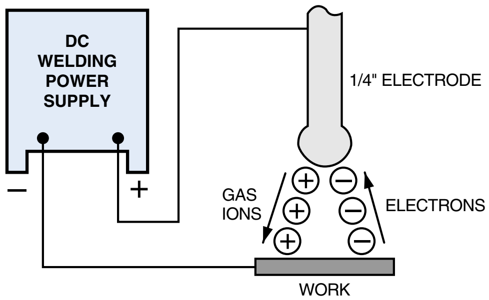


Figure 2.11 Direct current electrode positive.

When welding with direct current electrode positive (DCEP), the torch is connected to the positive terminal on the welding power source and the ground or work lead is connected to the negative terminal. Power sources with polarity switches will have the output terminals marked electrode and work. Internally, when the polarity switch is set for DCEP, this will be the connection. When using this polarity, the electron flow is still from negative to positive, however the electrode is now the positive side of the arc and the work is the negative side. The electrons are now leaving the work. Approximately 70% of the heat will be concentrated at the positive side of the arc; therefore, the greatest amount of heat is distributed into the electrode. Since the electrode receives the greatest amount of heat and becomes very hot, the electrode must be very large even when low amperages are used, to prevent overheating and possible melting. The workpiece receives a smaller amount of the total heat resulting in shallow penetration. Another disadvantage of this polarity is that due to magnetic forces the arc will sometimes wander from side to side when making a fillet weld when two pieces of metal are at a close angle to one another. This phenomena is similar to what is known as arc blow and can occur in DCEN, but DCEP polarity is more susceptible.

At this point, one might wonder how this polarity could be of any use in GTAW. The answer lies in the fact that some non-ferrous metals, such as aluminum and magnesium, quickly form an oxide coating when exposed to the atmosphere. This material is formed in the same way rust accumulates on iron. It's a result of the interaction of the material with oxygen. The oxide that forms on aluminum, however, is one of the hardest materials known to man. Before aluminum can be welded, this oxide, because it has a much higher melting point than the base metal, must be removed. The oxide can be removed by mechanical means like wire brushing or with a chemical cleaner, but as soon as the cleaning is stopped the oxides begin forming again. It is advantageous to have cleaning done continuously while the welding is being done.

The oxide can be removed by the welding arc during the welding process when direct current electrode positive is used. The positively charged gas ions which were flowing from the workpiece to the tungsten when welding with DCEN are now flowing from the tungsten to the negative workpiece with DCEP. They strike the workpiece with sufficient force to break up and chip away the brittle aluminum oxide, and provide what is called a cleaning action. Because of this beneficial oxide removal, this polarity would seem to be excellent for welding aluminum and magnesium. There are, however, some disadvantages.

For example, to weld at 100 amperes it would take a tungsten 1/4" in diameter. This large electrode would naturally produce a wide pool resulting in the heat being widely spread over the joint area. Because most of the heat is now being generated at the electrode rather than the workpiece, the resulting penetration would probably prove to be insufficient. If DCEN were being used at 100 amperes, a tungsten electrode of 1/16" would be sufficient. This smaller electrode would also concentrate the heat into a smaller area resulting in satisfactory penetration.

The good penetration of electrode negative plus the cleaning action of electrode positive would seem to be the best combination for welding aluminum. To obtain the advantages of both polarities, alternating current can be used.

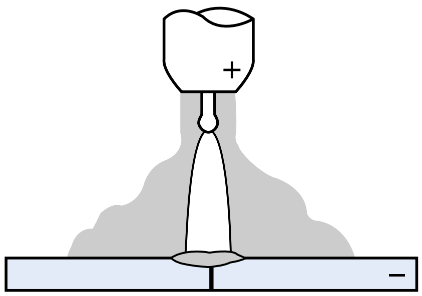


Figure 2.12 GTAW with DCEP produces good cleaning action as the argon gas ions flowing toward the work strike with sufficient force to break up oxides on the surface. Since the electrons flowing toward the electrode cause a heating effect at the electrode, weld penetration is shallow. Because of the lack of penetration and the required use of very large tungsten, continuous use of this polarity is rarely used for GTAW.

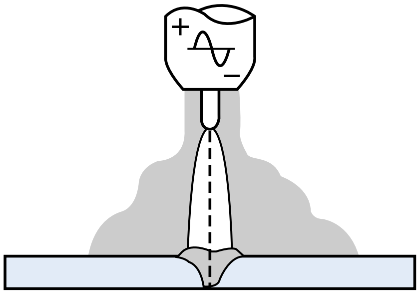


Figure 2.13 GTAW with AC combines the good weld penetration of DCEN with the desired cleaning action of DCEP. With certain types of AC waveforms high frequency helps re-establish the arc, which breaks each half cycle. Medium size tungstens are generally used with this process.

Welding with Alternating Current

When using alternating current sine waves for welding, the terms electrode positive (reverse polarity) and electrode negative (straight polarity) which were applied to the work-piece and electrode lose their significance. There is no control over the half cycles and you have to use what the power source provides. The current is now alternating or changing its direction of flow at a predetermined set frequency and with no control over time or independent amplitude. During a complete cycle of alternating current, there is theoretically one half cycle of electrode negative and one half cycle of electrode positive. Therefore, during a cycle there is a time when the work is positive and the electrode is negative. And there's a time when the work is negative and the electrode is positive. In theory, the half cycles of alternating current sine wave arc are of equal time and magnitude as seen in Figure 2.14.

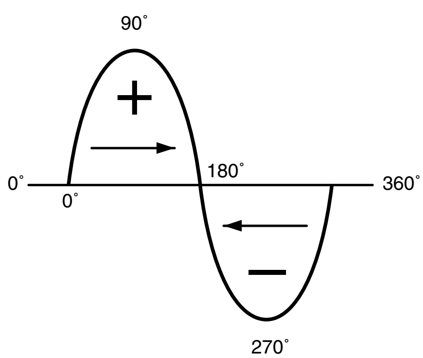


Figure 2.14 One complete cycle of AC sine wave showing reversal of current flow that occurs between the positive and negative half cycles. The degree symbol represents the electrical degrees. The arc goes out at 0˚, 180˚ and 360˚ and maximum amplitude is at 90˚ and 270˚.

Arc Rectification

When GTAW welding with alternating current, we find that the equal half cycle theory is not exactly true. An oscilloscope Figure 2.15 will show that the electrode positive half cycle is of much less magnitude than the electrode negative half cycle. There are two theories accounting for this. One is the oxide coating on nonferrous metals such as aluminum. The surface oxide acts as a rectifier, making it much more difficult for the electrons to flow from the work to the electrode, than from the electrode to the work. The other theory is that molten, hot, clean aluminum does not emit electrons as easily as hot tungsten. This results in more current being allowed to flow from the hot tungsten to the clean molten weld pool, with less current being allowed to flow from the clean molten weld pool to the electrode. This is referred to as "arc rectification" and must be understood and limited by the welder as indicated in Figure 2.16.

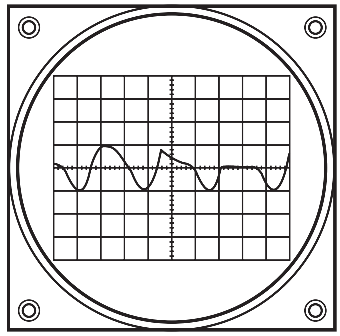


Figure 2.15 A reproduction of an actual unbalanced AC sine wave. *Note the positive half cycle is "clipped off". The missing portion was lost due to rectification of the arc. What can also be seen is a high current spike which can lead to tungsten breakdown and tungsten spitting.*

Arc Rectification

Indicators for the Welder	Results	Cures*
Arc noise	Tungsten inclusions	Don't dwell in the weld pool
Weld pool oscillation	Erratic arc	Add filler metal
Tungsten electrode breakdown	Lack of cleaning action	Keep arc moving along weld joint

*Power source of proper Advanced Squarewave design will eliminate this phenomenon.

Figure 2.16 Arc rectification.

Balanced and Unbalanced Waveforms

Squarewave AC power sources have front panel controls which allow the welder to alter the length of time the machine spends in either the electrode positive (cleaning) portion of the half cycle or electrode negative (penetration) portion of the half cycle. Machines of this type are very common for TIG welding in industry today. Very few industrial GTAW AC sine wave power sources are being produced today.

Waveform Balance Control

	% Time Electrode Negative*	% Time Electrode Positive
AC sine wave power source	Not applicable, control not available	Not applicable, control not available
Squarewave	45 – 68	32 – 55
Advanced Squarewave	10 – 90**	10 – 90

*This time controls the penetration and is most advantageous. Set to as high a percentage as possible without losing the cleaning. Very rare to set below 50%.

**Note the expanded electrode negative time available on the Advanced Squarewave machine.

Figure 2.17 Balance control time available from different types of machines.

Balance Wave Control Advantages

Max Penetration is when the balance control is set to produce the maximum time at electrode negative and minimum time at electrode positive.

- Can use higher currents with smaller electrodes
- Increased penetration at a given amperage and travel speed
- Use of smaller gas cup and reduced shielding gas flow rate
- Reduced heat input with resultant smaller heat affected zone and less distortion

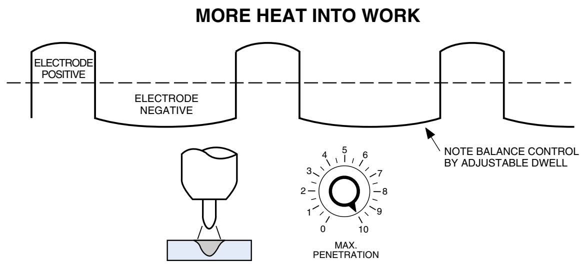


Figure 2.18 Maximum penetration balance control setting. The waveform has been set to an unbalanced condition, this allows more time in the negative half cycle where current flow is from the electrode to the work. (This produces more heat into the work and consequently deeper penetration.)

Balanced is when the balance control is set to produce equal amounts of time electrode negative and electrode positive. Thus on 60 Hz power, 1/120th of a second is spent electrode negative (penetration) heating the plate and 1/120th of a second is spent electrode positive (cleaning) removing oxides.

- Arc cleaning action is increased

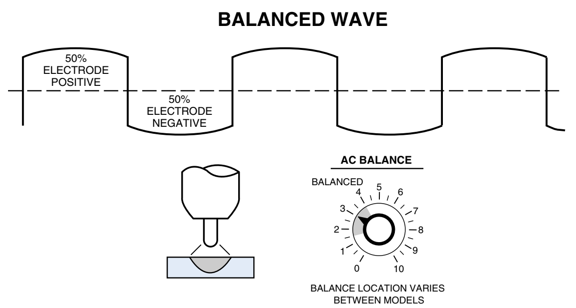


Figure 2.19 Balanced control setting. The waveform has been set to balanced. This allows equal time on each of the half cycles. *Note on this example balance occurs at a setting of 3 rather than at 5 as you might expect.* Other machines have digital read out that displays the exact % of time set. Whatever the method of setting, a plateau is reached where additional time in the positive half cycle is unproductive and will result in damage to the tungsten or torch. Therefore, most Squarewave machines will not permit settings that might cause damage to be made on the AC balance control.

Max Cleaning is when the balance control is set to produce the maximum time at electrode positive and minimum time at electrode negative.

- The most aggressive arc cleaning action is produced

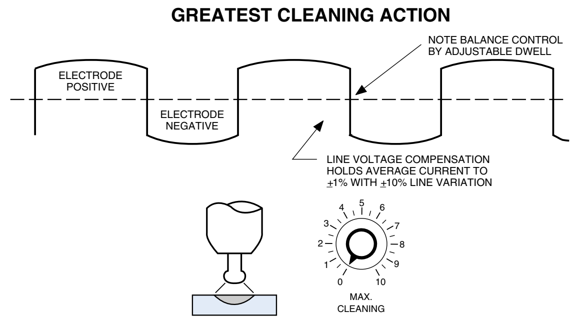


Figure 2.20 Maximum cleaning control setting. The waveform has been set to an unbalanced condition; this allows more time in the positive half-cycle where positive gas ions can bombard the work. Only a certain amount of total cleaning action is available, and increasing the time in the electrode positive half cycle will not provide more cleaning and may melt the tungsten, and damage the torch.

The benefits of the balance control should be well understood and applied in an appropriate manner. Figure 2.21 shows actual welds made at a given current and given travel speed with only the balance control being changed.

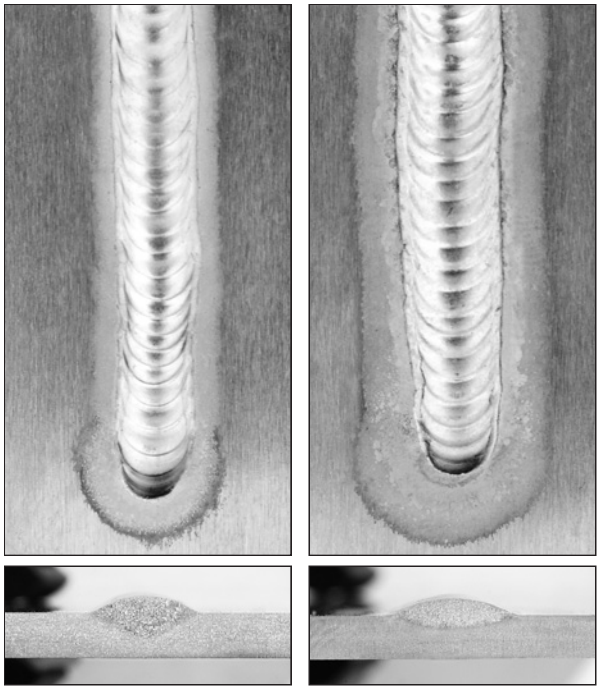


Figure 2.21 Note the variation in the cleaning band, and the weld profiles penetration pattern.

Adjustable Frequency (Hz)

As stated earlier in this section, alternating current makes constant reversals in direction of current flow. One complete reversal is termed a cycle and is referred to as its frequency. As stated, in the United States the frequency of its delivery is 60 cycles per second, or to use the preferred term 60 Hz. This means there are 120 reversals of current flow direction through the arc per second. The faster the current going through the arc changes direction, increases the arc pressure making the arc more stable and directional.

Figure 2.22 shows an illustration of the frequency effects on a welding arc and the resultant weld profile.

This can be beneficial in automated welding by reducing the amount of deflection and wandering that occurs in the direction of travel when fillet welding.

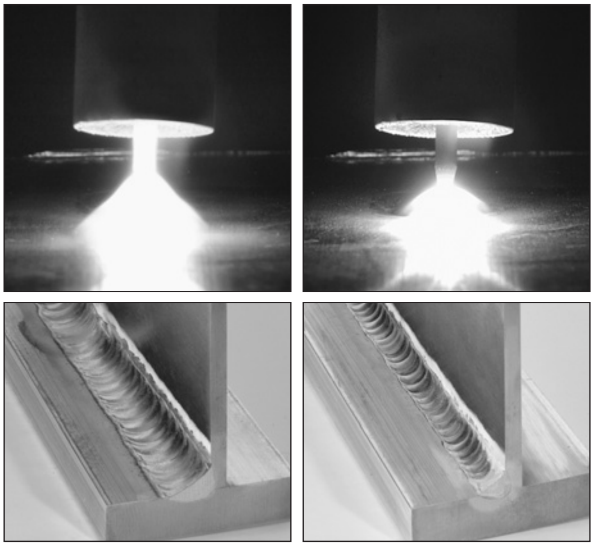


Figure 2.22 Normal 60 Hz arc compared to a 180 Hz arc. The current is changing direction 3 times faster than normal with a narrower arc cone and a stiffer more directional arc. The arc does not deflect but goes directly to where the electrode is pointed. This concentrates the arc in a smaller area and results in deeper penetration.

Frequency Adjustability

	Hz Range
AC sine wave power source	Not adjustable, must use what the power company supplies
Squarewave	Not adjustable, must use what the power company supplies
Advanced Squarewave	20 – 400

Figure 2.23 Frequency adjustment only available on the Advanced Squarewave designed power sources.

A lower than normal frequency (60 Hz) can be selected on the Advanced Squarewave power source, all the way down to 20 Hz, as indicated in Figure 2.23. This would have applications where a softer, less forceful arc may be required — build up, outside corner joints, or sections where a less penetrating, wider weld is required. As the frequency is increased, the arc cone narrows and becomes more directional. This can be beneficial for manual and automatic welding by reducing the amount of deflection and wandering that occurs in the direction of travel when making groove or fillet welds. Figure 2.24 is an example of a high cycle arc on an aluminum fillet weld. Figure 2.25 is an example of an Advanced Squarewave power source capable of frequency adjustment and enhanced balance control.

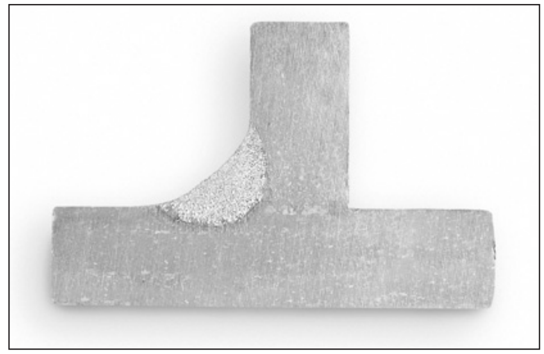


Figure 2.24 Advanced Squarewave arc at 180 Hz fillet weld on aluminum.

Figure 2.25 An Advanced Squarewave power source with arc frequency and enhanced balance control benefits.

Adjustable Frequency Advantages

- Higher frequency yields narrower arc
- Higher frequency increases penetration
- Lower frequency widens arc
- Lower frequency produces a softer less forceful arc

Independent Current Control

The ability to control the amount of current in the negative and positive half cycle independently is the last item in the AC cycle that is controllable. Certain Advanced Squarewave power sources allow this control. These power sources provide separate and independent amperage control of the electrode negative (penetration) and electrode positive (cleaning) half cycles.

The four major independently controllable functions of the Advanced Squarewave AC power source are:

1. Balance (% of time electrode is negative)
2. Frequency in hertz (cycles per second)
3. Electrode negative current level in amps*
4. Electrode positive current level in amps*

*Specially designed Advanced Squarewave power sources only.

Figure 2.26 shows you what an Advanced Squarewave output might look like on an oscilloscope.

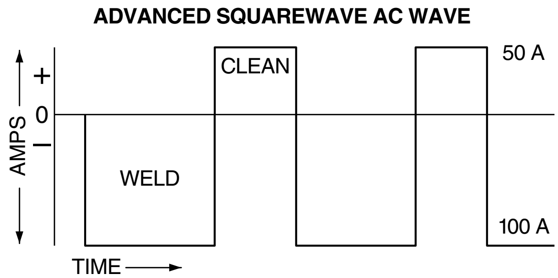


Figure 2.26 An Advanced Squarewave AC wave with independent current control.

The ability to control these separate functions with the Advanced Squarewave power source provides some unique advantages. A more efficient method of balancing heat input and cleaning action is available, which in turn, results in increased travel speeds.

The benefits of Advanced Squarewave forms go beyond increased travel speeds. This type of welding allows a narrower and deeper penetrating weld bead compared to that of Squarewave or sine wave machines. The Advanced Squarewave AC is capable of welding thicker material than Squarewave or sine wave power sources at a given amperage. Figure 2.27 shows an example of welds made with Squarewave and Advanced Squarewave power sources. Note with an extended balance control the etched cleaning zone can be narrowed or eliminated.

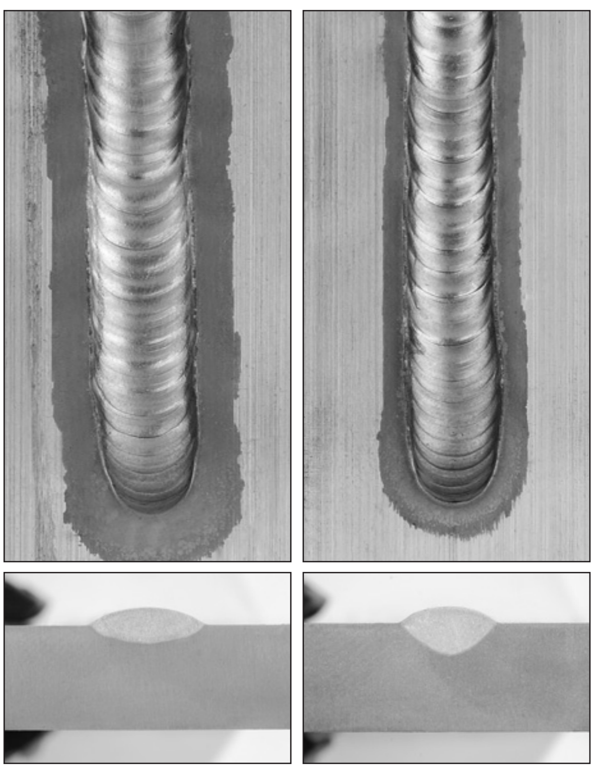


Figure 2.27 At 250 amps, note the weld profile comparison between the Squarewave and Advanced Squarewave on this 1/2" aluminum plate.

Figure 2.28 An Advanced Squarewave AC power source.

The transition through zero on Advanced Squarewave power sources is much quicker than Squarewave machines; therefore, no high frequency is required even at low amperages. High frequency is only used to start the arc and is not needed at all in touch start mode.

Advanced Squarewave Advantages

- More efficient control results in higher travel speeds
- Narrower more deeply penetrating arc
- Able to narrow or eliminate etched zone
- Improved arc stability
- Reduced use of high frequency arc starts
- Improved arc starting (always starts EP independent of current type or polarity set)

Controlling the Advanced Squarewave Power Source

Feature	Waveform	Effect on Bead	Effect on Appearance
AC Balance Control Controls arc cleaning action. Adjusting the % EN of the AC wave controls the width of the etching zone surrounding the weld.	**51 – 99% EN** Amperage; 0; % EP; % EN; Time (1 AC Cycle)	Reduces balling action and helps maintain point Deep, narrow penetration	Narrow bead, with no visible cleaning Bead No Visible Cleaning
	30 – 50% EN Amperage; 0; % EP; % EN; Time (1 AC Cycle)	Increases balling action of the electrode Shallow penetration	Wider bead and cleaning action Bead Cleaning
AC Frequency Control Controls the width of the arc cone. Increasing the AC Frequency provides a more focused arc with increased directional control.	**60 Cycles per Second** Amperage; 0; % EP; % EN; Time (1 AC Cycle)	Wider bead, good penetration — ideal for buildup work	Wider bead and cleaning action Bead Cleaning
	120 Cycles per Second Amperage; 0; % EP; % EP; % EN; % EN; Time (1 AC Cycle)	Narrower bead for fillet welds and automated applications	Narrower bead and cleaning action Bead Cleaning
Independent AC Amperage Control Allows the EN and EP amperage values to be set independently. Adjusts the ratio of EN to EP to precisely control heat input to the work and the electrode.	Current; 0; EP+; EN –; Time	**More current in EN than EP:** Deeper penetration and faster travel speeds	Narrow bead, with no visible cleaning Bead No Visible Cleaning
	Current; 0; EP+; EN –; Time	**More current in EP than EN:** Shallower penetration	Wider bead and cleaning action Bead Cleaning

Figure 2.29 The Advanced Squarewave power source allows the operator to shape the arc and control the weld bead. Separately or in any combination, the user can adjust the balance control, frequency (Hz) and independent current control, to achieve the desired depth of penetration and bead characteristics for each application.

Note: All forms of AC create audible arc noise. Many Advanced Squarewave AC combinations, while greatly improving desired weld performance, create noise that may be objectionable to some persons. Hearing protection is always recommended.

Welding Fluxes for GTAW

As has been seen, the type of welding current and polarity has a big effect on welding penetration. Developments have been made in producing chemical fluxes that effect the surface tension of the weld pool molecules and allow improved penetration on certain metals. The flux is applied prior to welding and at a given amperage penetration will be increased. Figure 2.30 is an example of weld profiles with and without the use of this “Fast TIG Flux”.

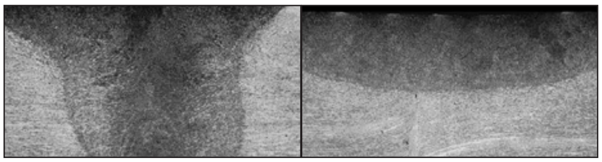


Figure 2.30 With and without use of FASTIG™ flux for enhanced penetration.

Arc Starting Methods

Gas Tungsten Arc Welding uses a non-consumable electrode. Since this tungsten electrode is not compatible with the metals being welded (unless you happen to be welding tungsten), it requires some unique arc starting and arc stabilizing methods.

Gas Ionization

Gas ionization is a fundamental requirement for starting and having a stable arc. An ionized gas, a gas that has been electrically charged, is a good conductor of electricity. There are two ways of charging this gas. Heat the gas to a high enough temperature and electrons will be dislodged from the gas atoms and the gas atoms will become positively charged gas ions. The heat of a welding arc is a good source for this thermal ionization. Unfortunately, when AC welding with conventional sine waves, as the current approaches zero there is not sufficient heat in the arc to keep the gas ionized and the arc goes out. The other ionization method is to apply enough voltage to the gas atom. The electrons will be dislodged from the gas atom and it is left as a positive gas ion.

High Frequency

This is a high voltage/low amperage generated at a very high cycle or frequency rate. Frequency rates of over 16,000 Hz and up to approximately 1 million Hz are typical. This high voltage allows for good arc starting and stability, while the high frequency it is generated at allows it to be relatively safe in the welding operation. Due to this high safe frequency, the high voltage ionizes the shielding gas, thus providing a good path for the current to follow. So the path between the electrode and the work becomes much more conducive to the flow of electrons, and the arc will literally jump the gap between the electrode and the workpiece. On materials sensitive to impurities, touching the tungsten to the work will contaminate it as well as the tungsten. This benefit of high frequency is used to start the arc without making contact with the work, eliminating this possible chance of contamination.

When alternating current first became available for SMAW, researchers immediately began looking for a means to assist the re-ignition of the arc during the positive half of the AC cycle. Shielded Metal Arc Welding electrodes at this time did not have arc stabilizers in the coating for AC welding. It was found that the introduction of a high frequency/high voltage into the secondary welding circuit of the power source assured arc re-ignition. This high-frequency source is actually superimposed on the existing voltage of the power source. The high frequency is used to eliminate the effects of the arc outage. While the primary 60 cycle current is going through its zero point, the HF may go through many cycles, thus preventing the arc from stopping. A common misconception is that the high frequency itself is responsible for the cleaning action of the arc. But the high frequency only serves to re-ignite the arc which does the cleaning. Figure 2.31 shows the relationship of superimposed high frequency to the 60 cycle frequency of the primary current.

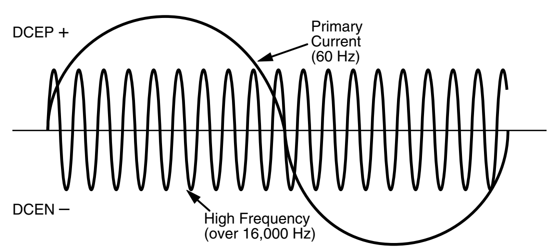


Figure 2.31 AC high frequency (not to scale).

With GTAW, high frequency is used to stabilize the arc. During the negative half of the AC cycle, electron flow is from the relatively small tungsten electrode to the much wider area of the pool on the workpiece. During the positive half cycle the flow is from the pool to the electrode. Aluminum and magnesium are poorer emitters of electrons when they are hot and molten than the hot tungsten. Plus the area of current flow on the molten weld pool is so much larger than the area on the end of the tungsten. The arc has a tendency to wander and become unstable. Because the high frequency provides an ionized path for the current to follow, arc re-ignition is much easier and the arc becomes more stable. Some power sources use high frequency for starting the arc only and some allow continuous high frequency to take advantage of its stabilizing characteristics.

High frequency has a tendency to get into places where it's not wanted and falls under control of the Federal Communication Commission (FCC). It can be a major interference problem with all types of electrical and electronic devices. See Figure 2.33 for installation information. The additional circuitry and parts required for the spark gap oscillator and its added expense is an additional drawback.

High-Frequency Usage

Control Setting	Effect	Application
OFF	Removes HF from the weld leads	For SMAW welding or where HF interference is a concern
Continuous	Imposes HF on the weld leads, all the time, when welding power is energized	For GTAW welding of the refractory oxide metals like aluminum and magnesium
Start only	Limit the time HF is imposed on the welding leads to when starting the arc	For GTAW DCEN welding of all metals that do not have refractory oxides (titanium, stainless steel, nickel, carbon steel, etc.)*

*Can also be used on aluminum and magnesium when welding with Advanced Squarewave power sources.

Figure 2.32 Explains proper use and applications.

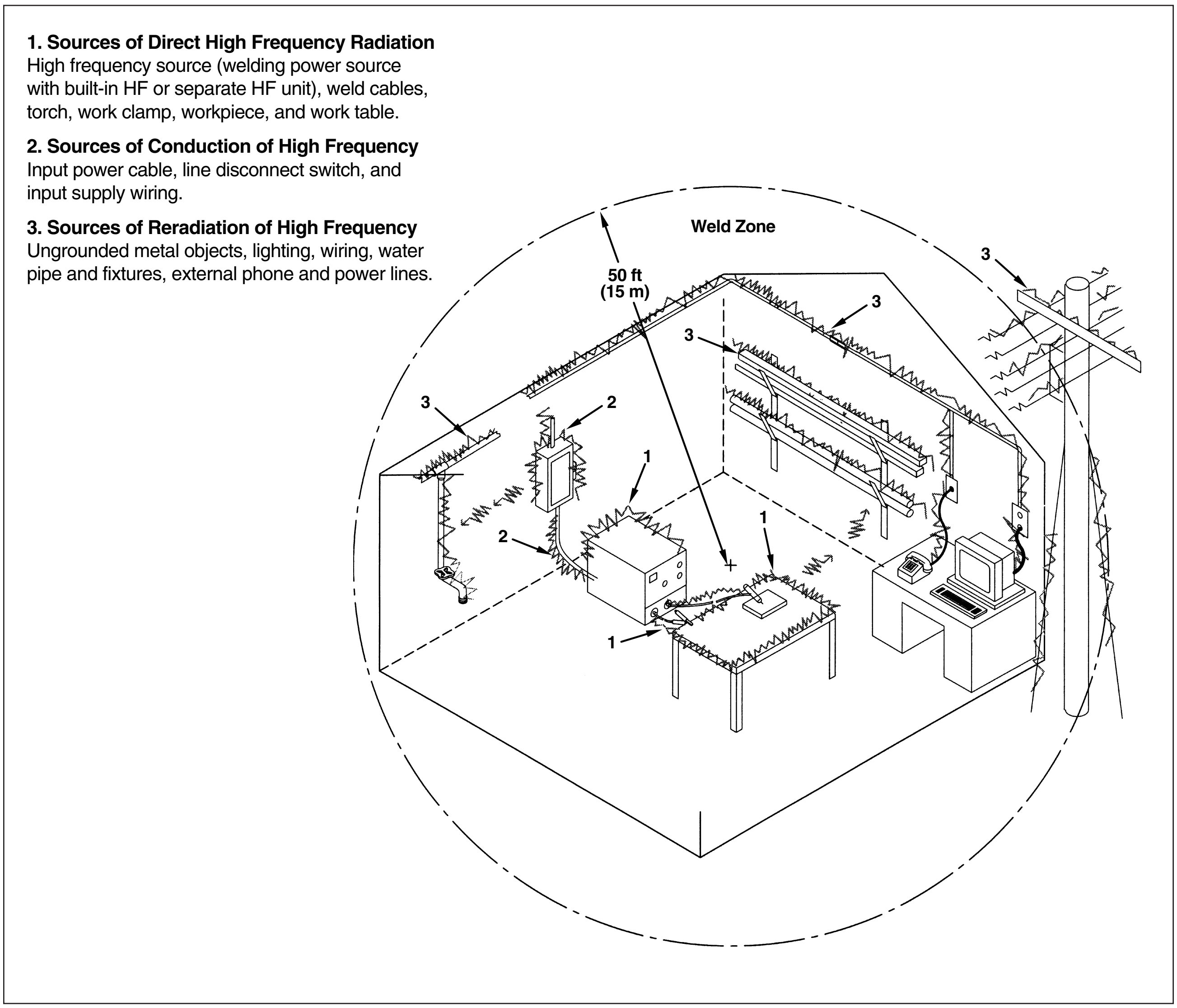


Figure 2.33 Illustrates sources of high-frequency radiation caused by an improper installation. The Federal Communications Commission has established guidelines for the maximum high-frequency radiation permissible.

Pulse Mode HF

These machines utilize special circuitry to impose a high intensity pulse on the output circuit when the voltage is at a specific value. Lets assume we have a machine that provides this pulse when voltage is 30 volts or more. When not welding, voltage (or pressure) is at maximum because no current is being allowed to flow and the pulsing circuitry is enabled. As the electrode is brought near the work, the pulses help jump start the arc and welding begins. Once the arc is started, weld circuit voltage typically drops to a value somewhere in the low teens to low twenties and the pulsing circuit senses this change and drops out. The pulse mode circuitry can also help stabilize the AC arc because it is enabled during times the voltage sine wave is transitioning through zero. The high intensity pulses do affect other electronic circuitry in the immediate vicinity, but the effect is not as pronounced as that of a high-frequency power source. You may find it necessary to move the electrode slightly closer to the workpiece to initiate the arc with pulse assist than you would with traditional high-frequency arc starting methods.

Lift-Arc™

Lift-Arc™ allows the tungsten to be placed in direct contact with the metal to be welded. As the tungsten is lifted off the part, the arc is established. This is sometimes referred to as touch start. Little if any chance of contamination is possible due to special power source circuitry. When the Lift-Arc switch is activated, lower power level is supplied to the tungsten electrode. This low power allows some preheating of the tungsten when it is in initial contact with the part. Remember hot tungsten is a good emitter of electrons. This power level is low enough not to overheat the tungsten or melt the work thus eliminating the possibility of contamination. Once the arc is established the power source circuitry switches from the Lift-Arc mode to the weld power mode and welding can commence. Figure 2.34 illustrates the proper techniques to use with the Lift-Arc starting method.

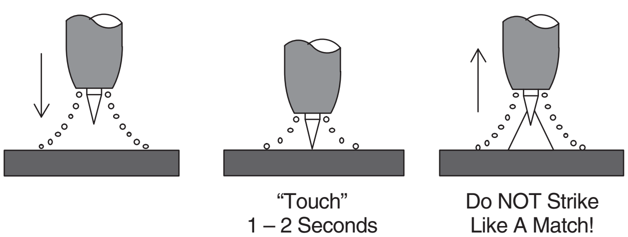


Figure 2.34 Proper arc starting procedure when using the Lift-Arc method.

Scratch Start

Scratch start is not generally considered an appropriate arc starting method as it can easily lead to contamination in the weld area. It is usually preformed when doing GTAW DC welding on a power source designed for SMAW only. These machines are not equipped with an arc starter so the only way to start the arc is with direct contact of the tungsten electrode with the metal. This is done at full weld power level and generally results in contamination of the electrode and or weld pool. This method as the name implies is accomplished much like scratching or striking the arc as would be done for Shielded Metal Arc Welding.

Capacitive Discharge

These machines produce a high voltage discharge from a bank of capacitors to establish the arc. The momentary spark created by these machines is not unlike a static discharge. Although capacitive discharge machines have good arc starting capability, they do not have the arc stabilization properties of high-frequency machines. They are typically used only for DC welding and not usable on AC welding.

Arc Starting

Methods	Alternating Current	Direct Current Electrode Neg.
High frequency	In continuous mode*	In start only mode
Pulse HF	In continuous mode*	In start only mode
Lift-Arc	Only with Advanced Squarewave power source**	Usable on any DC welding with appropriately equipped power source
Scratch start	Not recommended	Not recommended for x-ray quality welding due to tungsten inclusions possibility
Capacitor discharge	Not recommended	Usable on any DC welding with appropriately equipped power source

*With specially designed Squarewave power sources and Advanced Squarewave power sources it can be done in start mode as well.

**With specially designed Squarewave power sources appropriately equipped with Lift-Arc circuitry.

Figure 2.35 The various arc starting methods and applications of each.

Figure 2.36 A Squarewave GTAW welding power source.

Pulsed GTAW

Some of the advantages of Pulsed GTAW are:

- Good penetration with less heat input
- Less distortion
- Good control of the pool when welding out of position
- Ease of welding thin materials
- Ease of welding materials of dissimilar thickness

The main advantage of the Pulsed GTAW welding arc is that the process produces the same weld as a standard arc, but with considerably less heat input. As peak amperage is reached, penetration is quickly achieved. Before the workpiece can become heat saturated, the amperage is reduced to the point where the pool is allowed to cool but current is sufficient to keep the arc established. The pulsed arc greatly reduces the need to adjust heat input as the weld progresses. This gives the welder much greater pool control when welding out of position and in situations where joints are of differing thicknesses.

The basic controls for setting pulse parameters are:

Peak Amperage — This value is usually set somewhat higher than it would be set for a non-pulsed GTAW weld.

Background Amperage — This of course would be set lower than peak amperage.

Pulses Per Second — Is the number of times per second that the weld current achieves peak amperage.

% On Time — Is the pulse peak duration as a percentage of total time. It controls how long the peak amperage level is maintained before it drops to the background value.

Refer to Figure 2.37 to see what effect each of these settings has on the pulsed waveform.

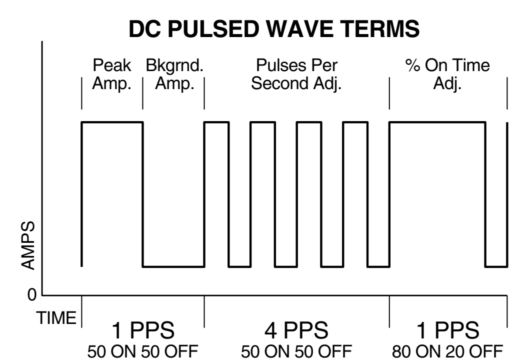


Figure 2.37 DC pulsed wave terms.

The pulsed waveform is often confused with the AC sine, or Squarewave. The AC sine wave represents direction of current flow in the welding circuit, while the pulsed waveform represents the amount and duration of two different output levels of the power source. The pulse waveform is not a sine wave at all. Note in Figure 2.37 that the actual output being displayed is direct current, and the signal does not switch between plus and minus values as it does in the AC sine wave. This is not to say that AC cannot be pulsed between two different output levels, as there are applications and power sources capable of doing just this.

High-Frequency Pulsed Welding

Although the majority of Pulsed GTAW welding is done in a frequency range of .5 to 20 pulses per second, there are applications where much higher frequencies are utilized. The advantage of high-frequency pulsing (200 to 500 pulses per second) is that the high-frequency pulse provides a much "stiffer" arc. Arc stiffness is a measure of arc pressure. As pressure increases, the arc is less subject to wandering caused by magnetic fields (arc blow). Welding with higher frequencies has also proven beneficial by producing better agitation of the weld pool which helps to float impurities to the surface resulting in a weld with better metallurgical properties. High-frequency pulsing is used in precision mechanized and automated applications where an arc with exceptional directional properties and stability is required. It is also used where a stable arc is required at very low amperages.

Since the electronic SCR and inverter type power sources have inherently very fast response time they can easily be pulsed. The SCR machines are somewhat limited in speed as compared to the inverters. However pulse controls are available for both types. They can be add-on controls like seen in Figure 2.38 or built directly into the power source.

Figure 2.38 An add-on pulse control for the SCR and inverter power sources.

III. GTAW Equipment

Safety First

Even though the majority of welding done is in the direct current mode, welding power is most often obtained from the local power company out of an AC wall socket.

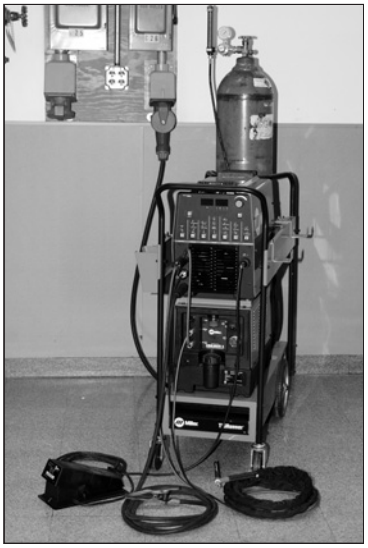


Figure 3.1 GTAW power source plugged into wall connection. Primary connection to the commercial power.

Notice the fuse box on the wall, where primary power to the machine must be shut off if work needs to be done on any part of the welding equipment. Also, the primary power at the fuse box should be shut off when the machine is idle for long periods of time.

Caution should always be taken when installing any welding equipment. Should a welding machine be improperly connected, a dangerous situation could exist. Improper connections could lead to an electrically “hot” welding machine case, which could result in a severe shock to anyone touching it. Primary wiring should only be done by an electrically qualified person who is absolutely sure of the electrical codes in a given area. Before any primary power is connected to welding equipment, the equipment’s operation manual should be read, and the instructions strictly followed.

Selecting a Power Source

With the many types of welding machines available, certain considerations must be made in order to fit the right machine to the job.

Rated output of the welding machine is an important consideration. The ranges of voltage and amperage needed for a particular process must be determined. Then, a welding machine can be selected to meet these output needs. Remember, the output must be within a proper duty cycle range.

Light welding, (low output requirements of about 200 amps or less) can often be done with single-phase welding machines. Duty cycles are often in the 60% or less range. These types of welding machines are especially suited for shops and garages where only single-phase power is available. Some of these smaller single-phase machines may be capable of using 115 volt AC primary power. Other machines may use 230 volt or higher primary power.

Larger DC TIG welding machines used for heavy plate, structural fabrication and high production welding generally need three-phase AC input power. Most industrial locations are supplied with three-phase power since it provides the most efficient use of the electrical distribution system and it is required by many electric motors and other industrial electrical equipment. These welding machines often have capacities of over 200 amps, and often have 100% duty cycles.

Figures 3.2 through 3.7 show some different types of welding machines and controllers.

Figure 3.2 An inverter-based welding machine which has the capability of modifying the frequency of the AC arc. This machine has multiprocess capability including GTAW, SMAW, and pulsing capability.

Figure 3.3 An electronically controlled AC/DC power source. Features include wave balance control to selectively unbalance the wave to optimize welding characteristics.

Figure 3.4 An AC/DC machine which was specifically designed for GTAW. It includes many built-in components that make it adaptable to a wide variety of applications.

Figure 3.5 An AC/DC machine of the type commonly used for Stick electrode (SMAW) welding. With the addition of other components, it will meet the requirements of many GTAW applications.

Figure 3.6 A multiprocess engine-driven welding generator capable of AC and DC GTAW welding when fitted with an optional high-frequency arc starter.

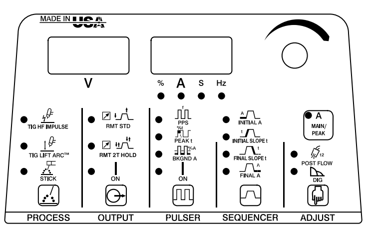


Figure 3.7 An advanced power source with a built-in programmer that enables the operator to program the entire welding sequence. This is recommended for automatic welding or whenever repeatability is required.

In order to best understand the arc welding power source and its requirements, it is best to start at the arc and work back to the wall receptacle. The GTAW process requires the welder to maintain the arc length. Any variation in arc length will affect the voltage. The longer the arc the higher the voltage, and the shorter the arc the lower the voltage. The welder will have difficulty maintaining the arc length, the voltage will change, as the arc is moved across the part being welded. This change in voltage (arc length) causes the output current (amperage) to fluctuate. This output current should be kept as constant as possible with the TIG process. The amperage creates the heat that melts the metal and allows for consistent welding.

The Constant Current Power Source

Arc welding power sources are classified in terms of their output characteristics with regard to voltage and amperage. They can be constant current (CC), constant voltage (CV) or both.

A constant current machine, the kind used in GTAW welding, maintains close to a constant current flow in the weld circuit no matter how much the voltage (arc length) varies. Processes like GTAW and Shielded Metal Arc Welding (SMAW) require the welder to maintain the arc length not the equipment.

A constant voltage power source maintains voltage at close to a preset value no matter how much current is being used in the process. This is the type of power source that is used in Gas Metal Arc Welding (GMAW) or Metal Inert Gas (MIG) welding. Processes like GMAW and Flux Cored Arc Welding (FCAW) require the equipment to maintain a specific arc length.

You'll notice that in both cases we say these machines maintain current and voltage values close to preset values respectively. They will vary slightly due to the fact that no power source is perfectly efficient.

The relationship between voltage and current output is best represented by plotting these values on a graph.

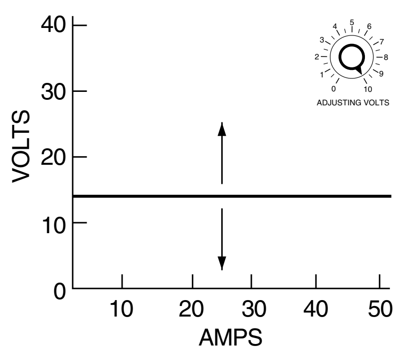


Figure 3.8 Volt-amp curve of a perfect battery.

Figure 3.8 shows the volt-amp curve of a perfectly efficient battery. This would be considered a CV power source because no matter how much current is produced, the voltage remains constant at twelve volts.

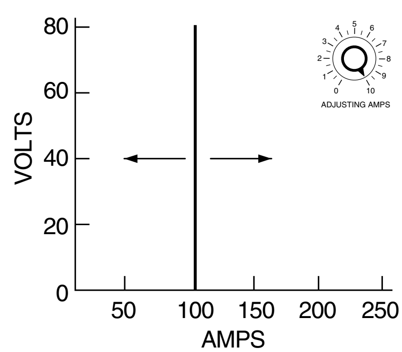
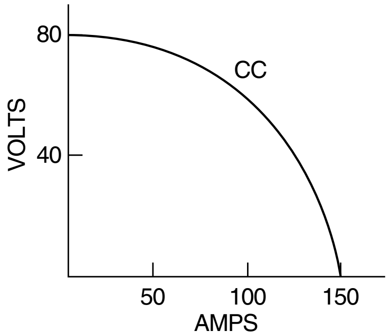
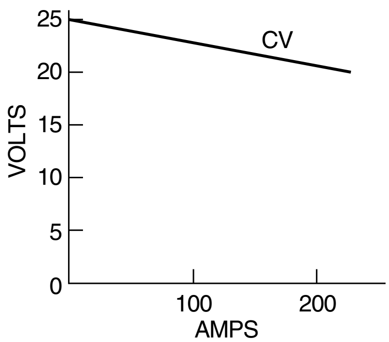


Figure 3.9 Volt-amp curve of a perfect CC power source.

A perfectly efficient power source of the CC variety as seen in Figure 3.9 would exhibit a volt-amp curve where a constant current of 100 amps is output no matter what the voltage.



Figures 3.10 CC volt-amp curve.



Figures 3.11 CV volt-amp curve.

The volt-amp curve shown in Figure 3.10 is indicative of those seen in GTAW power sources, and the volt-amp curve seen in Figure 3.11 represents the output of a constant voltage or GMAW power source. The sloping line on the constant current graph represents the output of a magnetic amplifier power source. Because of this sloping characteristic, these power sources are often referred to as droopers.

Figure 3.12 is an example of a basic DC power source for TIG welding. The single-phase high voltage, low amperage is applied to the main transformer. The transformer transforms this high voltage to low voltage and at the same time transforms the low amperage to high amperage for welding. It does not affect the frequency, 60Hz in and 60Hz out. This low voltage high amperage is now rectified from AC to DC in the rectifier. This produces a fairly rough DC unlike the power provided by a battery. The filter is used to smooth and stabilize the output for a more consistent arc. The filtered DC is now supplied to the TIG torch. These line frequency type power sources tend to be large and very heavy. Their arc performance is slow and sluggish and won't allow them to be used for advanced wave shaping or pulsing.

The true constant current power sources are an advantage in that what current is set is what is delivered to the welding arc. These electronically controlled power sources are desired over the older-style power sources and find applications in manual through automatic welding. The current settings are very accurate and welds are very repeatable. The electronically controlled and inverter-type power sources have special circuits that maintain their output very consistently. This is accomplished with a closed loop feedback circuit. This circuit compares the output current going to the arc against what has been set on the machine. It acts much like a car with the cruise control activated — if going up and down a hill the speed is maintained. If the welder raises and lowers the arc, the amperage is maintained. Figure 3.13 shows a block diagram of this closed loop feedback sense circuit. This feature is also helpful for line voltage compensation. By law the power company must supply a consistent voltage. However they are allowed a range, which can be as much as plus or minus 10% of the nominal voltage. If the primary voltage to a non-compensated GTAW power source changed up to 10%, the power going into the arc can fluctuate from 10 – 20%. With the line voltage compensated machine, a plus or minus fluctuation of up to 10% on the primary will only have a plus or minus 2% change in the arc, thus a very consistent weld. Most electronically-controlled power sources can also be used to provide pulsed welding current. Due to their fast response time and great control over the current level setting, two different heat levels pose no difficulty for these type power sources. These machines can also be remotely controlled and these controls can be very small and compact. They are small enough to be mounted directly on the torch or built into the torch handle. Limitations of this design can make them more complex to operate, and are relatively expensive in comparison to simpler control designs.

Squarewave Silicon-Controlled Rectifier (SCR) Power Sources

These type power sources were introduced to the welding industry in the mid 70s. They have now virtually replaced all the AC sine wave power sources for the GTAW process. The block diagram shown in Figure 3.14 is a representative of this type of control. These type power sources use the large bulky 50 or 60 Hz transformer. They are typically very similar in size and weight to the older style mechanically or magnetically controlled power sources. They do have simple wave shaping technology and possess closed loop feedback for consistent weld output.

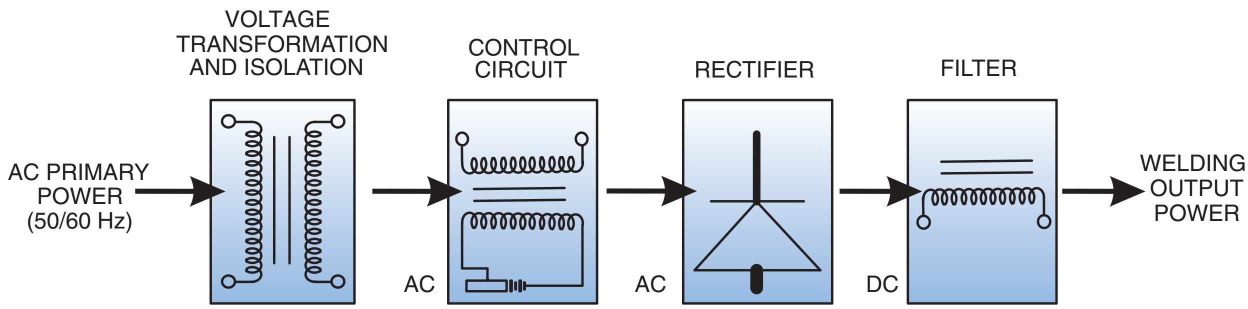


Figure 3.12 A conventional line frequency power source block diagram.

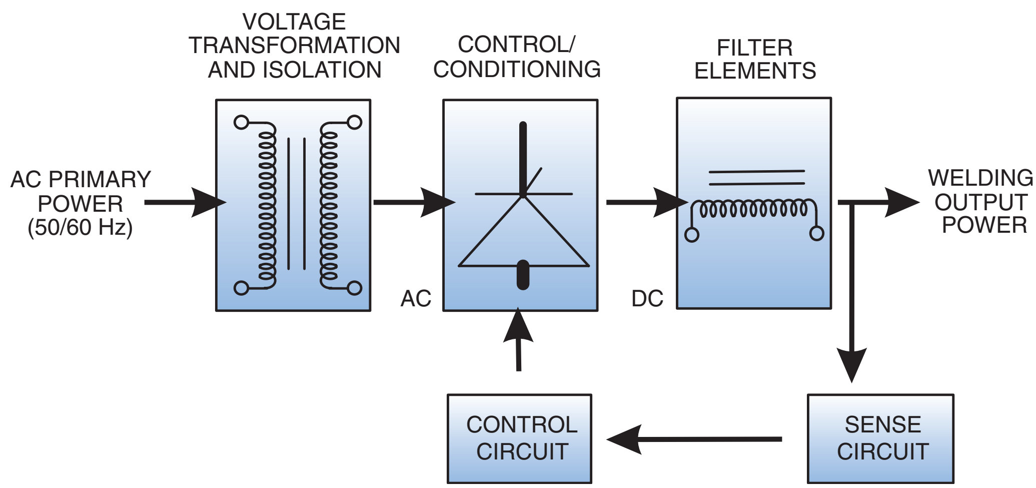


Figure 3.13 The closed loop feedback keeps the output consistent when the arc voltage is varied and to compensate for primary line voltage fluctuations.

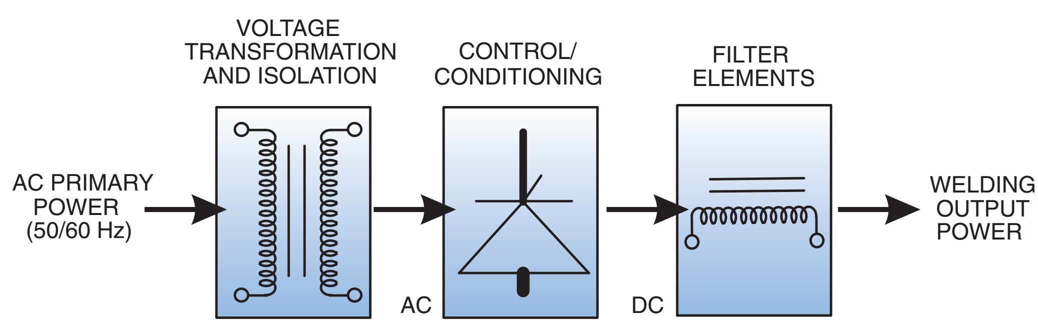


Figure 3.14 Block diagram of an SCR controlled power source, utilizes a line frequency weld transformer.

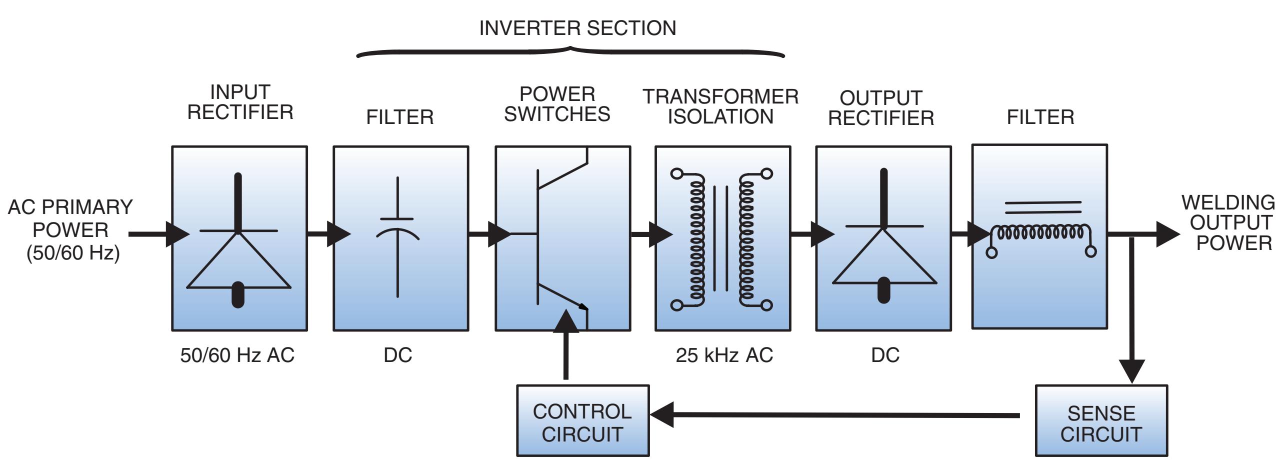


Figure 3.15 An inverter power source block diagram.

The Inverter Power Source

Inverter power sources were first conceived in the 1940s, but weren't successfully marketed until the 1970s.

Instead of operating at a common input power frequency of 50 or 60 Hz, inverters boost the frequency as much as 1000 times that of input frequency. This allows for a drastic reduction in the number of transformer coil turns and reduced core area resulting in a machine much smaller and lighter in weight than a conventional transformer rectifier power source. Another major advantage of this type of machine is its primary power requirements. Some inverters can be used on either three-phase or single-phase input power, and either 50 or 60 Hz. This is due to the fact that incoming primary power is rectified and converted to the extent that it is not a critical factor. Some inverters due to their unique circuitry, are multiprocess machines capable of GTAW, GMAW, SMAW, FCAW (Flux Cored) and Carbon Arc Gouging. Although these inverters are capable of accomplishing these multi-processes, some are specifically designed for and specialized for the TIG process.

Figure 3.15 is a block diagram of an inverter type power source. Machines of this type can run on single or three-phase power, which will be covered later in this section. The first thing the inverter does is rectify the high voltage low amperage AC into DC. It is then filtered and fed to the inverter's high-speed switching devices. Just like a light switch they turn the power on and off. They can switch at a very fast rate, up to 50,000 times per second. This high voltage, low amperage fast DC switching looks like AC to the transformer, which is many times smaller than a 60 Hz transformer. The transformer steps the voltage down and increases the amperage for welding. This low voltage high amperage is filtered for improved DC arc welding performance or converted to AC through the electronic polarity control. This AC or DC power is then provided to the TIG torch. This AC is fully adjustable as described in the section on Advanced Squarewave AC. The DC is extremely smooth and very capable of being pulsed or sequenced.

The Engine-Driven Power Source

Some of the first electric arc welding power sources invented were the motor generator type that produced welding current by means of a rotor moving inside a stator. This is the same principle of current generation by means of moving a conductor through a magnetic field. The movement in these machines was provided by an electric motor.

The concept is still being put to good use by modern power sources that replace the electric motor with gasoline or diesel engines. The most important feature of these electro-mechanical devices is that they free the welder from dependence on commercial power, and allow them the mobility to accomplish tasks nearly anywhere in the world. Most of these machines are welder generators that along with welding output produce AC/DC current for the operation of lights and power tools.

Engine driven welding power sources are usually referred to as rotating power sources of which there are two basic types. The ALTERNATOR, which produces alternating current, and the GENERATOR, which produces direct current. Most manufacturers produce machines that provide both AC and DC from the same unit.

Figure 3.16 Maintenance welding on agricultural equipment with an engine driven power source.

Duty Cycle

As mentioned earlier in this section, duty cycle is of prime importance in the selection of a welding machine. The duty cycle of a welding power source is the actual operating time it may be used at its rated load without exceeding the temperature limits of the insulation in the component parts. The duty cycle is based on a ten minute time period in the United States. However, in some parts of the world, Europe for example, the duty cycle is based on a five minute time period. Simply stated, if a power source is rated at a 50% duty cycle and it is operated at its rated output for five minutes, it must be allowed to cool for five minutes before operating again. The duty cycle is not accumulative. For example, a power source with a 50% duty cycle cannot be operated for thirty minutes then allowed to cool for 30 minutes. This violates the ten minute rule. Also a machine rated at 50% should not be operated at maximum for five minutes and then shut off. The cooling fan must be allowed to operate and cool the internal components, otherwise the machine might incur damage.

A power source with a 100% duty cycle may be operated at or below its rated output continuously. However if the machine is operated above its rated output for a period of time, it no longer has a 100% duty cycle.

Single-Phase — Three-Phase

DC welding machines normally require either single-phase or three-phase power. Three-phase power sources are quite popular in the welding industry because, generally speaking, a three-phase machine will deliver a smoother arc than a single-phase machine.

Most AC/DC TIG machines operate from single-phase power. Some power sources can be powered by either single-phase or three-phase power. These are usually inverter-type power sources.

A typical example of a three-phase rectified sine wave is shown in Figure 3.17.

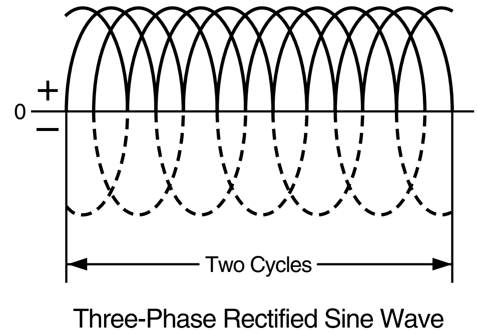
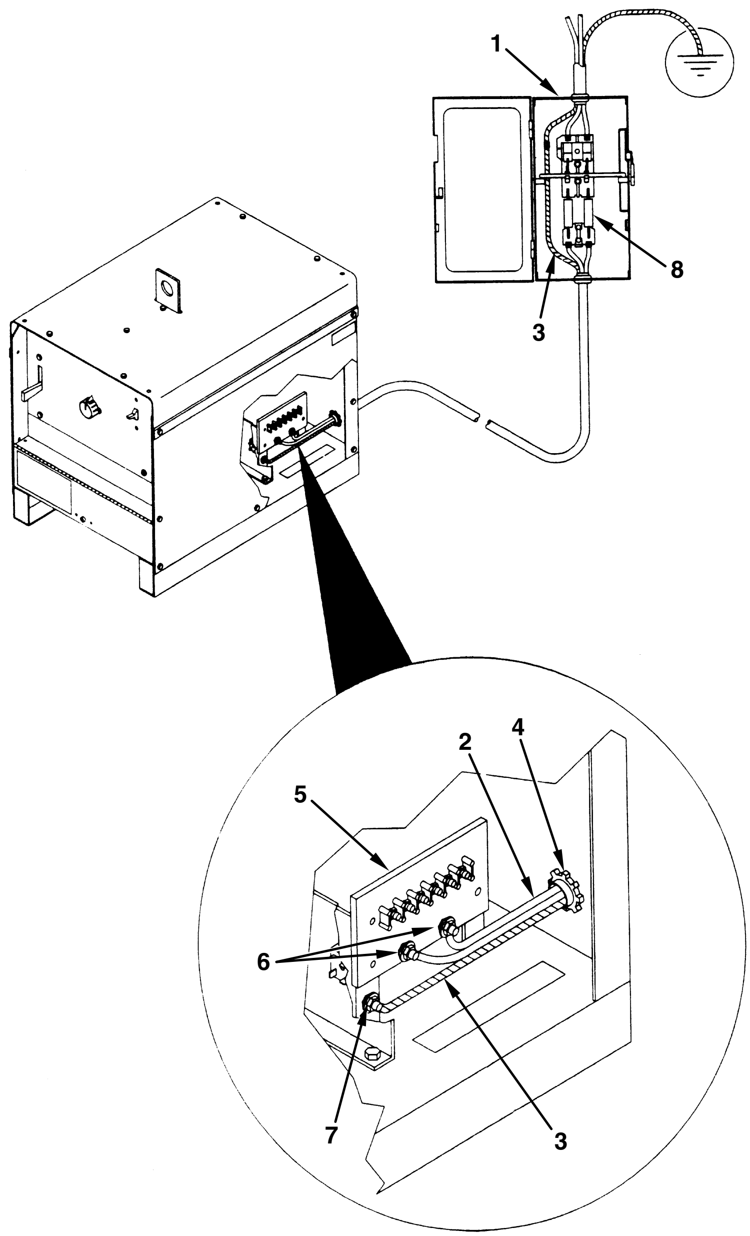


Figure 3.17 Three-phase DC current.



Have only qualified persons make this installation.

1. Line Disconnect Device of Proper Rating

2. Input Conductors

3. Grounding Conductor
Conductor rating must comply with national, state, and local electrical codes. Use lugs of proper amperage capacity and correct hole size.

4. Strain Relief Connector
Insert conductors through strain relief.

5. Input Terminal Board

6. Line Terminals

7. Ground Terminal
Connect grounding conductor and input conductors to line terminals and to ground terminal.

Install and connect grounding conductor and input conductors in conduit or equivalent to de-energized line disconnect device.

Be sure grounding conductor goes to an earth ground.

Reinstall side panel.

8. Line Fuses
Install into de-energized line disconnect switch.

Figure 3.18 Typical input conductor connections and component locations—single-phase.

Single-Phase Input Connections

AC and AC/DC transformer power sources operate from single-phase primary power. DC power sources may be either single or three-phase. Check the nameplate, literature, or owners manual to obtain this information.

Figure 3.18 shows connections for a single-phase connection to primary power. With single-phase power there are two current carrying conductors and a ground wire, as you can see in the electrical box, and the three connections on the terminal board of the power source.

Three-Phase Input Connections

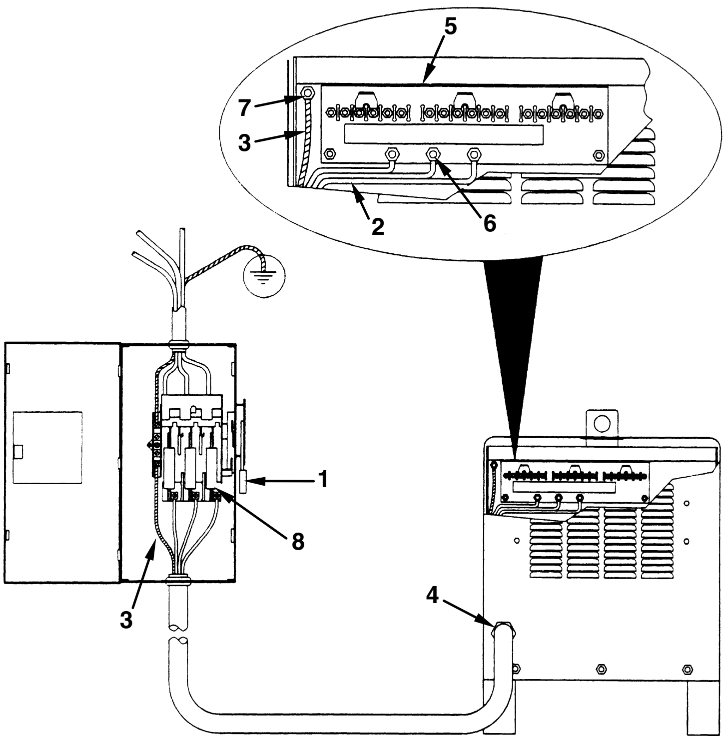
Many industrial DC welding power sources for GTAW utilize three-phase primary power. Three-phase DC power exhibits very smooth arc characteristics. This is because there are three separate sine wave traces within the same time span (1/60th of a second) as the single-phase sine wave trace.

Figure 3.19 shows how primary power is connected to the input of a three-phase power source. There are three current carrying conductors and a ground wire, as seen in the electrical box. The power source also shows three current carrying terminals and a ground terminal connection.

If a three-phase inverter power source is connected to a single-phase line the output rating will be reduced. Check the specific power source's specification for details.

Input Voltage

Most power sources are equipped with an input terminal board. This board is for the proper connection of the power source to the line voltage it is being supplied. This must be properly connected or severe damage can occur to the welding equipment. If the power source is moved from location to location with different input voltages, relinking this board will be required. Certain power sources are equipped with devices that will detect the input voltage and automatically set the equipment for proper operation. Two common types are



Have only qualified persons make this installation.

1. Line Disconnect Device of Proper Rating

2. Input Conductors

3. Grounding Conductor
Conductor rating must comply with national, state, and local electrical codes. Use lugs of proper amperage capacity and correct hole size.

4. Strain Relief Connector
Insert conductors through strain relief.

5. Input Terminal Board

6. Line Terminals

7. Ground Terminal
Connect grounding conductor and input conductors to line terminals and to ground terminal.

Install and connect grounding conductor and input conductors in conduit or equivalent to de-energized line disconnect device.

Be sure grounding conductor goes to an earth ground.

Reinstall side panel and top.

8. Line Fuses
Install into de-energized line disconnect switch.

Figure 3.19 Typical input conductor connections and component connections — three-phase.

referred to as Auto-Link® and Auto-Line™. Auto-Link uses a sensing circuit to mechanically relink the primary to the transformer as needed while Auto-Line electronically, on a sliding scale, constantly monitors and maintains the appropriate voltage to the transformer. Figure 3.20 represents how these two systems function.

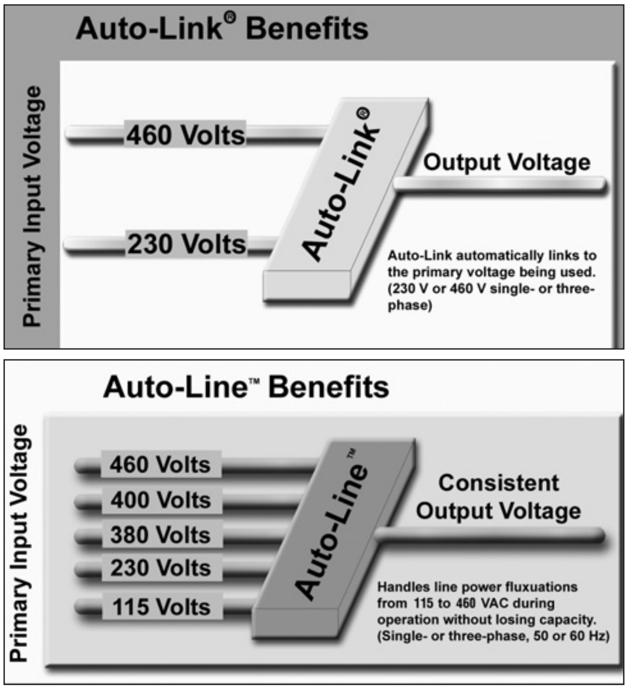


Figure 3.20 Note these automatic systems work on various voltages, frequencies, single- and three-phase power.

Accessory Items

Some of these items are required for the GTAW process while others are considered options.

Arc Starters/Stabilizers

High-frequency arc starters and stabilizers are for use with AC or DC GTAW welding power sources. (See the chapters on GTAW fundamentals, and GTAW techniques for more information on the use of high frequency for welding). These units are particularly useful when welding aluminum, magnesium, stainless steel, titanium, brass, copper and other hard to weld materials. Some DC GTAW power sources are not equipped with HF. They use Lift-Arc™ or touch start technology which allow them to function on specific metals. Some units will feature gas valves, time delay relays, and control circuits to regulate the flow of gas along with the high-frequency current.

Adding these type accessories to a power source not designed for TIG (especially the AC type sine wave machines) will require special precautions. An unbalanced condition occurs when the AC sine wave power sources are used for AC TIG welding. This unbalanced condition produces a circulating current that the power source must deal with. This "DC Component" generates additional heat in the power source. Some older GTAW power source designs used Ni-Chrome resistor bands to help balance and dissipate this heat, others used large capacitor banks built into the power source, while still others used battery banks connected in series with the arc. All were used to reduce this unbalance phenomenon. Since this phenomenon affects the AC sine wave power sources, it becomes an issue only on these type power sources. Since AC Squarewave power sources are designed to control the waveform, balance is not a concern with these type power sources.

Heating in the main transformer due to DC component causes at least two major problems:

1. Breakdown of insulation on the coils and core material.
2. A decrease in efficiency of the transformer due to the higher resistance of the heated coils and core.

When power sources not specifically designed for GTAW welding are used for welding aluminum or magnesium, DC component must be taken into account by derating the machines' duty cycle. The lowering of the current available will prevent overheating and damaging the main power transformer.

Derating Procedure

This derating procedure is necessary only with AC GTAW, and not with DC GTAW. It generally only applies to SMAW power sources that have had an HF arc starter added to them so they can be used for TIG welding.

Derate the AC sine wave power source by 30% from its rated amperage.

For example, a power source for SMAW is rated at 200 amps, 60% duty cycle. For GTAW, we lower the 200 amps by 30% to 140 amps at 60% duty cycle. It's important to remember with this method that the duty cycle for GTAW stays the same as it was for SMAW. If the GTAW welding will be done continuously, find the 100% duty cycle amperage rating for SMAW, then reduce this amperage by 30% for GTAW.

Remember, power sources specifically designed for GTAW do not have to be derated. This fact can usually be found on the machine's nameplate, or in its accompanying literature.

Figure 3.21 A high-frequency arc starter and stabilizer.

GTAW Torch

When welding with the TIG process it is true that the majority of heat goes into the arc, however a significant amount is retained in the torch. Consequently, some means must be provided to remove the wasted heat.

Torches used for GTAW welding may be either water- or air-cooled. High production or high amperage torches are usually water-cooled while lighter duty torches for low amperage applications may be air-cooled.

Air-cooled torches are popular for lower amperage applications. They require no additional cooling other than the surrounding air. The higher amperage versions are less flexible and harder to manipulate than water-cooled torches. The power cable must be heavier than the cable in water-cooled torches, and may be wound around the gas carrying hose or located inside the gas hose to provide additional cooling. Figure 3.22 illustrates the typical air-cooled torch, showing the basic components.

The water-cooled torch is designed so that water is circulated through the torch cooling it and the power cable. Figure 3.23 shows an exploded view of a water-cooled torch.

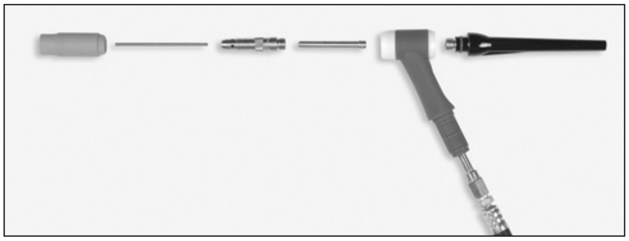


Figure 3.22 An air-cooled GTAW torch.

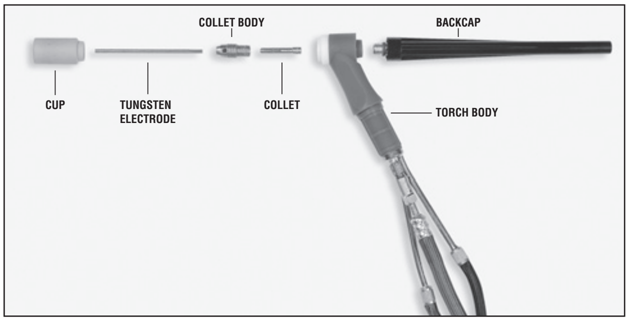


Figure 3.23 A water-cooled GTAW torch.

The power cable is contained inside a hose, and the water returning from the torch flows around the power cable providing the necessary cooling. In this way, the power cable can be relatively small making the entire cable assembly light and easily maneuverable by the welder. When using a water-cooled torch a lack of cooling water or no cooling water at all will cause the polyethylene or braided rubber sheath to melt or possibly burn the power cable in two. A torch manufacturer's specifications will designate the required amount of cooling water for a specific torch. A safety device known as a "fuse assembly" can be installed in the power cable. This assembly contains a fuse link, which is also cooled by the water. If there is no cooling water circulating, the fuse link will melt in two and prevent damage to other more expensive components. The fuse link is easily replaced. When the fuse link is replaced and water flow is maintained, welding can continue. Figure 3.24 shows a GTAW welding setup using a water-cooled torch and a radiator recirculating system.

Figure 3.24 A GTAW welding set-up with a water-cooled torch and radiator cooling system.

GTAW Torch Components

Collet Body

The collet body screws into the torch body. It is replaceable and is changed to accommodate various size tungstens and their respective collets.

Collets

The welding electrode is held in the torch by the collet. The collet is usually made of copper or a copper alloy. The collet's grip on the electrode is secured when the torch cap is tightened in place. Good electrical contact between the collet and tungsten electrode is essential for good current transfer.

Gas Lenses

A gas lens is a device that replaces the normal collet body. It attaches to the torch body and is used to reduce turbulence and produce a longer undisturbed flow of shielding gas. A gas lens will allow the welder to move the nozzle further away from the joint allowing increased visibility of the arc. A much larger diameter nozzle can be used, which will produce a large blanket of shielding gas. This can be very useful in welding material like titanium. The gas lens will also enable the welder to reach joints with limited access such as inside corners. Figure 3.25 is an example of a gas lens and its set up on a torch with a large nozzle and exaggerated tungsten extension.

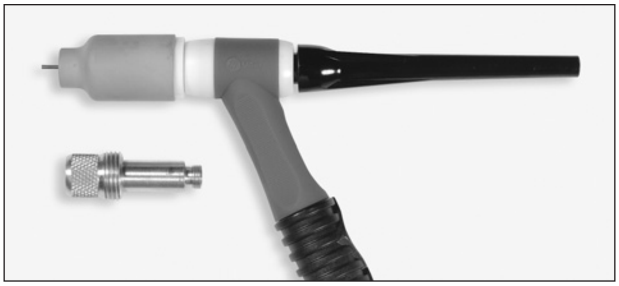


Figure 3.25 Gas lens and set up for welding on a TIG torch.

Nozzles

Gas nozzles or cups as they are better known, are made of various types of heat resistant materials in different shapes, diameters and lengths. The nozzles are either screwed into the torch head or pushed in place. Nozzles can be made of ceramic, metal, metal-jacketed ceramic, glass, or other materials. Ceramic is the most popular, but are easily broken and must be replaced often. Nozzles used for automatic applications and high amperage situations often use a water-cooled metal design.

Gas nozzles or cups must be large enough to provide adequate shielding gas coverage to the weld pool and surrounding area. A nozzle of a given size will allow only a given amount of gas to flow before the flow becomes turbulent. When this occurs the effectiveness of the shielding is reduced, and nozzle size must then be increased to restore an effective non-turbulent flow of gas.

Coolers and Coolants

Water free-flowing directly out of the tap from well or city water sources is not recommended to continuously cool the torch head. Since cold tap water can be below the dew point and cause moisture build-up inside the torch body, this may lead to weld zone contamination until the torch temperature exceeds the dew point. Continuous flow of tap water is not recommended as a coolant because of its inherent mineral content, which can build up over a period of time and clog the small cooling orifices in the torch head. Conservation also dictates use of less wasteful methods, such as coolant radiator re-circulating systems.

The re-circulating coolant must be of the proper type. Since high frequency is being used it should be de-ionized to prevent the coolant from bleeding off the HF prior to it getting to the arc. If the ambient temperature can drop below freezing it must also be protected, but DO NOT use antifreeze. Antifreeze contains leak preventers or other additives and is electrically conductive. Some method of reducing algae growth is advisable. Consult with the coolant system manufacturer for their recommendation on proper coolant solution. De-ionized water can be used if the prior concerns are addressed. All coolants must be clean. Otherwise, blocked passages may cause overheating and damage the equipment. It is advisable to use a water strainer or filter on the coolant supply source. This prevents scale, rust, and dirt from entering the hose assembly.

The rate of coolant flow through the torch is important. Rates that are too low may decrease cooling efficiency. Rates that are too high damage the torch and service line. The direction the coolant flows through the torch is critical. It should flow from the coolant source directly through the water hose to the torch head. The torch head is the hottest spot in the coolant system and should be cooled first with the coolant at its most efficient thermal transfer temperature. This coolant upon leaving the torch head should cool the electrode power cable on its return to the re-circulating system.

Remote Control

Sometimes a welding application requires the welder to place a weld in a location where access to controls on the power source is not readily available. The welder may need to control the amount of current being used. Extra amperage may be required at the start to establish a weld pool more quickly on cold metal, or when making long welds on materials such as aluminum, where weld current must be gradually reduced because of the arc pre-heating the work.

Most welding machines designed primarily for TIG welding provide remote control capability. The remote control capabilities usually include output and current control. Generally, output and current control are located as separate switches on the machine’s front panel and can be operated independently if desired. By using a remote control device, the welder can safely get to a location away from the power source, activate the power source and its systems, (gas flow, arc starter, etc.) and vary the amperage levels as desired.

Remote output gives the welder control of open circuit voltage (OCV) which is present at the output studs of the power source with no load attached. Once a torch is connected to the output, the electrode would be continuously energized if it were not for the output control. The remote outputs primary job then is to interrupt the weld circuit until the welder is prepared to start the arc.

The current control switch on the power source when in the remote position works in conjunction with the main current control. If the main current control is set at 50%, the maximum output current available through the remote device is 50%. To obtain full machine output current through the remote device, the main current control must be set at 100%. Understanding this relationship allows the welder to fine tune the remote control device for the work being done.

The most popular of the remote output and current controls is the foot pedal type seen in Figure 3.26. This type operates much the same as the gas pedal in an automobile: the more it is depressed, the more current flows. Another type which affords greater mobility is the finger-tip control seen in Figure 3.27. The finger-tip control mounts on the torch.

Figure 3.26 TIG foot control. A foot-operated remote output and current control.

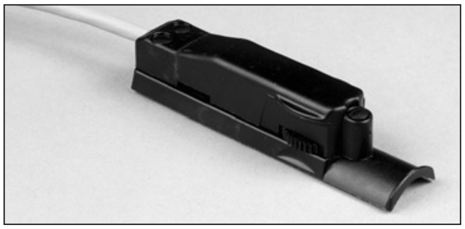


Figure 3.27 Finger-tip control. A finger-tip torch mounted output and current control.

Running Gear and Cylinder Racks

In order for the GTAW process to work most effectively, it is necessary to keep the TIG torch to a fairly short length, generally never over about 50 feet. To allow the power source to be moved within easy reach of the work, having it mounted on a running gear is very advantageous. It not only allows for ease in mobility but aides in keeping the workshop clean. Having the power source mounted a few additional inches off the floor also keeps the internal components in the machine cleaner.

Cylinders are considered high-pressure vessels and must be protected from damage. If the cylinder cap is not in place and the cylinder is not secured, a serious accident can occur. Never leave one of these high-pressure cylinders in an unsecured manner. Figure 3.28 shows a combination running gear and cylinder rack.

Figure 3.28 Cylinder is securely chained in a safe operating condition with a running gear to allow ease of moving the power source and related equipment.

Automated TIG Welding

With increasing needs for high productivity and quality, automated welding is becoming more popular. This can be as simple as a fixed torch head (arc) with the workpiece (joint) being moved by it. Or a fixed workpiece (joint) with the torch (arc) being moved along it. Figure 3.29 shows an example of this type of automation.

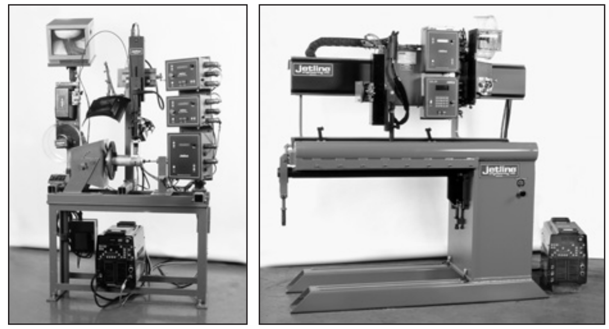


Figure 3.29 Examples of "Hard" Automation. Note the stationary workpiece in one case while the arc is stationary in the other.

One of the most common forms of automation with the GTAW process is its use in orbital welding. The orbital welding equipment clamps onto the workpiece and is used to make tube to tube and tube to sheet type welds. Continued refinement in the computer controls and the inverter power sources systems have made them extremely reliable for precise repeatability. Figure 3.30 shows an orbital welding head and related equipment.

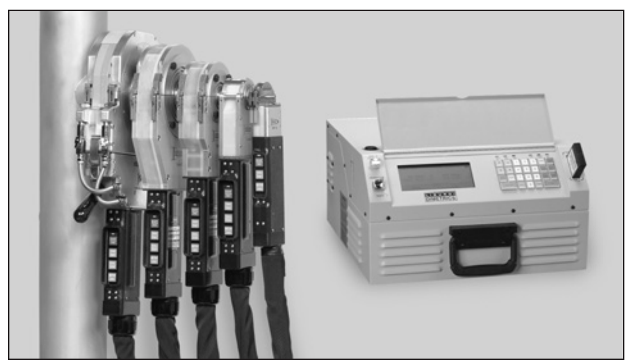


Figure 3.30 An orbital welding head and related equipment.

Whichever method is used, additional control is required over the welding sequence for automation.

A weld sequence is what happens when a signal is given to start the welding operation and also what happens when the welding operation is shutdown. Figure 3.31 is an example of a weld sequence.

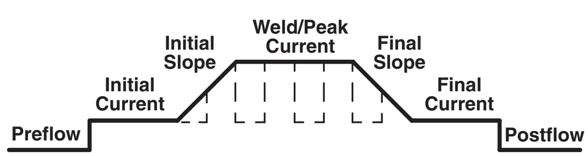


Figure 3.31 The various functions controlled by the weld sequence controller.

These sequence controllers can be built directly into the power source (see Figure 3.32) or be housed in a separate control box (see Figure 3.33).

Figure 3.32 An inverter type power source with built-in weld sequencer primarily used for automated welding.

Figure 3.33 A precision TIG controller with built-in weld sequencer, HF, timers for gas flow, metering and relay control for fixturing.

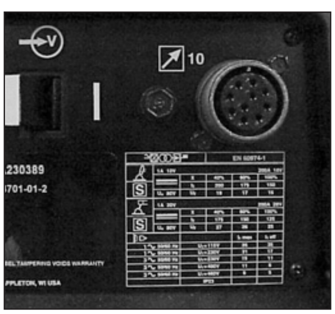


Figure 3.34 The 10-pin connector on an inverter power source capable of being connected for automation operation.

Microprocessors

The ability to control the weld sequence is brought about by the use of microprocessors. These powerful controllers are almost always used in automated welding systems where repeatability is of great importance.

Microprocessor controllers usually have the ability to store numerous weld programs in memory assuring repeatability as well as reducing set-up time.

Those functions controlled by microprocessors might include:

- Arc starting
- Initial current, initial time and initial slope
- Weld current, and weld time
- Final slope, final current and final time
- Pulse peak and background current
- Pulse frequency
- Percent of on time (pulse)
- Post-flow

Connection for Automation Applications

In order to interface the automatic welding power source with the peripheral equipment some means of connection must be provided. This peripheral equipment can be the fixture holding the part, to initiate part clamping or positioning for welding. It can also be for starting the arc movement along the seam or the part moving under the fixed arc. This is a timing function and can best be handled by the weld controller. Figure 3.34 is a 10-pin connection port for connecting this power source to peripheral equipment. It provides indications of the output at specific points in time.

Arc Length Control System

Since arc length is critical on some applications, devices like Figure 3.35 are available to maintain it consistently to plus or minus 0.1 volts. Arc length and arc voltage mean the same thing. Monitoring the voltage and using this data to control the arc length will provide for consistent weld appearance, profile and penetration.

Figure 3.35 An arc length control and head mechanism.

Figure 3.36 Control and magnetic head for arc manipulation.

Figure 3.37 A cold wire TIG set up.

Figure 3.38 A seam tracker for maintaining the arc and joint alignment.

Magnetic Arc Control

This control uses magnetic fields to deflect the arc in advantageous directions. It is useful for high speed automatic welding to even out the weld pool, prevent undercut, and promote uniform penetration. The oscillation and positioning effects of these magnetic fields on the arc improve weld appearance and weld bead profiles. See Figure 3.36.

Cold Wire Feed System

GTAW is generally considered a low-deposition process. However, by automating it and adding the filler wire in an automatic fashion its deposition rate can be increased. Increased weld deposition means higher travel speeds and more parts out the door at the end of the day. Figure 3.37 represents a Cold Wire Feed System. Improved penetration and weld profiles can be had by feeding the filler wire into the back edge of the weld pool versus the front half of the weld pool, which is typically done with manual welding. Some systems can be set up where the filler wire is preheated electrically. These systems are referred to as Hot Wire TIG.

Seam Tracking

In order to keep the welding arc on track when following a constantly varying weld seam, systems like Figure 3.38 have been developed. This type control allows the equipment to constantly monitor the weld joint location both horizontally and vertically over the joint. In order to have consistency at high travel speeds, devices like this can control the position of the welding arc within plus and minus 0.005 inch or 0.13 mm.

IV. Electrodes and Consumables

Tungsten Electrodes for GTAW

Electrodes made of tungsten and tungsten alloys are secured within a GTAW torch to carry current to the welding arc. Tungsten is preferred for this process because it has the highest melting point of all metals.

The tungsten electrode establishes and maintains the arc. It is said to be a “nonconsumable” in that the electrode is not melted and included in the weld pool. In fact, great care must be taken so that the tungsten does not contact the weld pool in any way, thereby causing a contaminated, faulty weld. This is generally referred to as a “tungsten inclusion”.

Tungsten electrodes for GTAW come in a variety of sizes and lengths. They may be composed of pure tungsten, or a combination of tungsten and other elements and oxides. Electrodes are manufactured to specifications and standards developed by the American Welding Society and the American Society For Testing And Materials. Electrodes come in standard diameters from .010" through 1/4", as seen in Figure 4.1. The diameter of tungsten electrode needed is often determined by the thickness of base metal being welded and the required amperage to make the weld.

Lengths of tungstens needed are often determined by the type of torch used for a particular application. Standard lengths are shown in Figure 4.2. Of these, the 7" length is the most commonly used. For special applications some suppliers provide them in cut lengths to your specifications. For example, .200" – .500", .501" – 3.000" and 3.001" – 7.000".

Standard Tungsten Sizes

U.S. Customary		SI Units	
Diameter in	Tolerance ± in. [b, c]	Diameter in	Tolerance ± mm [b, c]
0.010[a]	0.001	0.300	0.025
0.020	0.002	0.50	0.05
0.040	0.002	1.00	0.05
0.060	0.002	1.60	0.05
0.093	0.003	2.00	0.05
0.125 (1/8)	0.003	2.40	0.08
0.156 (5/32)	0.003	2.50	0.08
0.187 (3/16)	0.003	3.00	0.08
0.250 (1/4)	0.003	3.20	0.08
		4.00	0.08
		4.80	0.08
		5.00	0.08
		6.40	0.08
		8.00	0.08

Notes:
a. 0.010 in. (0.30 mm) electrodes are also available in coils.
b. Tolerances, other than those listed, may be supplied as agreed upon between supplier and user.
c. Tolerances shall apply to electrodes in both the clean finish and ground finish conditions.

Figure 4.1 Diameters of standard tungsten electrodes (Courtesy AWS).

3" (76 mm)	12" (305 mm)
6" (152 mm)	18" (457 mm)
7" 178 mm)	24" (610 mm)

Figure 4.2 Standard tungsten lengths.

Chemical Composition Requirements for Electrodes[a]							
		Weight Percent					
AWS Classification	UNS Number[b]	W Min. (difference)[c]	CeO_2	La_2O_3	ThO_2	ZrO_2	Other Oxides or Elements Total
EWP	R07900	99.5	—	—	—	—	0.5
EWCe-2	R07932	97.3	1.8 – 2.2	—	—	—	0.5
EWLa-1	R07941	98.3	—	0.8 – 1.2	—	—	0.5
EWLa-1.5	R97942	97.8	—	1.3 – 1.7	—	—	0.5
EWLa-2	R07943	97.3	—	1.8 – 2.2	—	—	0.5
EWTh-1	R07911	98.3	—	—	0.8 – 1.2	—	0.5
EWTh-2	R07912	97.3	—	—	1.7 – 2.2	—	0.5
EWZr-1	R07920	99.1	—	—	—	0.15 – 0.40	0.5
EWG[d]	—	94.5	NOT SPECIFIED				0.5

Notes:

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

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

c. Tungsten content shall be determined by subtracting the total of all specified oxides and other oxides and elements from 100%.

d. Classification EWG must contain some compound or element additive and the manufacturer must identify the type and minimal content of the additive on the packaging.

Figure 4.3 Tungsten electrode requirements (Courtesy AWS).

Types of tungsten and tungsten alloy electrodes for GTAW are classified according to the chemical makeup of the particular electrode types. Figure 4.3 shows the nine types of electrodes classified by the American Welding Society.

In the first column of Figure 4.3, the AWS identifies the nine classifications as they would for filler metal specifications. The letter "E" is the designation for electrode. The "W" is the designation for the chemical element tungsten.

The next one or two letters designates the alloying element used in the particular electrode. The "P" designates a pure tungsten electrode with no intentionally added alloying elements. The "Ce", "La", "Th", and "Zr" designate tungsten electrodes alloyed with cerium, lanthanum, thorium, or zirconium, respectively.

The number "1", "1.5" or "2" behind this alloy element indicates the approximate percentage of the alloy addition.

The last electrode designation, "EWG", indicates a "general" classification for those tungsten electrodes that do not fit within the other categories. Obviously, two electrodes bearing the same "G" classification could be quite different, so the AWS requires that a manufacturer identify on the label the type and content of any alloy additions.

Electrodes are color coded for ease of identification. Care should be exercised when working with these electrodes so that the color-coding can be kept intact.

Types of Electrodes

EWP (100% Tungsten, Green)

These electrodes are unalloyed, "pure" tungsten with a 99.5% tungsten minimum. They provide good arc stability when using AC current, with either balanced wave or unbalanced wave and continuous high-frequency stabilization. Pure tungsten electrodes are preferred for AC sine wave welding of aluminum and magnesium because they provide good arc stability with both argon and helium shielding gas. Because of their inability to carry much heat, the pure tungsten electrode forms a balled end.

EWCe-2 (2% Cerium, Orange)

Alloyed with about 2% ceria, a non-radioactive material and the most abundant of the rare earth elements, the addition of this small percentage of cerium oxide increases the electron emission qualities of the electrode which gives them a better starting characteristic and a higher current carrying capacity than pure tungsten. These are all-purpose electrodes that will operate successfully with AC or DC electrode negative. Compared with pure tungsten, the ceriated tungsten electrodes provide for greater arc stability. They have excellent arc starting properties at low current for use on orbital tube, pipe, thin sheet and small delicate part applications. If used on higher current applications the cerium oxide may be concentrated to the excessively hot tip of the electrode. This condition and oxide change will remove the benefits of the cerium. The nonradioactive cerium oxide has slightly different electrical properties as compared to the thoriated tungsten electrodes. For automated (orbital tube, etc.) welding these slight changes may require welding parameters and procedures to be adjusted. The cerium electrodes work well with the Advanced Squarewave power sources and should be ground to a modified point.

EWLa-1 (1% Lanthanum, Black), EWLa-1.5 (1.5% Lanthanum, Gold) and EWLa-2 (2% Lanthanum, Blue)

Alloyed with nonradioactive lanthanum oxide, often referred to as lanthana, another of the rare earth elements. These electrodes have excellent arc starting, low-burn-off rate, arc stability, and excellent re-ignition characteristics. The addition of 1 – 2% lanthana increases the maximum current carrying capacity by approximately 50% for a given size electrode using alternating current compared to pure tungsten. The higher the percentage of lanthana, the more expensive the electrode. Since lanthana electrodes can operate at slightly different arc voltages than thoriated or ceriated tungsten electrodes these slight changes may require welding parameters and procedures to be adjusted. The 1.5% content appears to most closely match the conductivity properties of 2% thoriated tungsten. Compared to cerium and thorium the lanthana electrodes had less tip wear at given current levels. Lanthanum electrodes generally have longer life and provide greater resistance to tungsten contamination of the weld. The lanthana is dispersed evenly throughout the entire length of the electrode and it maintains a sharpened point well, which is an advantage for welding steel and stainless steel on DC or the AC from Advanced Squarewave power sources. Thus the lanthana electrodes work well on AC or DC electrode negative with a pointed end or they can be balled for use with AC sine wave power sources.

EWTh-2 (2% Thorium, Red) and EWTh-1 (1% Thorium, Yellow)

Commonly referred to as 1 or 2% thoriated tungstens, these are very commonly used electrodes since they were the first to show better arc performance over pure tungsten for DC welding. However, thoria is a low-level radioactive material, thus vapors, grinding dust and disposal of thorium raises health, safety and environmental concerns. The relatively small amount present has not been found to represent a health hazard. But if welding will be done in confined spaces for prolonged periods of time, or if electrode grinding dust might be ingested, special precautions should be taken concerning proper ventilation. The welder should consult informed safety personnel and take the appropriate steps to avoid the thoria.

The thoriated electrode does not ball as does the pure tungsten, cerium or lanthana electrodes. Instead, it forms several small projections across the face of the electrode when used on alternating current. When used on AC sine wave machines, the arc wanders between the multiple projections and is often undesirable for proper welding. Should it be absolutely necessary to weld with these type machines, the higher content lanthana or thoria electrodes should be used. The thoriated electrodes work well with the Advanced Squarewave power sources and should be ground to a modified point. These electrodes are usually preferred for direct current applications. In many DC applications, the electrode is ground to a taper or pointed. The thorium electrode will retain the desired shape in those applications where the pure tungsten would melt back and form the ball end. The thoria content in the electrode is responsible for increasing the life of this type over the pure tungsten, EWP.

EWZr-1 (1% Zirconium, Brown)

A zirconium oxide (zirconia) alloyed tungsten electrode is preferred for AC welding when the highest quality work is necessary and where even the smallest amounts of weld pool contamination cannot be tolerated. This is accomplished because the zirconium alloyed tungsten produces an extremely stable arc which resists tungsten spitting in the arc. The current carrying capability is equal to or slightly greater than an equal sized cerium, lanthana or thorium alloyed electrode. Zirconium electrodes are typically used only for AC welding with a balled end.

EWG (unspecified alloy, Gray)

This classification covers tungsten electrodes containing unspecified additions of rare earth oxides or combinations of oxides. As specified by the manufacturer, the purpose of the additions is to affect the nature or characteristics of the arc. The manufacturer must identify the specific addition or additions and the quantity or quantities added.

Some “rare earth” electrodes are in this category and they contain various percentages of the 17 rare earth metals. One mixture is 98% tungsten, 1.5% lanthanum oxide, and a .5% special mixture of other rare earth oxides. Some of these electrodes work on AC and DC, last longer than thoriated tungsten, can use a smaller size diameter tungsten for the same job, can use a higher current than similar sized thoriated tungstens, reduce tungsten spitting, and are not radioactive.

Tungsten electrodes for GTAW can easily be recognized by their color code. See Figure 4.4.

Electrode Identification Requirements[a,b]

AWS Classification	Color
EWP	Green
EWCe-2	Orange
EWLa-1	Black
EWLa-1.5	Gold
EWLa-2	Blue
EWTh-1	Yellow
EWTh-2	Red
EWZr-1	Brown
EWG	Gray

Notes:
a. The actual color may be applied in the form of bands, dots, etc., at any point on the surface of the electrode.
b. The method of color coding used shall not change the diameter of the electrode beyond the tolerances permitted.

Figure 4.4 Color codes for tungsten electrodes (Courtesy AWS).

Use of Tungsten Electrodes

Electrodes used for GTAW welding differ greatly in many respects from electrodes used in consumable metal arc welding. The tungsten electrode is not melted or used as filler metal as is the case with SMAW or GMAW electrodes. At least it is not intended to be melted and become part of the weld deposit. However, in cases where the wrong electrode type, the wrong size of electrode, the wrong current, the wrong polarity or technique is used, tungsten particles can be transferred across the arc. The power source used may affect the amount of tungsten which may be transferred across the arc. A machine designed specifically for GTAW welding will usually have characteristics advantageous for the process. Excessive current surges or “spikes” will cause “spitting” of tungsten. Excessive arc rectification on aluminum or magnesium will cause a half-wave effect, and cause particles of tungsten to be transferred across the arc. An understanding of the electrode materials and types of electrodes and their recommended uses will enable the user to make the proper electrode selection.

Tungsten is a very hard steel gray metal. It is a highly refractory metal and does not melt or vaporize in the heat of the arc. It has a melting point of 6170˚ F (3410˚ C), and a boiling point of 10,220˚ F (5600˚ C). Tungsten retains its hardness even when red hot.

With the choice of several alloy types and a variety of sizes, many factors must be considered when selecting the electrode. One of the main considerations is welding current. The welding current will be determined by several factors including base metal type and thickness, joint design, fit-up, position, shielding gas, type of torch, and other job quality specifications.

An electrode of a given diameter will have its greatest current carrying capacity with direct current electrode negative (DCEN), less with alternating current and the least with direct current electrode positive (DCEP). Figure 4.5 lists some typical current values for electrodes with argon shielding.

Tungsten has a high resistance to current flow and therefore, heats up during welding. In some applications the extreme tip forms a molten hemisphere. The "ball" tip is characteristic of pure tungsten and is most desirable for AC welding with sine wave power sources. The extreme tip is the only part of the electrode which should be this hot. The remainder of the electrode should be kept cool. Excessive electrode stickout beyond the collet will cause heat build-up in the electrode. In a water-cooled torch, the heat is more rapidly dissipated from the collet assembly and helps cool the electrode. Excessive current on a given size electrode will cause the tip to become excessively hot.

		Typical Current Range (Amps)				
		Direct Current, DC	Alternating Current, AC			
		DCEN	70% Penetration		(50/50) Balanced Wave A	
Tungsten Diameter	Gas Cup Inside Diameter	Ceriated Thoriated Lanthanated	Pure	Ceriated Thoriated Lanthanated	Pure	Ceriated Thoriated Lanthanated
.040	#5 (3/8 in)	15 – 80	20 – 60	15 – 80	10 – 30	20 – 60
.060 (1/16 in)	#5 (3/8 in)	70 – 150	50 – 100	70 – 150	30 – 80	60 – 120
.093 (3/32 in)	#8 (1/2 in)	150 – 250	100 – 160	140 – 235	0 – 130	100 – 180
.125 (1/8 in)	#8 (1/2 in)	250 – 400	150 – 200	225 – 325	100 – 180	160 – 250
All values are based on the use of Argon as a shielding gas. Other current values may be employed depending on the shielding gas, type of equipment, and application. DCEN = Direct Current Electrode Negative (Straight Polarity)						

Figure 4.5 Typical current ranges for electrodes with argon shielding.

After the proper size and type of electrode has been selected, how the electrode is used and maintained will determine its performance and life. There are many misconceptions about tungsten electrodes and their correct use. The following information is intended to serve as a guideline to common sense decisions about tungsten electrodes.

Electrode Preparation

For AC Sine Wave and Conventional Squarewave

These electrodes should have a hemispheric or balled end formed. The diameter of the end should not exceed the diameter of the electrode by more than 1.5 times. As an example, a 1/8" electrode should only form a 3/16" diameter end. If it becomes larger than this because of excessive current, there is the possibility of it dropping off to contaminate the weld. If the end is excessively large, and the current is decreased before the molten tip drops off, the arc tends to wander around on the large surface of the electrode tip. The arc becomes very hard to control as it wanders from side to side. If welding conditions are correct, a visual observation of the electrode should reveal a ball end of uniform shape and proper size.

For improved arc focus set the balance control to maximum penetration and try a ceriated, lanthanated or thoriated tungsten with a modified point.

For Advanced Squarewave Use (Pointed)

With the expanded balance control of up to 90% electrode negative, the electrode shape is very nearly the same as for DC electrode negative welding. This improves the ability to focus the arc along with an even greater localization of the heat into the work. Do not use with pure tungsten.

For DC Electrode Negative Use (Pointed)

Since all of the weld energy is provided by electrode negative, there is very little heating affect on the tungsten and a sharp pointed tungsten is generally preferred. Figure 4.6 shows the preferred shapes for balled and the various types of points used with the DC and AC wave shaped power sources.

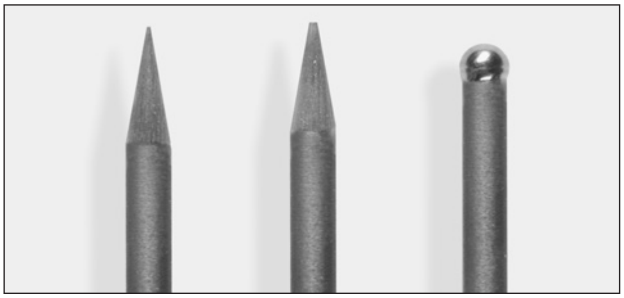


Figure 4.6 The ball diameter should never exceed 1.5 times the electrode diameter. Pointed tungstens are as noted.

Pointing of electrodes is a subject which has received much discussion. There are many theories and opinions on the degree of the point. Again, the application has a bearing on the configuration of the point. Along with application experience, the following should serve as a guide to pointing of electrodes.

A common practice in pointing electrodes is to grind the taper for a distance of 2 to 2-1/2 electrode diameters in length for use on DC and usually to a sharp needle point (see top of Figure 4.7). Using this rule for a 1/8" electrode, the ground surface would be 1/4 to 5/16" long.

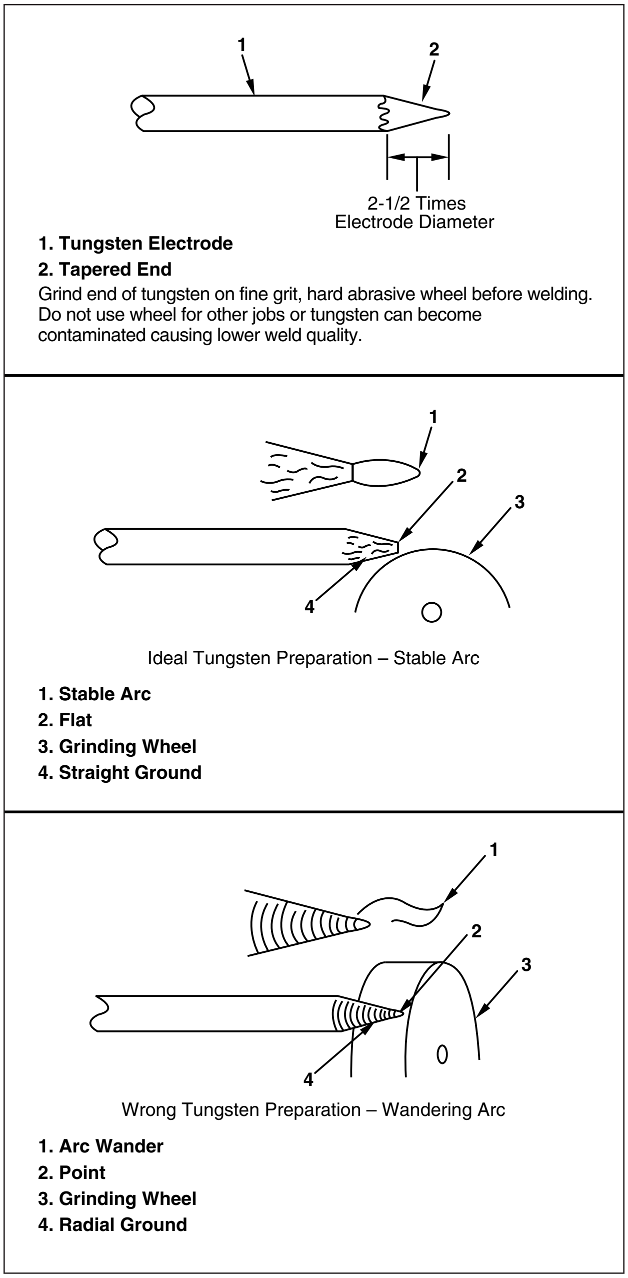


Figure 4.7 Preparing tungsten for DC electrode negative welding and AC with wave shaping power sources.

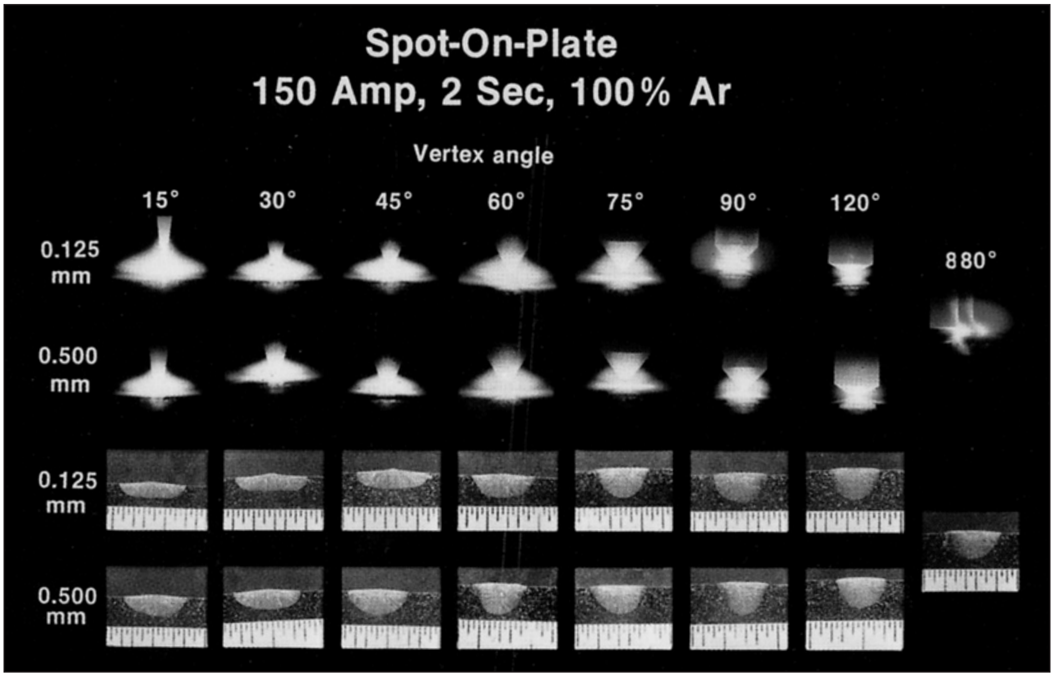


Figure 4.8 Arc shape and weld profile as a function of electrode tip angle. Image courtesy of *American Welding Society (AWS) Welding Handbook, 8th ed., Volume 2*, "Welding Processes." Miami: American Welding Society.

Needle-pointed electrodes are usually preferred on very thin metals in the range of .005" to .040". In other applications, a slightly blunted end is preferred because the extreme point may be melted off and end up in the deposit. In many applications, pointing is done where actually a smaller electrode should be used. Figure 4.8 shows examples of various arcs and weld profiles produced by changing the electrode tip angle.

Tungsten is harder than most grinding wheels, therefore it is chipped away rather than cut away. The grinding surface should be made of some extremely hard material like diamond or borazon. The grinding marks should run lengthwise with the point (see middle and bottom of Figure 4.7). If the grinding is done on a coarse stone and the grinding marks are concentric with the electrode, there are a series of ridges on the surface of the ground area. There is a possibility of the small ridges melting off and floating across the arc. If the stone used for grinding is not clean, contaminating particles can be lodged in the grinding crevices and dislodge during welding, ending up in the deposit. The grinding wheel used on tungsten electrodes should be used for no other material.

The surface of the tungsten after use should be shiny and bright. If it appears dull, an excess of current is indicated. If it appears blue to purple or blackened, there is insufficient postflow of the shielding gas. This means the surrounding atmosphere oxidized the electrode while still hot, and it is now contaminated. Continuing to weld with this condition can only result in the oxide flaking off and ending up in the weld deposit. A general rule for postflow is one second for each ten amperes of welding current. This is normally adequate to protect the tungsten and weld pool until they both cool below their oxidizing temperature.

Contamination of the electrode can occur in several ways in addition to the lack of postflow shielding gas. The most common form of contamination is contact between electrode and weld pool or electrode and filler rod. Loss of shielding gas or contamination of the shielding gas due to leaking connections or damaged hoses causes electrode contamination. Excessive gas flow rates and nozzles that are dirty, chipped or broken cause turbulence of the shielding gas. This aspirates atmospheric air into the arc area causing contamination.

The electrode that has been contaminated by contact with the pool or filler rod will have a deposit of the metal on the electrode. If this is not too serious, maintaining an arc on a scrap piece of material for a period of time may vaporize the deposit off the electrode. If the contamination cannot be removed in this manner, the preferred method is to grind the electrode to remove the contamination. Use good grinding techniques, as improper techniques can cause problems or injury. Breaking the contaminated tungsten off is generally not recommended as it may cause a jagged end, split or bend the electrode. This may result in excessive electrode heating and a poorly shaped arc. Proper tungsten shaping and removal of contamination is a key to maintaining consistent welds. A properly prepared tungsten will reduce or eliminate arc wandering, splitting, spitting and weld quality inconsistencies. Figure 4.9 shows a specially designed grinder for tungsten preparation.

Figure 4.9 Bench model tungsten grinder.

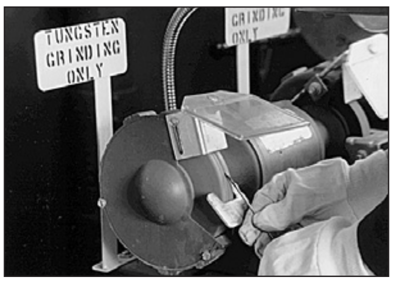


Figure 4.10 Tungsten electrode preparation.

Use good techniques when grinding the electrode to remove contamination. Grinding should be done on a fine grit hard abrasive wheel. Figure 4.11 shows several 1/8" tungsten electrodes. Notice the different tip configurations.

Figure 4.12 A typical air separation facility operated by the Canadian Liquid Air company at Varennes, Quebec, Canada.

Shielding Gas

All arc welding processes utilize some method of protecting the molten weld pool from the atmosphere. Without this protection, the molten metal reacts with gases in the atmosphere and produces porosity (bubbles) in the weld bead greatly reducing weld strength.

The importance of atmospheric shielding is reflected in the fact that all arc welding processes take their names from the method used to provide the shielding; Gas Tungsten Arc, Gas Metal Arc, Submerged Arc, Shielded Metal Arc, Flux Cored, etc.

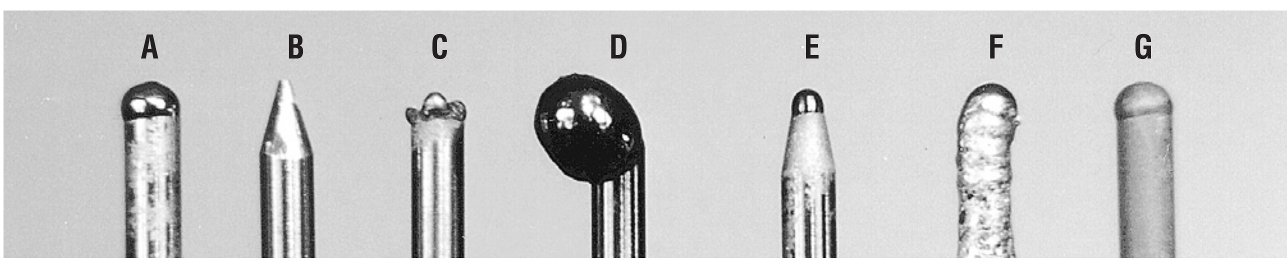


Figure 4.11 1/8" Tungstens.

ELECTRODE "A" has the "ball" end. This pure tungsten was used with alternating current with a sine wave power source on aluminum. Notice the end is uniform in shape and possesses a "shiny bright" appearance.

ELECTRODE "B" is a 2% thoriated tungsten ground to a taper and was used with direct current electrode negative, or a similar shape for Advanced Squarewave applications.

ELECTRODE "C" is a 2% thoriated tungsten used with an alternating current sine wave power source on aluminum. Note that this electrode has several small ball shaped projections rather than a round complete "ball end" like the pure tungsten.

ELECTRODE "D" is a pure tungsten used with alternating current sine wave power source or balance control set to excessive cleaning action on an AC wave controlled power source on aluminum. This electrode was subjected to a current above the rated capacity. Notice the "ball" started to droop to one side. It became very molten during operation and continuing to operate would have caused the molten end to drop into the weld pool.

ELECTRODE "E" is a pure tungsten that was tapered to a point and used on direct current electrode negative. Notice the "ball" tip characteristic of the pure tungsten. Pointing of pure tungsten is not recommended as the extreme point will always melt when the arc is established, and often times the molten tip will drop into the molten weld pool.

ELECTRODE "F" was severely contaminated by touching the filler rod to the tungsten. In this case, the contaminated area must be broken off and the electrode reshaped as desired.

ELECTRODE "G" did not have sufficient gas postflow. Notice the black surface which is oxidized because the atmosphere contacted the electrode before it cooled sufficiently. If this electrode were used, the oxidized surface will flake off and drop into the weld pool. Postflow time should be increased so the appearance is like electrode "A" after welding.

Primarily two inert gases are used for shielding purposes for TIG. They are argon and helium. Shielding gases must be of high purity for welding applications. The purity required is at a level of 99.995%.

Although the primary function of the gas is to protect the weld pool from the atmosphere, the type of gas used has an influence on the characteristics and behavior of the arc and the resultant weld bead. The chief factor influencing the effectiveness of a shielding gas is the gas density. Argon, with an atomic weight of 40, is about one and a half times heavier than air and ten times heavier than helium which has an atomic weight of 4. Argon after leaving the torch nozzle tends to form a blanket over the weld, whereas helium tends to rise rapidly from the arc area. In order to obtain equivalent shielding, flow rates for helium are usually two to three times that of argon.

An examination of the characteristics and a comparison of these gases will serve as a guide to shielding gas selection.

Argon

Argon is obtained as a byproduct in the manufacturing of oxygen. Breaking down the contents of the atmosphere would approximately yield the following:

.9% Argon
78.0% Nitrogen
21.0% Oxygen
.1% Other rare gases

Looking at these percentages, it's evident that many cubic feet of air must be processed in order to obtain a cylinder of argon. The price of argon may vary widely depending on locality and volume purchased.

Argon may be obtained in the gaseous state in cylinders or as a liquid in specially constructed cylinders or in bulk tanks. As a liquid, argon will be at a temperature of slightly below -300˚ F (-184˚ C). The most commonly used size of cylinder contains 330 cubic feet (935 Liters) at 2640 p.s.i. (18,203 kPa) at 70˚ F (21˚ C). When large volumes are required a bulk liquid supply is most desirable and economical. Each gallon (3.785 liters) of liquid will produce approximately 112 cubic feet (317 L) of gaseous argon. Liquid argon may be obtained in cylinders containing up to 4,000 cubic feet (11.328 kL) of gaseous argon. If larger quantities are desired, a bulk liquid tank may be installed.

When choosing a shielding gas, a fact that must be considered is the ionization potential of the gas. Ionization potential is measured in volts and is the point where the welding arc will be established between the electrode and the workpiece through the shielding gas. In other words, it is the voltage necessary to electrically charge the gas so that it will conduct electricity. The ionization potential of argon is 15.7 volts. So this is the minimum voltage that must be maintained in the welding circuit to establish the arc or to weld with argon. The ionization potential is different for every gas and has a major effect on the arc and weld bead. The ionization potential for helium is 24.5 volts. Comparing two welding circuits, each being equal except for shielding gas, the arc voltage produced with argon would be lower than that produced by helium.

Argon has low thermal conductivity which means it is not a good conductor of heat. This results in a more compact, higher density arc. Arc density refers to the concentration of energy in the arc. With argon this energy is confined to a narrow or more "pinpointed" area.

Argon provides excellent arc stability and cleaning action even at low amperages.

Helium

Unlike argon, helium has high thermal conductivity. Due to this higher thermal conductivity, the arc column expands, reducing current density in the arc. The arc column will become wider and more flared out than the arc column with argon shielding gas. Figure 4.13 illustrates the two arc columns. The more flared out the arc column, the more work surface area is being heated. The heat at the center of the arc can move more readily downward toward the colder metal at the bottom of the workpiece. This results in a deeper penetrating arc. Figure 4.13 also illustrates the resultant weld beads and the difference in penetration produced by argon and helium.

It was mentioned previously that with an equivalent arc length, helium will produce a higher arc voltage than will argon. Since the total power is a product of voltage and amperage, it is apparent that more heat energy is available with helium. Helium or argon-helium mixtures are desirable on thick material and where high travel speeds are desired. The use of a 2:1 helium to argon gas mixture has also been shown to yield lower porosity welds in production situations by allowing wider variation in welding parameters. With helium shielding any slight variation of arc length can have quite an affect on arc voltage and consequently total arc power. For this reason, helium is not as desirable as argon for manual welding applications.

Because of its higher ionization potential, it is more difficult to start an arc with helium shielding gas, especially at lower amperages. Argon is used almost exclusively when welding at 150 amps and lower.

Because helium is a light gas, flow rates are usually two or three times higher than argon for equivalent shielding. The cost of helium is considerably more than argon, and with the increased flow rate, total cost of shielding goes up sharply. The cost must be weighed against increased penetration on thick material and the increased travel speed attainable.

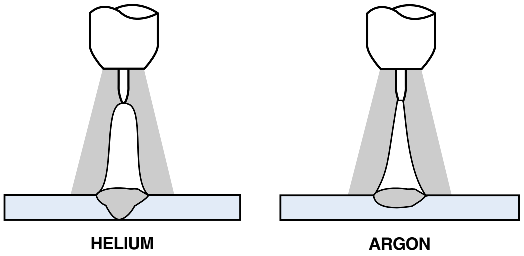


Figure 4.13 A representation of the affects on the arc and bead produced by argon and helium shielding gases. Note the wider arc and deeper penetration produced by the helium shielding gas.

Hydrogen

Just as helium is mixed with argon to take advantage of the best features of both gases, hydrogen is mixed with argon to further constrict the arc and produce a cleaner weld with a greater depth to width ratio (penetration). This mix is used primarily for welding austenitic stainless steel and some nickel alloys. The addition of hydrogen to argon also increases travel speed. It should be noted that an argon hydrogen mix will introduce the risk of hydrogen cracking and metal porosity particularly in multipass welds.

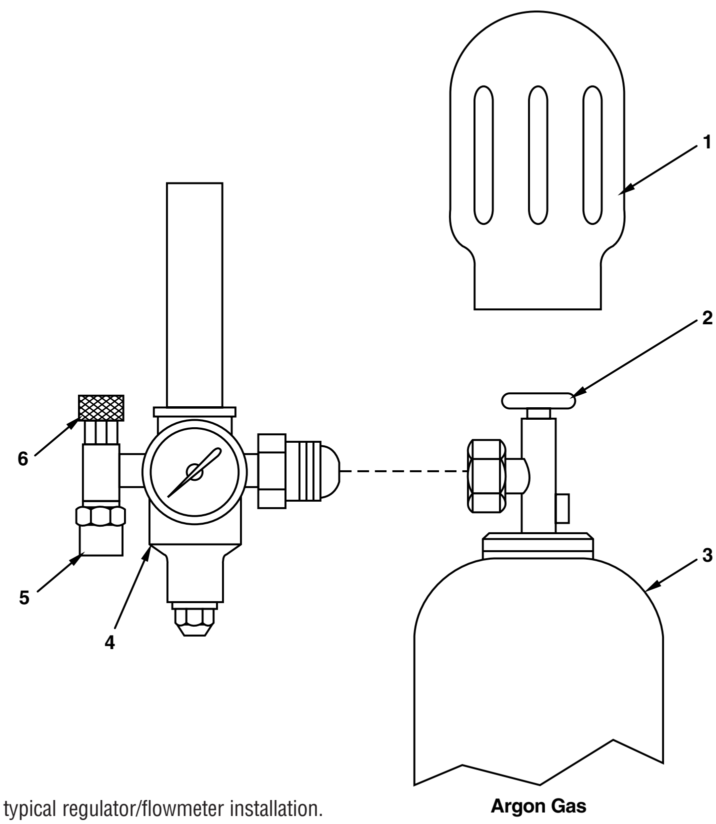
Nitrogen

Nitrogen when mixed with argon provides the capability of producing more energy to the work than with argon alone. This can be particularly beneficial when welding materials of high conductivity such as copper. However, a nitrogen mix cannot be used on ferrous metals such as steel and stainless steel because nitrogen pick up in the weld pool causes a significant reduction in strength and a weaker, more porous bead.

Flow Rate

The correct flow rate is an adequate amount to shield the molten weld pool and protect the tungsten electrode. Any greater amount than this is wasted. The correct flow rate in cubic feet per hour is influenced by many variables that must be considered on each application. Generally speaking, when the welding current, nozzle diameter, or electrode stickout is increased, the flow rate should be increased. When welding in the AC mode the current reversals have a disturbing affect on the shielding gas and flow should be increased by 25%. And of course when welding in a drafty situation, flow rate should be doubled. When welding corner or edge joints, excessive flow rates can cause air entrapment. In this situation, the effectiveness of the shielding gas can be improved by reducing the gas flow by about 25%.

Figure 4.15 The regulator/flowmeter regulates the flow of shielding gas from the cylinder to the welding torch. This meter displays the amount of pressure in the cylinder as well as the rate of flow.



Obtain gas cylinder and chain to running gear, wall, or other stationary support so the cylinder cannot fall and break off valve.

1. Cap

2. Cylinder Valve
Remove cap, stand to side of valve, and open valve slightly. Gas flow blows dust and dirt from valve. Close valve.

3. Cylinder

4. Regulator/Flowmeter
Install so face is vertical.

5. Gas Hose Connection
Fitting has 5/8 – 18 right-hand threads. Obtain and install gas hose.

6. Flow Adjust
Typical flow rate is 15 cfh (cubic feet per hour)
Make sure flow adjust is closed when opening cylinder to avoid damage to the flowmeter.

Figure 4.14 A typical regulator/flowmeter installation.

Preflow and Postflow

The purpose of both preflow and postflow is to prevent contamination of both the weld pool and the tungsten electrode by the surrounding atmosphere.

When the torch is not in use, air will enter the system through the nozzle. Moisture in the air can condense inside the nozzle and gas hose and then cause hydrogen contamination during initial stages of the weld. The shielding gas preflow will clear the air and moisture from the torch and prevent this contamination.

Postflow works a little differently. Immediately after the welding arc is extinguished, the weld bead, filler rod and the tungsten electrode remain hot enough to cause a chemical reaction with oxygen in the atmosphere. The result of this oxidization is quite obvious when it occurs because it causes the weld bead, filler rod and tungsten to turn black. Proper postflow will prevent oxidization from occurring by shielding the hot electrode and weld area, and by speeding up the cooling process. It should be remembered that a tungsten that has discolored because of oxidization must be properly removed.

Backing Dams and Trailing Shields

Just as the surface of the weld bead must be protected from atmospheric contamination, the backside must be protected as well. In the case of pipe welding or other full penetration butt joints, this can be accomplished with a backing dam, as seen in Figure 4.16. Often a backing dam can be something as simple as heavy paper used to close off the ends of the pipe through which a gas hose is passed to fill the pipe with shielding gas to elaborate diaphragms, hoses and valves. A length of angle iron can be clamped to the backside of straight line weldments to hold the gas in place for that type of weld.

In some cases where the weld occurs too fast for the torch supplied shielding gas to protect the pool and tungsten, a trailing shield may be used. Trailing shields are available as separate devices that attach to the torch or torch nozzle. Back or trail shielding is required on reactive metals like titanium, duplex steels, stainless steels, etc. This type shielding keeps the welds bright and shiny without discoloration and oxidation, thus reducing rework due to contamination.

Figure 4.16 A welder prepares to install a backing dam over the end of a pipe to be welded.

GTAW and Use of Filler Metal

The GTAW tungsten electrode is a nonconsumable (does not melt) and thus does not become part of the weld, as do SMAW or GMAW electrodes that melt and become filler metal which adds to the weld volume. This is advantageous on thin materials (usually under 1/16") where the GTAW weld fuses the edges of the base materials together. This is referred to as an “autogenous” weld (no filler), and is common on thin metal butt, lap and flange joints.

Welds on thicker metals (about 1/16" and up), beveled joints and poor fitup joints may need filler wire added to the weld pool for proper fusion and weld strength. This is usually done by hand feeding the filler wire into the pool. The filler rod diameter should be approximately the same as the electrode diameter. The hot end of the filler rod should be kept in the blanket of shielding gas and/or postflow until it has cooled below its oxidation temperature.

Automated GTAW uses a wire feeder to automatically feed a continuous wire into the weld pool as the weld proceeds along the joint. Figure 3.37 on page 30 shows this type of equipment.

Types of GTAW Filler Metals

Perhaps the most common filler material for GTAW takes the form of 36" straight rods that are fed by one hand while the other hand manipulates the torch. Figure 4.17 shows standard sizes for filler rods, according to the American Welding Society. These rods usually come in 10 or 50 pound boxes or tubes and often have the wire type on a tag or stamped into the side of each piece of filler rod. TIG is preferred for critical work that is generally done to a code and approved welding procedures. To maintain control the filler metal must be identifiable.

Standard Sizes[a]

Standard Package Form	Diameter in.	Diameter mm	Tolerance[b] in.	Tolerance[b] mm
Straight lengths[b,c] and Coils without support	1/16 (0.0625)	1.6	±0.0015	±0.04
	3/32 (0.094)	2.4		
	1/8 (0.125)	3.2		
	5/32 (0.156)	4.0		
	3/16 (0.187)	4.8		
	1/4 (0.250)	6.4		

Notes:

a. Dimensions, tolerances, and package forms (for round filler metal) other than those shown shall be agreed by purchaser and supplier.

b. There is no specified tolerance for cast rod in straight lengths.

c. Length of wrought rods shall be 36 in.,+0. — − 1/2 in. (approximately 900 ± 20 mm). Length of cast rods shall be 18 in. ± 1/2 in. (approximately 450 ± 12 mm)

Figure 4.17 Sizes of GTAW filler rod.

Also used to a lesser degree are flattened rods. These are preferred by some welders who feel it is easier to feed the rods because of their shapes. Figure 4.18 shows sizes of flattened rods.

Another type of filler material is coiled wire for automated GTAW. This would be the same wire used on a given material for the GMAW process.

Typical Sizes of Flattened Rods*

Equivalent Round Diameter		Thickness		Width	
in.	mm	in.	mm	in.	mm
1/16	1.6	0.047	1.2	0.072	1.8
3/32	2.4	0.070	1.8	0.105	2.7
1/8	3.2	0.095	2.4	0.142	3.6
5/32	4.0	0.115	2.9	0.175	4.4
3/16	4.8	0.140	3.6	0.210	5.3
1/4	6.4	0.187	4.8	0.280	7.1

*Standard length shall be 36 in. +0, –1/2 in. (approximately 900 ±20 mm).

Figure 4.18 Flattened rod sizes for GTAW.

Filler Metal Specifications

The American Welding Society (AWS) publishes several booklets of specifications for GTAW filler materials. Often these booklets are used as specifications for GMAW electrode wires as well. Figure 4.19 is a list of AWS filler material, shielding gas and tungsten electrode specification booklets.

A5.7	Copper and Copper Alloy Bare Welding Rods and Electrodes
A5.9	Corrosion Resisting Chromium and Chromium-Nickel Steel Bare and Composite Metal Cored and Stranded Welding Electrodes and Welding Rods
A5.10	Bare Aluminum and Aluminum Alloy Welding Electrodes and Rods
A5.12	Tungsten and Tungsten Alloy Electrodes for Arc Welding and Cutting
A5.13	Solid Surfacing Welding Rods and Electrodes
A5.14	Nickel and Nickel Alloy Bare Welding Rods and Electrodes
A5.16	Titanium and Titanium Alloy Welding Electrodes and Rods
A5.18	Carbon Steel Filler Metals for Gas Shielded Arc Welding
A5.19	Magnesium Alloy Welding Rods and Bare Electrodes
A5.21	Composite Surfacing Welding Rods and Electrodes
A5.24	Zirconium and Zirconium Alloy Bare Welding Rods and Electrodes
A5.28	Low Alloy Steel Filler Metals for Gas Shielded Arc Welding
A5.30	Consumable Inserts
A5.32	Welding Shielding Gases

Figure 4.19 AWS specifications for GTAW filler materials, shielding gases and tungsten electrodes.

Types and Designations of Filler Metals

Steel

There are seven designations for carbon steel filler rods. A typical designation would be ER70S-6 for TIG. The "ER" means the filler can be used for either GTAW or GMAW. If the designation lacked the "R" it would signify a continuous electrode for use with GMAW only. There is no designation for rod using just the "R", it will always be "ER". The "70" stands for the welded tensile strength, measured in thousands of pounds per square inch. "S" stands for "Solid" electrode as opposed to a tubular or hollow wire such as that used in the flux cored welding process. And the "6" refers to the particular degree of manufactured chemical percentages within the rods composition. In other words, the number at the end of the description refers to which classification of wire is being used.

Stainless Steels

There are many more stainless steel designations than there are steel designations. A typical classification of a stainless rod would be ER308. The "ER", as it is in steel, stands for either continuous electrode, or electrode rod. The "308" designates a specific stainless steel chemical composition. These numbers are often used to match the filler rod to specific compositions of base metals being welded.

Certain types of stainless steel rods may have letters or numbers after the three digits, such as "L" meaning low carbon content, or "Si" meaning high silicon content. Sometimes a manufacturer's brand name may use "ELC" instead of "L" to mean Extra Low Carbon, or "HiSil" instead of "Si" meaning High Silicon Content.

It's important to remember the "ER" designations because the AWS has separate specification books for "ER" filler metals and for "E" filler metals. "E" filler metals, such as E308-16, would refer to covered welding electrodes, such as those used for SMAW (Stick).

Titanium

There are approximately 13 different designations for titanium filler rods. A typical designation would be ERTi-5ELI. The "ER" means the filler can be used for either GTAW or GMAW. The "Ti" indicates titanium, the "5" is specific characteristics such as alloy content, and the "ELI" means extra-low interstitial impurities. If the base metal has extra-low interstitial impurities the filler metal selected should also carry the same classification. The interstitial nature of elements such as carbon, hydrogen, oxygen and nitrogen are kept very low with the ELI classification.

When welding titanium and its alloy, the filler metal should closely match the alloy content of the base metal being welded. The ERTi-1, -2, -3 and -4 are designations for commercially pure titanium (CP) welding. These unalloyed filler metals can tolerate some contamination from the welding atmosphere without significant loss in ductility. Unalloyed filler metals may be used to weld titanium alloys when ductility is more important than joint strength. Less than 100% joint efficiencies can be expected.

Filler metal contamination is very serious when welding titanium. The filler wire should be wiped clean with acetone and a lint-free cloth. Cleaning should continue until the cloth is free from any indications of contamination. The filler wire should also be inspected for any physical defects such as cracks, seams or laps. These defects may trap contaminations making them difficult or impossible to remove. To prevent recontamination of the filler rod, it should be handled after cleaning in a so-called "white glove" procedure (clean lint free gloves).

Aluminum

There are approximately 12 designations for aluminum filler rods. A common all purpose rod is ER4043. The "ER" designates electrode or rod, and the "4043" designates a specific chemical composition. ER4043 is used with many aluminum base metals, but always consult electrode wire manufacturers for the proper filler to use in critical welds. Figure 4.20 contains some typical examples.

Base Metal, (T)Temper	Filler Metal
1100	ER1100
2014-T6	ER4043
2219-T81	ER2319
3003	ER1100
5005	ER5356
5456	ER5556
6061-T4	ER4043
6061T-6	ER5356
7005T-53	ER5356

Figure 4.20 Typical aluminum base metal filler metal recommendations.

Figure 4.21 represents some GTAW filler metals cross referenced between the AWS classification number and a typical manufacturers specification number.

Table 3.6
Guide to the Choice of Filler Metal for Aluminum

Base Metal	319.0,333.0 354.0,355.0 C355.0,380.0	356.0,A356.0 A357.0,359.0 413.0,A444.0 443.0	511.0,512.0 513.0,514.0	7005[k],7039 710.0,711.0 712.0	6070	6061 6063.6101 6201,6151 6351,6951	5456	5454	5154 5254[a]	5086	5083	5052 5652[a]	5005 5050	3004 Alc.3004	2219 2519	2014 2036	1100 3003 Alc.3003	1060 1070,1080 1350
1060,1070, 1080,1350	4145[c,i]	4043[i,f]	4043[e,i]	4043[i]	4043[i]	4043[i]	5356[c]	4043[i]	4043[e,i]	5356[c]	5356[c]	4043[i]	1100[c]	4043	4145	4145	1100[c]	1188[j]
1100,3003 Alclad 3003	4145[c,i]	4043[i,f]	4043[e,i]	4043[i]	4043[i]	4043[i]	5356[c]	4043[e,i]	4043[e,i]	5356[c]	5356[c]	4043[e,i]	4043[e]	4043[e]	4145	4145	1100[c]	
2014,2036	4145[g]	4145			4145	4145									4145[g]	4145[g]		
2219,2519	4145[g,c,i]	4145[c,i]	4043[i]	4043[i]	4043[f,i]	4043[f,i]	4043	4043[i]	4043[i]	4043	4043	4043i	4043	4043	2319[c,f,i]			
3004 Alclad 3004	4043[i]	4043[i]	5654[b]	5356[e]	4043[e]	4043[b]	5356[e]	5654[b]	5654[b]	5356[e]	5356[e]	4043[e,i]	4043[e]	4043[e]				
5005,5050	4043[i]	4043[i]	5654[b]	5356e	4043[e]	4043[b]	5356[e]	5654[b]	5654[b]	5356[e]	5356[e]	4043[e,i]	4043[d,e]					
5052,5652[a]	4043[i]	4043[b,i]	5654[b]	5356[e]	5356[b,c]	5356[b,c]	5356[b]	5654[b]	5654b	5356[e]	5356[e]	5654[a,b,c]						
5083		5356[c,e,i]	5356[e]	5183[e]	5356[e]	5356[e]	5183[e]	5356[e]	5356[e]	5356[e]	5183[e]							
5086		5356[c,e,i]	5356[e]	5356[e]	5356[e]	5356[e]	5356[e]	5356[b]	5356[b]	5356[e]								
5154,5254[a]		4043[b,i]	5654[b]	5356[b]	5356[b,c]	5356[b,c]	5356[b]	5654[b]	5654[a,b]									
5454	4043[i]	4043[b,i]	5654[b]	5356[b]	5356[b,c]	5356[b,c]	5356[b]	5554[c,e]										
5456		4043[b,i]	5356[e]	5556[e]	5356[e]	5356[e]	5556[e]											
6061,6063, 6351,6101 6201,6151, 6951	4145[c,i]	5356[c,e,i]	5356[b,c]	5356[b,c,i]	4043[b,i]	4043[b,i]												
6070	4145[c,i]	4043[e,i]	5356[c,e]	5356[c,e,i]	4043[e,i]													
7005[k],7039, 710.0,711.0 712.0	4043[i]	4043[b,i]	5356[b]	5356[e]														
511.0,512.0 513.0,514.0		4043[b,i]	5654[b,d]															
356.0,A356.0 A357.0,359.0 413.0 A444.0,443.0	4145[c,i]	4043[d,i]																
319.0,333.0 354.0,355.0, C355.0,380.0	4145[d,c,i]																	

NOTES:

1- Service conditions such as immersion in fresh or salt water, exposure to specific chemicals or a sustained high temperature (over 150 °F) may limit the choice of filler metals. Filler alloys 5356, 5183, 5556, and 5654 are not recommended for sustained elevated temperature service.

2- Recommendations in this table apply to gas shielded arc welding processes. For gas welding, only 1100, 1188, and 4043 filler metals are ordinarily used.

3- All filler metals are listed in AWS specification A5.10.

a Base metal alloys 5652 and 5254 are used for hydrogen peroxide service. 5654 filler metal is used for welding both alloys for low temperature service (150°F and below)

b 5183, 5356, 5554, 5556, and 5654 may be used. In some cases they provide: (1) improved color match after anodizing treatment; (2) highest weld ductility, and (3) higher weld strength. 5554 is suitable for elevated temperature service.

c 4043 may be used for some applications.

d Filler metal with the same analysis as the base metal is sometimes used.

e 5183, 5356, or 5556 may be used.

f 4145 may be used for some applications

g 2319 may be used for some applications

i 4047 may be used for some applications

j 1100 may be used for some applications

k This refers to 7005 extrusions only (X-prefix still applies to sheet and plate).

4- Where no filler metal is listed, the base metal combination is not recommended for welding.

Figure 4.21 Cross reference chart on GTAW filler metals. Courtesy of the Aluminum Association.

V. Safety

As in any welding process, GTAW safety precautions are very important. All information relating to the safe operation of the welding equipment and the welding process must be fully understood before attempting to begin work. A careless welder who does not observe simple rules can cause a dangerous situation for everyone in the area. The process of arc welding creates several hazards which must be guarded against. Useful safety information can be found in the owner's manual that comes with each piece of welding equipment.

Gas Tungsten Arc Welding (TIG) is an electrical welding process. Therefore, electrical energy is required from a welding machine. If the welding machine has the characteristics of a transformer or a motor-generator design, electrical energy is required as primary power to operate it. The welding machine must be installed according to the manufacturer's recommendation and in accordance with the National Electrical Code and local code requirements.

Electrical Shock

Welders must be concerned about the possibility of electrical shock. It should be remembered that electricity will always take the path of least resistance. If there is a proper secondary circuit, the current will follow that path. However, if there are poor connections, bare spots on cables, or wet conditions, the possibility of electrical shock does exist.

A welder should never weld while standing in water. If wet working conditions exist, certain measures should be taken. Such measures include standing on a dry board or a dry rubber mat when welding. Likewise, the welding equipment should not be placed in water. In addition, gloves and shoes must be kept dry. Even a person's perspiration can lower the body's resistance to electrical shock.

Fumes

As with most welding processes, the heat or the arc and molten pool generate fume. Since TIG does not typically use flux or produce slag, it is highly recommended that the material being welded is clean. Few fumes are produced compared to other arc welding processes like SMAW or FCAW. However, the base metals may contain coatings or elements such as lead, zinc, copper, nickel, etc. that may produce hazardous fumes. Ozone can also be produced as the ultraviolet light emitted by the arc hits the oxygen in the surrounding area, producing a very distinctive, pungent odor.

The welder should keep their head and helmet out of the fumes rising off the workpiece. Proper ventilation should be supplied, especially in a confined space. Since this is a gas shielded process, care must be taken not to extract too much air from the arc area, which would disturb the process.

Arc Rays

Several possible hazards exist due to the electric arc which include infrared and ultraviolet rays. The light and rays can produce a burn similar to sunburn. The arc rays, however, are more severe than sunburn since the welder is so close to the source. Any exposed skin can be quickly burned by these rays.

Clothing

Clothing made from a dark-colored, tightly woven material is best suited for welding. Flammability of clothing material must also be considered since sparks could ignite the fabric. Oxygen, for instance, supports combustion and should never be used for blowing off equipment or used on any person or personal clothing.

Shirt collars and shirt cuffs should be buttoned, and open front pockets are not advisable as they may catch sparks. Pant cuffs are not recommended, as they will also catch sparks. Matches or lighters should never be stored in pockets.

Since welding sparks can burn through clothing, for many applications leather capes, sleeves and aprons are recommended. To protect the feet, high-top leather shoes or boots are necessary. Canvas shoes are definitely not suitable. Clothing and shoes must be kept free of oil and grease or other flammable materials. Gauntlet type leather gloves should be worn to protect the hands and wrists. See Figure 5.1 and 5.2.

Figure 5.1 Properly dressed welder.

Figure 5.2 Boots, leathers, gloves.

It is essential to know that some Gas Tungsten Arc Welding results in relatively high levels of visible light and infrared radiant energy. This can add to the disintegration of cotton clothing due to ultraviolet radiation. Thus, recommended clothing should be worn at all times.

Eye Protection

The welding arc should never be observed with unprotected eyes. A short exposure to the arc, which sometimes occurs accidentally, may cause an eye condition known as "flash burn". Usually this is not a permanent injury, but may be painful for a short time after exposure. The feeling can be described as having sand in one's eyes. Sometimes it is possible for a period of 4 to 8 hours to pass before a painful sensation in the eyes develops. Mild cases of flash burn can possibly be treated by a doctor. Continued exposure to flash burn could cause permanent eye damage.

Persons passing by an area where welding is being done could possibly get a mild flash burn from a stray arc glare. It is recommended that not only welders, but all people in the welding area, wear approved tinted safety glasses. Most industrial locations require the use of safety glasses, but they are absolutely necessary in the welding area. See Figure 5.3.

Figure 5.3 Safety glasses.

The welder should wear a welding helmet equipped with the proper shade lens for the work being done. Welding lenses are not simply colored glass, but are special lenses which screen out almost 100% of the infrared and ultraviolet rays. Lenses are manufactured in various shades designated by a shade number, and the higher the shade number, the darker the lens. The choice of a shade may vary depending upon a person's sensitivity of eyesight and the welding variables. Generally speaking, the current used determines the shade lens needed. The higher the current, the darker the shade lens. The welding helmet can be equipped with an electronic lens which automatically lightens and darkens as required, as shown in Figure 5.4. Some electronic lens have adjustment for the darkness level. Safety rules can be found in the AWS approved ANSI Z49.1 booklet, *Safety In Welding And Cutting*. Another source of information is the booklet, *Recommended Practices For Gas Tungsten Arc Welding* (AWS C5.5). Refer to table 8 in Section XI for proper lens selection.

Figure 5.4 Welding helmet.

The Welding Environment

The area surrounding the welder can be called the welding environment. The Gas Tungsten Arc Welding process can create light, heat, smoke, sparks and fumes which influence that environment. In addition to the protective clothing the welder wears, other precautions must be taken.

The light given off from welding may bother other workers in the area. Permanent booths or portable partitions can be used to contain the light rays in one area. The heat and sparks given off are capable of setting flammable materials on fire. Welding should not be done in areas containing flammable gases, vapors, liquids or dusty locations where explosions are a possibility.

Many injuries have resulted from welding on containers that have held materials easily capable of catching fire or exploding. These are often referred to as combustibles. This problem not only refers to containers such as petroleum tanks, but also to tanks which have a volatile (explosive) nature when heated by a welding arc. Acceptable methods of cleaning such containers before welding are outlined in AWS A6.0, *Safe Practices For Welding And Cutting Containers That Have Held Combustibles*. Unless these procedures are read and carried out, no attempt should be made to weld on these containers.

Metals that have plating, coatings, paint or other materials near the arc area may give off smoke and fumes during welding. Health hazards, especially to the lungs, may exist from these fumes. Exhaust hoods or booths can remove fumes from a particular area. When welding in confined spaces such as inside tanks, in compartments of a ship or inside other containers, toxic (poisonous) fumes may gather. Also, the oxygen we breathe can be replaced by shielding gases used for welding or purging in an enclosed room. This condition can cause death due to the lack of oxygen. Care must be taken to provide enough clean air for breathing. Some type of system should be present to bring clean air to an area where fumes are being exhausted. In some instances, it may even be necessary to provide welders with air masks or self-contained breathing equipment.

Safe Handling of Cylinders

Regardless of the content, pressurized cylinders must at all times be handled with great care. Shielding gases such as carbon dioxide, argon and helium are nonflammable and nonexplosive. A broken off valve, however, will release extremely high pressures, which could cause the cylinder to be hurled about at dangerously high speeds. Another way of thinking about this pressure is to compare a cylinder to a balloon. If a balloon is blown up and then released, the jet force of air escaping causes the balloon to fly about quite rapidly and erratic. The same would be true if a cylinder valve would break off. The weight of the cylinder and the extremely high pressure could easily cause a very damaging and possibly fatal accident.

Cylinders should be securely fastened at all times (Figure 5.5). Chains are usually used to secure a cylinder to a wall or cylinder cart. When moving or storing a cylinder, a threaded protector cap must be fastened to the top of the cylinder. This protects the valve system should it be bumped or the cylinder dropped (Figure 5.6). It is accepted procedure to roll a cylinder in the upright position when moving the cylinder. Figure 5.7 shows this. In some shops cylinder carts are used to move cylinders about. Whatever the method, common sense must be used to ensure a safe working area.

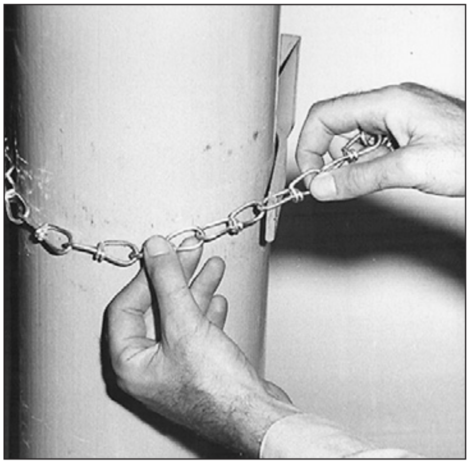


Figure 5.5 Securing cylinder to cart.

It is also very important to keep excess heat of any kind away from cylinders. Never weld on any cylinder. When a cylinder is exposed to too much heat, the pressure inside the cylinder will increase. To prevent the excess pressure from causing the cylinder to explode, the cylinder valve is equipped with a safety nut and bursting disc as shown in Figure 5.8.

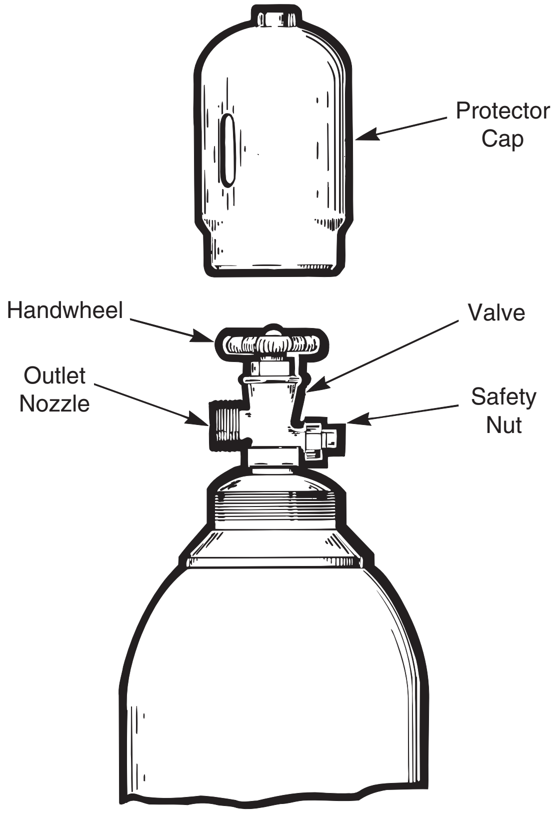


Figure 5.6 Shielding gas cylinder.

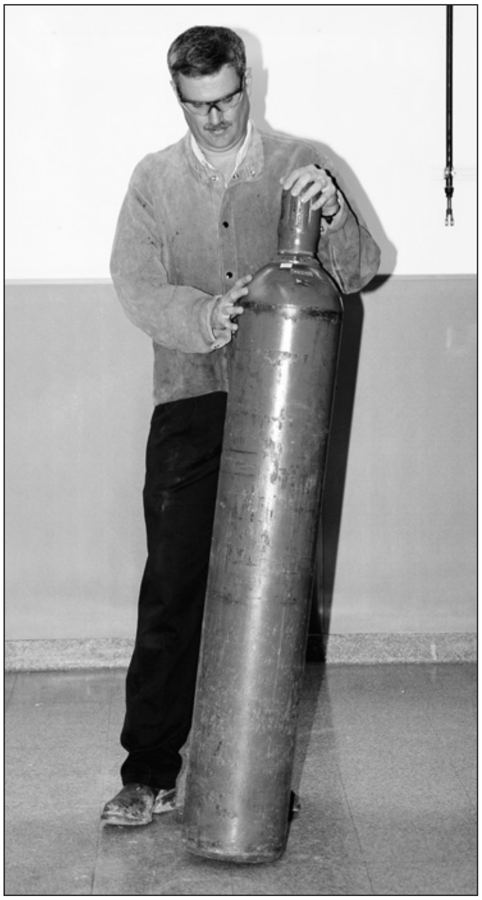


Figure 5.7 Rolling a cylinder.

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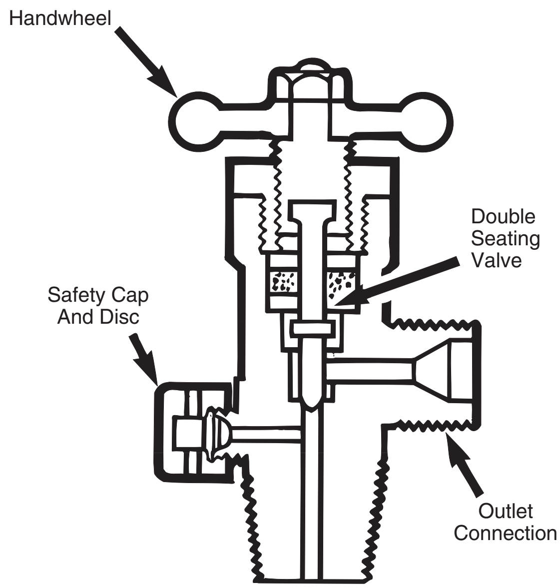

Figure 5.8 Cross section of cylinder valve.

Cylinders should not be stored or used in a horizontal position. This is because some cylinders contain a liquid which would leak out or be forced out if the cylinder was laid in a flat position.

Welding torches and other cables should not be hung on or near cylinders. A torch near a cylinder could cause an arc against the cylinder wall or valve assembly, possibly resulting in a weakened cylinder or even a rupture.

It is very important to be absolutely sure of yourself before attempting to use any welding equipment. ***Always think about what you are doing, and if you are not sure of the next step to take in any procedure, be sure to talk it over first with your welding supervisor. Remember, safety is an important factor not only for you, but for everyone around you!***

It can be said that common sense is the most important tool a welder can bring to the welding area. Common sense tells us we must respect the basic safety steps which must be taken to avoid both personal injury and injury to a fellow worker. Horseplay or practical jokes have no place in the working area!

VI. Preparation for Welding

Certain basic preparations should be made prior to establishing an arc. Preparations include base metal preparation, set up of the machine and its controls. (Basic preparation of commonly welded base metals will be covered later in this section.)

Figure 6.1 illustrates the front panel of a typical AC/DC machine designed for GTAW welding. Keep in mind that not all power sources will have all the features or controls of this machine. And the controls and switches mentioned in the following paragraphs may be found in locations on the power source other than the front panel. The various controls each have a specific function and the operator changes or varies them as the application changes. Power sources have symbols that represent these various controls; table 10 in Section XI covers these symbols.

Preparing the Power Source

Power Switch

This switch controls the primary line power to the transformer. When the switch is in the "on" position, voltage is applied to the control circuit. Operation of the fan with the power switch is dependent upon if the power source is equipped with Fan-On-Demand™ or not. In some cases, a pilot light will indicate the power source is in the “on” mode. In other cases the LED meters will indicate that the power is on. ***Before activating the “On” switch make certain the electrode is not in contact with the work lead or any portion of the work circuit!***

SMAW/GTAW Mode Switch

This switch should be set for the particular process being used. It will disable various functions that are not required when running one process or the other. For example, the gas solenoid valves will not be active in the SMAW mode as they are not required for this process.

Amperage Control Panel/Remote Switch

When a remote control device is being used, the switch must be in the “remote” position. When amperage control is to be at the front panel of the machine, the switch must be in the “panel” position.

Output Control Panel/Remote Switch

When a remote output control device is being used, the switch must be in the “remote” position. When using SMAW and not using a remote output control device, the switch must be in the “on” position. The “on” position means the output terminal of the machine will have voltage applied as soon as the power switch is turned on.

Arc Force/Balance Control

On this particular power source, when the high-frequency switch is enabled for GTAW welding, the arc force (Dig) circuitry drops out, and this control becomes the balance arc control. This will set the amount of time spent in the electrode negative (maximum penetration equals more DCEN) and electrode positive (maximum cleaning equals more DCEP) portions of the AC cycle. For additional information, refer to section II on GTAW fundamentals on the balance control. In the SMAW or Stick electrode welding mode, the arc force control will affect the arc action from a soft mushy type arc (minimum arc control) to a driving-digging, forceful type arc (maximum arc control). The arc force control is also referred to as "dig", and when used with the SMAW process it increases the short circuit amperage. When set at 0, short circuit amperage is the same as normal weld amperage.

Preflow and Postflow

Preflow control is not always a standard feature on all GTAW power sources. It is made up of a timer control and an on/off function switch. When "on", the arc will not start until the pre-flow timer has timed out assuring the arc will start in an inert atmosphere. This reduces the possibility of air contaminating the start of the weld. When "off" the preflow timer is out of the circuit and the arc is able to start as soon as the remote output control is activated. Postflow is a standard feature on all GTAW power sources and consists of only a timer control. It is used to allow the electrode, weld pool and filler rod to be protected from the air while they cool down from welding temperatures. Once they have cooled, they will no longer oxidize. The postflow timer should time out and conserve shielding gas. It is usually set to allow one second of postflow time for each 10 amperes of welding current being used. The tungsten should cool bright and shiny. Any bluing or blackening indicates a lack of postflow.

Start Mode

The high-frequency switch has four (4) selections: start, off, lift, and continuous.

When it is desired to use high frequency only to start the arc, the "start" position is selected. The high frequency remains on only until an arc is established and then it is automatically removed from the circuit. This allows for starting the arc without touching the electrode to the work. This setting should be used when welding materials that might contaminate the electrode.

The "off" position is used when high frequency is not desired, such as when scratch starts are suitable, or when the machine is used for Stick electrode welding.

"Lift" arc is selected when high frequency is undesirable and yet tungsten inclusions must be eliminated.

The "continuous" position is selected when welding with alternating current on aluminum or magnesium. This provides continuous high frequency for arc stabilization and starting.

Primary Overload Circuit Breaker

The circuit breaker provides protection against overloading the main components of the welding machine. The circuit breaker must be "on" before the primary contactor of the machine can be energized.

Figure 6.1 Front panel of a typical AC/DC machine designed for GTAW welding.

Weld Current Control or Amperage Control

This control sets the output current of the machine when no remote current device is being used. With a remote device attached, the control provides a percentage of total output. For example, if the control is set at 50%, the remote device at full output will deliver 50% of the machines available current.

Remote Amperage Control Receptacle

This receptacle is provided for connecting a remote hand control or a remote foot control. This allows the operator to have amperage control while welding at a work station which may be a considerable distance from the power source. With the foot control, the operator can vary the amperage as he progresses along a joint. This is particularly helpful when starting on a cold workpiece. Amperage may be increased to establish a weld pool quickly, and as the material heats up, the operator can decrease the amperage. When coming to the end of a joint, the amperage can be further decreased to taper off and "crater out".

AC/DC Selector and Polarity Switch

This three-position switch permits the operator to select direct current electrode positive, direct current electrode negative, or alternating current.

High-Frequency Intensity Control

This control allows the operator to choose the proper intensity for the high-frequency output. As this control is increased, the current in the high-frequency circuit is increased. It should be set for the required intensity to start the arc. It is recommended that this control be kept at a minimum setting that will provide satisfactory weld starts. The higher the setting the greater the amount of radiation which will cause interference with communication equipment.

Spark Gap Assembly

The spark gap points are normally set at the factory for optimum performance. A feeler gauge can be used to check the spacing or make adjustments on some machines.

Preparing the Weld Joint

Many GTAW problems, or supposed problems, are a direct result of using improper methods to prepare the joint. Chief among these is the improper use of grinding wheels to prepare joints. Soft materials such as aluminum become impregnated with microsized abrasive particles which, unless subsequently removed, will result in excessive porosity. Grinding wheels should be cleaned and dedicated exclusively to the material being welded. The ideal joint preparation is obtained with cutting tools such as a lathe for round or cylindrical joints, or a milling machine for longitudinal preparations.

Cleaning

Cleanliness of both the weld joint area and the filler metal is an important consideration when welding with the Gas Tungsten Arc Welding process. Oil, grease, shop dirt, paint, marking crayon, and rust or corrosion deposits all must be removed from the joint edges and metal surfaces to a distance beyond the heat affected zone. Their presence during welding may lead to arc instability and contaminated welds. If a weld is made with any of these contaminants present, the result could be a weld bead with pores, cracks, or inclusions. Cleaning may be accomplished by mechanical means, by the use of vapor or liquid cleaners, or by a combination of these.

Fixturing

Fixturing may be required if the parts to be welded cannot be self supported during welding or if any distortion cannot be tolerated or corrected by straightening. Fixturing should be massive enough to support the weight of the weldment and to withstand stresses caused by thermal expansion and contraction. The decision to use fixturing for the fabrication of a weldment is governed by economics and quality requirements.

Preheating

Preheating is sometimes required, the necessity being dictated for the most part by the thickness of the material to be welded. Preheating is most often achieved with the use of an oxy-acetylene torch. However care must be taken when using this method that localized overheating doesn't occur, and the base metal is not contaminated with combustion by-products of the oxy-fuel process. Other methods of preheating include induction coils, heating blankets and heating furnaces.

Preparing Aluminum for Welding

The preparation of aluminum deserves more consideration than it is often times given. Aluminum is very susceptible to contaminants which can cause considerable problems when welding. First of all, aluminum has a surface oxide which must be removed. This oxide removal is mentioned in detail in the text devoted to Squarewave current. There have been various theories as to how the arc action actually provides the cleaning action. High speed photographs and films of the arc let us observe the oxide removal.

When the electrode is positive and the work is negative (reverse polarity or during one half of the AC cycle), the positively charged gas ions are attracted to the negative workpiece. These ions strike the surface with sufficient force to chip away at the brittle oxide much like a miniature sand-blasting operation. The electron flow from the work to the electrode lifts the loosened oxide leaving clean base metal to be welded.

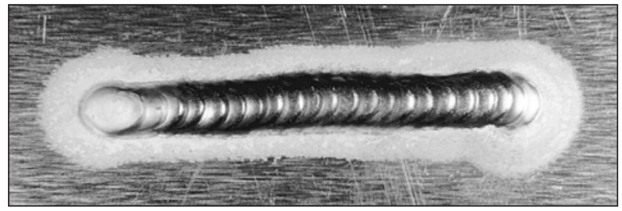

Figure 6.2 Aluminum TIG Weld. Note bright area where oxides have been removed through cleaning action of the arc.

This cleaning action should not be relied upon to do all the cleaning. Mechanical or chemical cleaning methods should be employed to remove heavy oxide, paint, grease, and oil, or any other materials that will hinder proper fusion. Mechanical cleaning may be done with abrasive wheels, wire brushes, or other methods. Special abrasive wheels are available for aluminum, and stainless steel wire brushes are recommended. The important point is that the abrasive wheels and wire brushes should be used only on the material being cleaned. If a wire brush for example were used on rusty steel, and then on aluminum, the brush could carry contaminants from one piece to another. The vigorous brushing can impregnate the contaminants carried in the brush into the aluminum. The same is true of the abrasive wheel and equipment used to cut and form aluminum.

There's another problem that sometimes occurs when only the side of the joint being welded is cleaned. Contamination from the backside or between butting edges can be drawn into the arc area. It is recommended that both sides of the joint be cleaned if it contains foreign material.

Another frequent source of contamination is the filler metal. Aluminum filler wire and rod oxidizes just like the base metal. If it is severe enough the rod must be cleaned prior to use. The operator sometimes transfers contaminants from dirty welding gloves onto the filler rod and consequently into the weld area. Stainless steel wool is a good material to use for cleaning filler wire and rod.

Welding Aluminum

The information contained in Figures 6.3a and 6.3b will serve as a guide to aluminum welding parameters.

Aluminum is a very good conductor of heat. The heat is rapidly conducted away from the arc area and spread over the work-piece. On small weldments, the entire part may heat up to a

Aluminum…Manual Welding – Alternating Current – High Frequency Stabilized						
Metal Thickness	Joint Type	Tungsten Electrode Diameter	Filler Rod Diameter (If Required)	Amperage	Gas Type	Gas Flow-CFH
1/16"	Butt	1/16"	1/16"	60 – 85	Argon	15
	Lap	1/16"	1/16"	70 – 90	Argon	15
	Corner	1/16"	1/16"	60 – 85	Argon	15
	Fillet	1/16"	1/16"	75 – 100	Argon	15
1/8"	Butt	3/32" – 1/8"	3/32"	125 – 150	Argon	20
	Lap	3/32" – 1/8"	3/32"	130 – 160	Argon	20
	Corner	3/32" – 1/8"	3/32"	120 – 140	Argon	20
	Fillet	3/32" – 1/8"	3/32"	130 – 160	Argon	20
3/16"	Butt	1/8" – 5/32"	1/8"	180 – 225	Argon	20
	Lap	1/8" – 5/32"	1/8"	190 – 240	Argon	20
	Corner	1/8" – 5/32"	1/8"	180 – 225	Argon	20
	Fillet	1/8" – 5/32"	1/8"	190 – 240	Argon	20
1/4"	Butt	5/32" – 3/16"	3/16"	240 – 280	Argon	25
	Lap	5/32" – 3/16"	3/16"	250 – 320	Argon	25
	Corner	5/32" – 3/16"	3/16"	240 – 280	Argon	25
	Fillet	5/32" – 3/16"	3/16"	250 – 320	Argon	25

Figure 6.3a Aluminum weld parameters.

Aluminum with Advanced Squarewave…Manual Welding – Alternating Current – High Frequency Stabilized								
Metal Thickness	Joint Type	Tungsten Size	Filler Material Diameter	Electrode Positive Amperage	Electrode Negative Amperage	AC Frequency Setting (Hz)	Balance Setting	Shielding Gas
1/16"	Butt	1/16"	1/16"	20	50	110	75% EN	100% Argon
	Lap	1/16"	1/16"	20	50	110	70% EN	100% Argon
	Corner	1/16"	1/16"	20	50	110	70% EN	100% Argon
	Fillet	1/16"	1/16"	20	50	110	70% EN	100% Argon
1/8"	Butt	3/32"	3/32"	60	120	140	70% EN	100% Argon
	Lap	3/32"	3/32"	60	120	140	73% EN	100% Argon
	Corner	3/32"	3/32"	60	120	140	68% EN	100% Argon
	Fillet	3/32"	3/32"	60	125	175	78% EN	100% Argon
1/4"	Lap	3/32"	3/32"	110	230	250	73% EN	100% Argon
	Corner	3/32"	3/32"	110	220	140	70% EN	100% Argon
	Fillet	3/32"	3/32"	110	240	250	75% EN	100% Argon

Figure 6.3b Aluminum with Advanced Squarewave weld parameters.

point that requires reduction of amperage from the original setting. Remote foot amperage controls are advantageous in these situations. When welding out-of-position, the amperages shown in Figures 6.3a and 6.3b may be decreased by about 15%. A water-cooled torch is recommended for amperages over 150. The electrode stickout beyond the cup may vary from approximately 1/16" on butt joints to possibly 1/2" in joints where it is difficult to position the torch. The normal recommended arc length is approximately the same as the electrode diameter.

Preparing Stainless Steel for Welding

"Stainless steel" is a common term used when referring to chromium alloyed and chromium-nickel alloyed steel. There are magnetic and non-magnetic types of stainless steel. There are a large number of alloy types and each type possesses some specific properties as to corrosion resistance and strength. A check with the manufacturer is recommended when in doubt about the specific properties of an alloy.

When welding stainless steel, it should be thoroughly cleaned. Protective paper or plastic coatings are applied to many stainless sheets. Foreign material may cause porosity in welds and carburetion of the surface which will lessen the corrosion resisting properties. Any wire brushing should be done with stainless steel wire brushes to prevent iron pick up on the stainless surfaces. As with other welding procedures, clean and dry filler metal should be used and proper precautions taken to prevent contamination during welding.

Welding Stainless Steel

Figure 6.4 contains parameters which will serve as a guide for welding stainless steel.

Chromium-nickel stainless steels are considered readily weldable. Normally the welding does not adversely affect the strength or ductility of the deposit, parent metal, or fusion zone. The filler metal used should be compatible, of similar composition, to the base metal. The heat conductivity of chrome-nickel stainless steels are about 50% less than mild steel with a high rate of thermal expansion. This increases the tendency for distortion on thin sections.

Values shown in Figure 6.4 are for single pass welds on the thinner sections, multiple pass welds on heavier material, and for welding out-of-position. Job conditions will affect the actual amperage, flow rate, filler rod, and tungsten used. Some examples are:

- Joint design and fit-up
- Job specifications
- Use of backing (gas, rings, bars)
- Specific alloy
- Operator

Heat input can be critical. In many applications, it is desirable to keep the heat input as low as possible. In the weld and heat affected zone, a metallurgical change takes place known as carbide precipitation. If corrosion resistance is a big factor in the completed weld, it should be noted that some of the corrosion resistance properties are lost in the weld and adjacent areas that are heated above the temperature where carbide precipitation occurs (800 – 1400˚ F). Keeping heat input to a minimum is necessary in this situation. The longer the work is at the 800 – 1400˚ F temperature, the greater the precipitation. Rapid cooling through this range will help keep precipitation to a minimum. On some alloys of stainless steel, columbium or titanium are added to prevent carbide precipitation. It is important that the filler metal used is of the same general analysis as the material being welded.

Preparing Titanium for Welding

Titanium's light weight, excellent corrosion resistance, and high strength-to-weight ratio make this a desirable metal for applications in the chemical, aerospace, marine and medical fields. Its use in the petrochemical industry and in the manufacture of sports equipment is some more recent application areas. Many consider titanium as very hard to weld. Titanium alloys can be embrittled by not following proper welding techniques, but titanium is much more readily welded than typically believed.

Before welding titanium, it is essential that the weld area and the filler metal be cleaned. All mill scale, oil, grease, dirt, grinding dust and any other contamination must be removed. If the titanium is scale free, degreasing is all that is required. If oxide scale is present, it should be degreased prior to descaling. An area at least 1 inch (25mm) from where the weld is to be made should be cleaned. The joint edges should be brushed with a stainless steel wire brush and degreased with acetone just prior to welding. Any titanium part handled after cleaning should be done so in a so-called "white glove" procedure to eliminate recontamination of the weld area. The cleaned parts should be welded within a few hours or properly stored by wrapping in lint-free and oil-free materials.

If grinding or sanding is used to clean titanium or prepare a joint, be very cautious of the fine titanium dust particles. Titanium is flammable and the smaller the dust particles are, the more flammable it becomes.

Stainless Steel … Manual Welding … Direct Current – Electrode Negative

Metal Thickness	Joint Type	Tungsten Electrode Diameter	Filler Rod Diameter (If Required)	Amperage	Gas	
					Type	Flow-CFH
1/16"	Butt	1/16"	1/16"	40 – 60	Argon	15
	Lap	1/16"	1/16"	50 – 70	Argon	15
	Corner	1/16"	1/16"	40 – 60	Argon	15
	Fillet	1/16"	1/16"	50 – 70	Argon	15
1/8"	Butt	3/32"	3/32"	65 – 85	Argon	15
	Lap	3/32"	3/32"	90 – 110	Argon	15
	Corner	3/32"	3/32"	65 – 85	Argon	15
	Fillet	3/32"	3/32"	90 – 110	Argon	15
3/16"	Butt	3/32"	1/8"	100 – 125	Argon	20
	Lap	3/32"	1/8"	125 – 150	Argon	20
	Corner	3/32"	1/8"	100 – 125	Argon	20
	Fillet	3/32"	1/8"	125 – 150	Argon	20
1/4"	Butt	1/8"	5/32"	135 – 160	Argon	20
	Lap	1/8"	5/32"	160 – 180	Argon	20
	Corner	1/8"	5/32"	135 – 160	Argon	20
	Fillet	1/8"	5/32"	160 – 180	Argon	20

Figure 6.4 Stainless steel weld parameters.

Welding Titanium

Figure 6.5 contains parameters which will serve as a guide for welding titanium.

These welding parameters are useable on the three various types of titanium alloys. The three types of titanium alloys are:

1. Titanium (CP). Commercially pure (98 to 99.5% Ti), can be strengthened by small additions of oxygen, nitrogen, carbon and iron.
2. Alpha Alloy. Generally single-phase alloys which contain up to 7% aluminum and a small amount <0.3% of oxygen, nitrogen and carbon.
3. Alpha-Beta Alloys. They have a characteristic two-phase microstructure brought about by the addition of up to 6% aluminum and varying amounts of beta formers. Beta forming alloys are vanadium, chromium, and molybdenum.

Figure 6.6 shows some of the relative weldability of these various alloy groups. Also displayed are recommended filler metals. When welding titanium and its alloy, the filler metal should closely match the alloy content of the base metal being welded.

Titanium… Manual Welding – Direct Current Electrode Negative						
Metal Thickness	Joint Type	Tungsten Electrode Diameter	Filler Rod Diameter (If Required)	Amperage	Gas Type	Gas Flow-CFH*
1/16"	Butt	1/16" – 3/32"	1/16"	65 – 105	Argon	15
	Lap	1/16" – 3/32"	1/16"	100 – 165	Argon	15
	Corner	1/16" – 3/32"	1/16"	65 – 105	Argon	15
	Fillet	1/16" – 3/32"	1/16"	100 – 165	Argon	15
1/8"	Butt	3/32"	3/32"	95 – 135	Argon	15
	Lap	3/32"	3/32"	150 – 200	Argon	15
	Corner	3/32"	3/32"	95 – 135	Argon	15
	Fillet	3/32"	3/32"	150 – 200	Argon	15
3/16"	Butt	3/32" – 1/8"	3/32"	150 – 225	Argon	20
	Lap	3/32" – 1/8"	3/32"	150 – 250	Argon	20
	Corner	3/32" – 1/8"	3/32"	150 – 225	Argon	20
	Fillet	3/32" – 1/8"	3/32"	150 – 250	Argon	20
1/4"	Butt	1/8"	3/32" – 1/8"	175 – 275	Argon	20
	Lap	1/8"	3/32" – 1/8"	200 – 300	Argon	20
	Corner	1/8"	3/32" – 1/8"	175 – 275	Argon	20
	Fillet	1/8"	3/32" – 1/8"	200 – 300	Argon	20

*This is the torch (primary) shielding gas flow rate, a trailing (secondary) shield gas flow rate should be 2 to 4 times this rate. A trailing shielding gas is generally required for welding titanium.

Figure 6.5 Titanium weld parameters.

Weldability Rating			
Alloy		Rating	Filler Metal
Commercially Pure (CP)	Ti-0.15 O2	A	ERTi-1
	Ti-0.20 O2	A	ErTi-2
	Ti-0.35 O2	A	ERTi-4
Alpha Alloys	Ti-0.2 Pd	A	ERTi-7
	Ti-5 Al-2.5 Sn	B	ERTi-6
	Ti-5 Al-2.5 Sn ELI*	A	ERTi-6ELI
Alpha-Beta Alloys	Ti-6 Al-4V ELI	A	ERTi-5ELI
	Ti-7 Al-4Mo	C	ERTi-12
	Ti-8 Mn	D	Welding Not Recommended

Figure 6.6 Titanium welding ability.

*ELI = Extra-low interstitial impurities are specified. These interstitial impurities are carbon, hydrogen, oxygen and nitrogen and both the filler metal and base metal are low in these impurities.

Key

A = Excellent; useful as-welded, near 100% joint efficiency if base metal annealed condition.

B = Fair to good; useful as-welded, near 100% joint efficiency if base metal annealed condition.

C = Limited to special applications; cracking can occur under high restraint.

D = Welding not recommended; cracking under moderate restraint; use preheat (300 – 350˚ F) followed by post weld heat treatment.

Shielding of the titanium weld and surrounding metal (this includes the hot end of the filler rod) that reach temperatures of 1200˚ F (650˚ C) is required. When doing manual "open air" (not in a bubble or totally enclosed chamber) care must be taken to prevent atmospheric contamination of the titanium. Since titanium has a very low thermal conductivity, it will stay hot for a long time after the welding arc has moved along the joint. Thus a trailing gas is essential. This can be accomplished with a large gas lens on the torch or a trailing gas shoe that attaches to the TIG torch. This metal shoe (chamber) has a porous metal diffuser to allow the gas to blanket the titanium until it has cooled below its oxidation temperature. Figure 6.7 is an example of a trailing gas shield. The primary gas shielding is what is flowing through the torch and the secondary gas shielding is what is flowing through the trailing shield. If the back side of the joint is going to be exposed to oxidation temperatures >500˚ F, it must also be protected from the atmosphere by a backing gas shielding or in the case of pipe or tubing purging the inside of the pipe or tube.

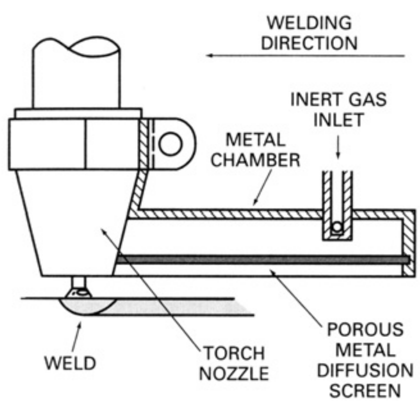

Figure 6.7 Torch trailing shield for TIG welding of titanium and other reactive metals.

Preparing Mild Steel for Welding

Mild steel should always be mechanically cleaned prior to welding. Rust, paint, oil and grease, or any surface contaminants should be removed. Hot-rolled products such as angle iron, plate, and pipe may contain a heavy mill scale. For best results, remove scale prior to welding. Black pipe usually contains a varnish type coating, which should be removed before welding.

Welding Mild Steel

Low carbon steels, commonly referred to as mild steels, are readily welded by the GTAW process. These groups of steels are available in many different alloys and types. The familiar structural shapes, plates, and hot rolled sheet metal are usually comprised of what is termed "semi-killed steel". This term means the steel has been partially deoxidized during manufacture. The steel, however, still contains some oxygen, and this oxygen can cause problems when welding. These problems will appear in the form of bubbles in the weld pool, and possibly in the finished weld bead. "Killed steel" has had more oxygen removed in its manufacture, and presents less of a problem when welding.

A filler wire containing sufficient silicon and manganese, added as deoxidizers, is necessary. Lower grade filler rods used for oxyacetylene welding of many hot rolled products are not suitable for making high-quality GTAW welds. Direct current electrode negative is recommended with high-frequency start. A 2% thoriated tungsten with point or taper on the electrode should be used.

Figure 6.8 contains parameters which will serve as a guide for welding mild steel.

Mild Steel…Manual Welding…Direct Current – Electrode Negative						
					Gas	
Metal Thickness	Joint Type	Tungsten Electrode Diameter	Filler Rod Diameter (If Required)	Amperage	Type	Flow-CFH
1/16"	Butt	1/16"	1/16"	60 – 70	Argon	15
	Lap	1/16"	1/16"	70 – 90	Argon	15
	Corner	1/16"	1/16"	60 – 70	Argon	15
	Fillet	1/16"	1/16"	70 – 90	Argon	15
1/8"	Butt	1/16" – 3/32"	3/32"	80 – 100	Argon	15
	Lap	1/16" – 3/32"	3/32"	90 – 115	Argon	15
	Corner	1/16" – 3/32"	3/32"	80 – 100	Argon	15
	Fillet	1/16" – 3/32"	3/32"	90 – 115	Argon	15
3/16"	Butt	3/32"	1/8"	115 – 135	Argon	20
	Lap	3/32"	1/8"	140 – 165	Argon	20
	Corner	3/32"	1/8"	115 – 135	Argon	20
	Fillet	3/32"	1/8"	140 – 170	Argon	20
1/4"	Butt	1/8"	5/32"	160 – 175	Argon	20
	Lap	1/8"	5/32"	170 – 200	Argon	20
	Corner	1/8"	5/32"	160 – 175	Argon	20
	Fillet	1/8"	5/32"	175 – 21 0	Argon	20

Figure 6.8 Mild steel weld parameters.

VII. Joint Design and Types of Welds

A weld joint is the term used for the location where two or more pieces of metal will be or have been welded together. Figure 7.1 shows the five basic weld joint designs.

To obtain a quality weld and cost-effective use of filler metal, joint design must be considered in any type of weldment. This will depend upon several factors including material type, thickness, joint configuration and strength required.

It is quite possible that a welder would have little to do with how a particular joint is designed. However, a good welder should be familiar enough with joint design to carry out a welding job.

A proper joint design will provide the required strength and the highest quality weld at the most economical cost. The joint design selected will dictate what type of weld is required.

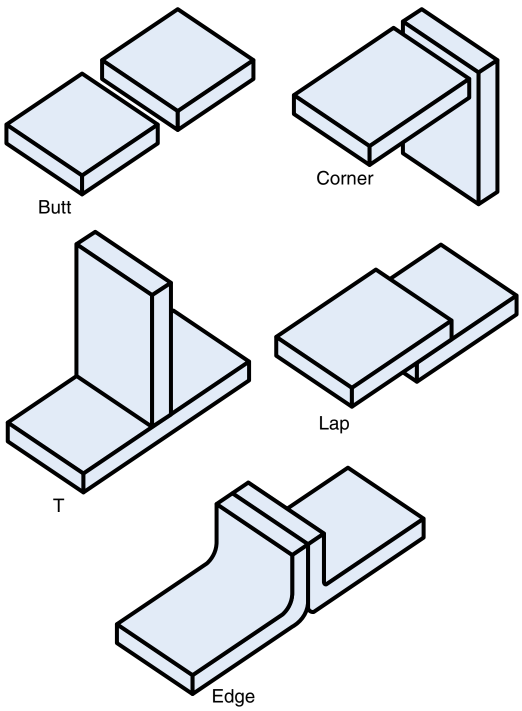

Figure 7.1 Five basic joint designs.

The five basic joint designs are typically welded with the TIG process using either a groove or a fillet weld. Groove welds are those made into a prepared joint to get deeper penetration. To prepare the joint, material must be removed and replaced with weld metal. Groove welded joints are very efficient but are more expensive than a fillet welded joint. Groove welds generally require some form of joint preparation while fillet welds are made on joints requiring no joint preparation. When the edge or surface of joint members come together at a right angle to each other, the resulting weld, which is triangular in shape, is called a fillet weld. Fillet welds on lap or T-joints are commonly used in the welding industry.

A few considerations for joint design are specific to GTAW. Naturally the weld joint must be accessible to the GTAW torch, making it possible for proper torch movements. Weld joints should not be too narrow, so as to restrict access of the gas cup. In some cases, using a narrower gas cup, or a gas lens with the electrode extending up to an inch beyond the gas cup will help.

Edge Joints

Edge joints are often used when the members to be welded will not be subjected to great stresses. Edge joints are not recommended where impact or great stress may occur to one or both of the welded members. An edge joint occurs when the edges of parallel or nearly parallel members meet and are joined by a weld. Figure 7.2 shows different types of edge joints. Figure 7.2 demonstrates the various types of edges that can be applied to the joints. If required, the joints can be altered by grinding, cutting or machining the edges into a groove. The groove can be a square, beveled, V, J, or U. The main purpose of the groove is to allow proper penetration or **depth of fusion**. See Figure 7.3.

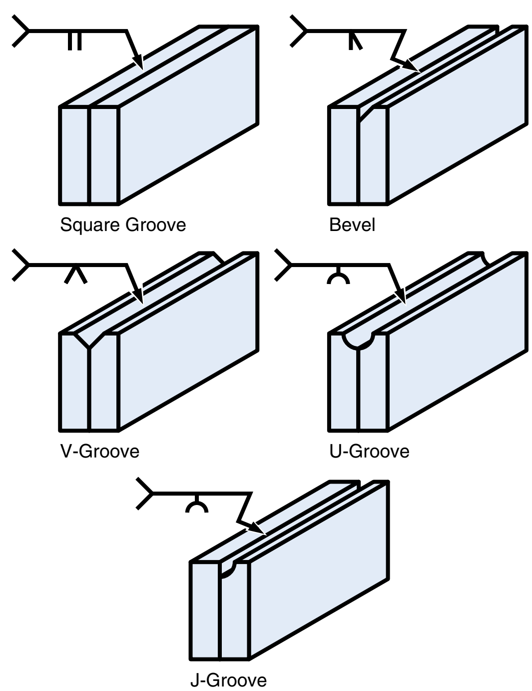

Figure 7.2 Edge Joints

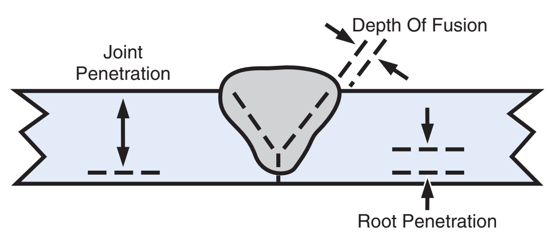

Figure 7.3 Depth of fusion and types of penetration. Complete joint penetration refers to weld metal that extends completely through the groove and has complete fusion into the base metal. What is shown is a partial joint penetration, which if not intended is referred to as incomplete joint penetration.

Butt Joints

A **butt joint** occurs when the surfaces of the members to be welded are in the same plane with their edges meeting. Figure 7.4 shows butt joints with various types of grooves. Butt joints are often used to join pressure vessels, boilers, tanks, plate, pipe, tubing or other applications where a smooth weld face is required. They generally require more welding skill than other joints. Butt joints have very good mechanical strength if properly made. They can be expensive joints since a prepared groove is generally required to get the proper penetration and weld size. This involves the extra operation of joint preparation, removal of material to open up the joint and then welding to penetrate and fill the groove.

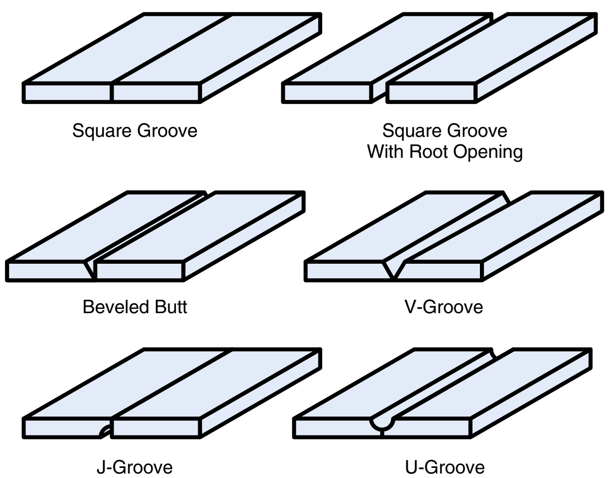

Figure 7.4 Butt joints.

Distortion and **residual stresses** can be problems with butt joints.

Butt joints can be designed in various ways. They may be welded with or without a piece of metal or ceramic backing the joint, usually referred to as a "backing bar" or "backing strip". The edges can be prepared into a groove that is square, beveled, V, J, or U grooved. Edges may be held tight together or a small gap known as a root opening may be left between the edges.

Figure 7.5 shows the various parts of a V-groove butt joint. Note the groove angle, groove face, root face and root opening. The groove angle is the total included angle of the joint. If two 37.5˚ bevels are brought together, they form a 75˚ V-groove. The groove face is the surface of the metal in the groove, including the root face. The root face is sometimes called the "land". In this example, the root face is 1/8" and the root opening 3/32". The main purpose of the various grooves and root openings is to allow proper penetration and depth of fusion.

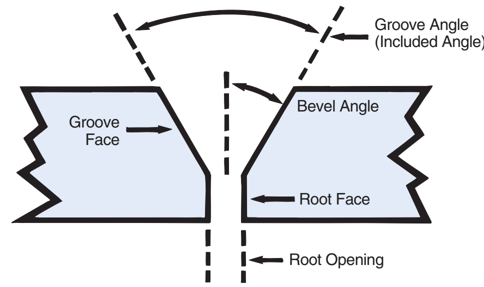

Figure 7.5 V-groove butt joint.

If material thickness is less than approximately 1/8" thick, square edges butted tight together (no root opening) can be used. (Aluminum would probably require a small root opening.) Plate thicknesses 1/8" and greater generally require single or double V-groove and root openings for proper penetration and depth of fusion. Joint preparation before welding will depend upon the joint design and the equipment available to do the edge preparation. The oxy-fuel torch, carbon arc gouging or plasma arc cutting/gouging is often used to cut a bevel-, J-, U-, or square-groove edge on steel plates. Aluminum is best prepared with mechanical cutting tools or the plasma arc cutting/gouging process.

Lap Joints

Another joint design used a great deal in the welding industry is the lap joint. Various types of lap joints are shown in Figure 7.6. As can be seen in the figure, lap joints occur when the surfaces of joined members overlap one another. A lap joint has good mechanical properties, especially when welded on both sides. The type of weld used on a lap joint is generally a fillet weld. If a groove weld is called for, it can be applied as shown in the figure with a single or double bevel. The groove weld may or may not be followed with a fillet weld. This would be indicated by the appropriate welding symbol. The degree of overlap of the members is generally determined by the thickness of plate. In other words, the thicker the plate, the more overlap is required.

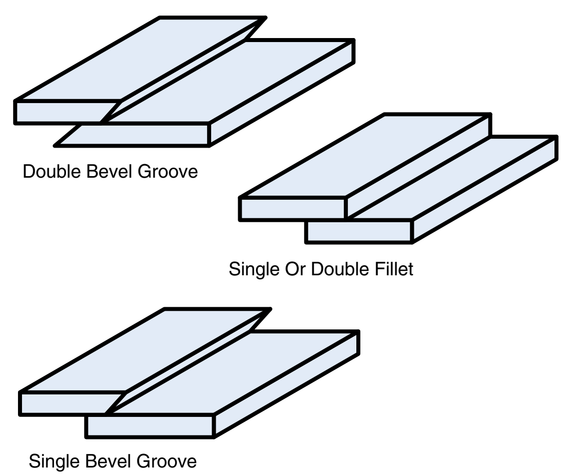

Figure 7.6 Lap joints.

Corner Joints

When members to be welded come together at about 90˚ and take the shape of an "L", they are said to form a corner joint. Several types of corner joints and grooves are shown in Figure 7.7. Welds made on the inside of the "L" are considered fillets and welds made on the outside of the "L" are considered groove welds. Corner joints are quite easily assembled and require little if any joint preparation. After welding, the welds are generally finished, that is, ground smooth to present a smooth attractive appearance. When this is the case, all effort by the welder should be made to prevent overlap (weld material rolling onto one of the members and not fusing), high spots, low spots and undercut. These problems can all mean more work since additional grinding time, rewelding and regrinding may be required.

There are two main types of corner joints, open corner and closed corner. On lighter gauge material, it may be necessary to increase travel speed somewhat, especially on open corner joints where excessive melt through is a possibility.

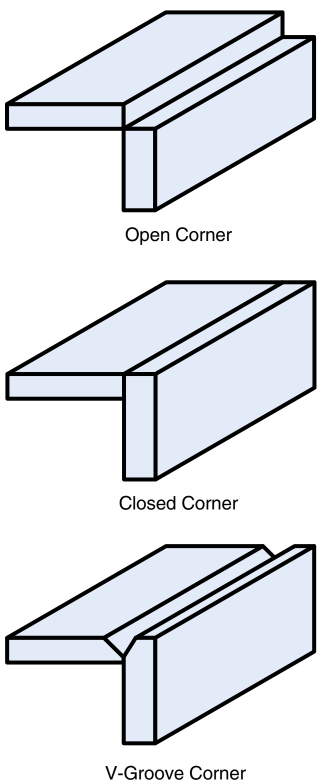

Figure 7.7 Corner joints.

T-Joints

A T-joint occurs when the surfaces of two members come together at approximately right angles, or 90˚, and take the shape of a "T". See Figure 7.8. On this particular type of joint, a fillet weld is used.

T-joints possess good mechanical strength, especially when welded from both sides. They generally require little or no joint preparation and are easily welded when the correct parameters are used. The edges of the T-joint may be left square if only a fillet weld is required. For groove welding they may be altered by thermal cutting/gouging, machining or grinding.

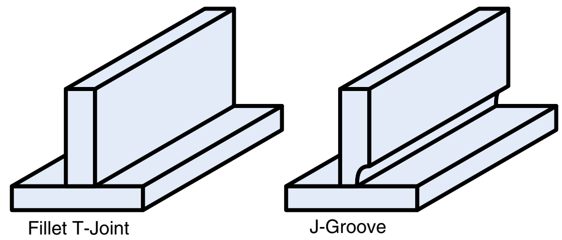

Figure 7.8 T-Joints

Fillet Welds

Fillet welds are approximately triangular in cross sectional shape and are made on members whose surfaces or edges are approximately 90˚ to each other. Fillet welds can be as strong, or stronger than the base metal if the weld is the correct size and the proper welding techniques are used. When discussing the size of fillet welds, weld contour must first be determined. Contour is the shape of the face of the weld. Figure 7.9 shows a cross section profile of the three types of fillet weld contours: flat, convex, and concave.

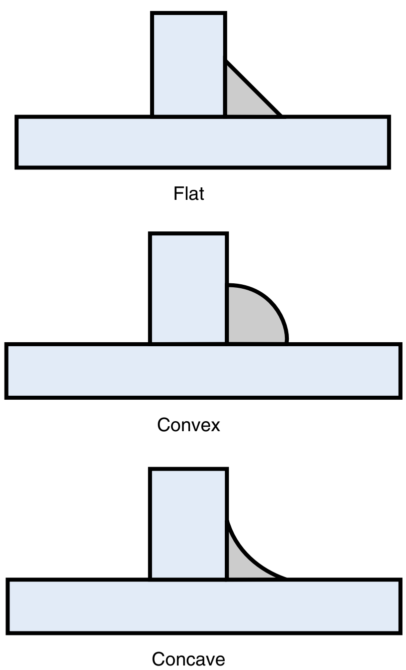

Figure 7.9 Fillet face contours.

Fillet Weld Size

It is important when discussing weld size and joint design to be familiar with the various parts of a weld. Figure 7.10 indicates the parts of a fillet weld.

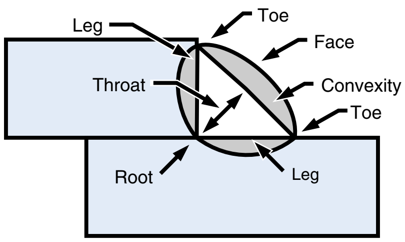

Figure 7.10 Convex fillet weld.

The size of a convex fillet weld is generally the length of the leg referenced. Figure 7.11 shows a convex fillet weld and the associated terms.

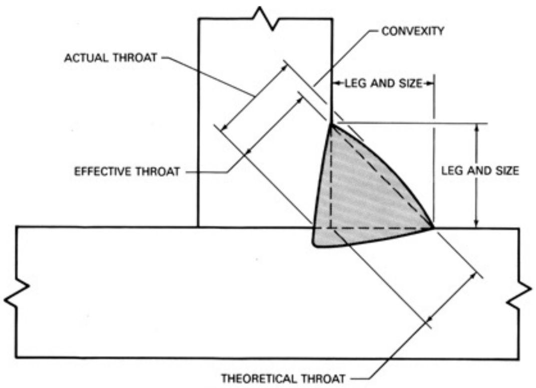

Figure 7.11 Convex fillet weld.

For concave fillet welding, the size and leg are two different dimensions. The leg is the dimension from the weld toe to the start of the joint root, however, the actual size of a convex fillet weld as shown in Figure 7.12, is measured as the largest triangle that can be inscribed within the weld profile. A special fillet weld gauge is used to measure concave fillet welds. If the weld is flat, the concave or convex fillet weld gauge can be used.

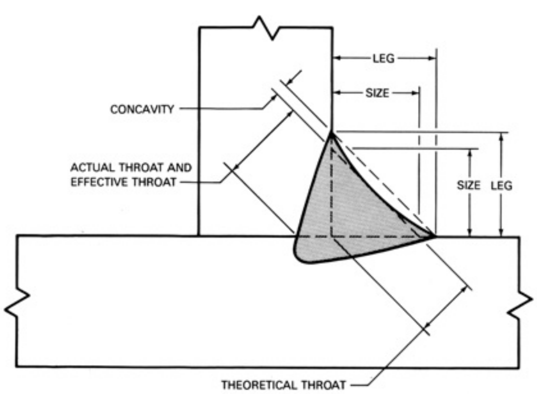

Figure 7.12 Concave fillet weld.

Fillet welds can also be measured in a slightly more complex way — by determining throat size. Three different throat sizes may be referred to when discussing the size of fillet welds, as seen in Figure 7.11 and 7.12.

Design engineers sometimes refer to the theoretical throat of a weld. As Figure 7.11 and 7.12 show, the theoretical throat extends from the point where the two base metal members join (beginning of the joint root), to the top of the weld minus any convexity on the convex fillet weld and on the concave fillet weld, to the top of the largest triangle that can be inscribed in the weld. The theoretical measurement looks at the weld as if it were an actual triangle and the penetration is not figured into the theoretical throat size.

The effective throat of a fillet weld is measured from the depth of the joint root penetration. This is an important consideration as the penetration is now considered part of this dimension. However, no credit is given for the convexity. ***(The convexity by many is considered reinforcement, which would indicate more strength. The exception is a fillet weld where too much convexity is detrimental to the overall joint strength. Excess convexity increases stresses at the weld toes and can lead to cracking.)*** On convex and concave fillet welds, effective throat is measured to the top of the largest triangle that can be drawn in the weld. This measurement can be used to indicate the size of the weld. The outward appearance of the weld may look too small but if the penetration can be assured, the weld will be of sufficient strength.

The actual throat of a fillet weld is the same as the effective throat on a concave fillet weld. But as can be seen on Figure 7.11, there is a difference. This throat dimension can also be used to indicate size and strength. If anything other than the theoretical throat is used to size a fillet weld, the welding procedure would have to be carefully written and in-process inspection would be required to assure that the joint is being properly penetrated. The overall reduction in fillet weld size, increased speed of welding, reduced heat input and reduction of internal stresses and distortion may make the effort worthwhile.

The general rule for fillet weld size is ***the leg should be the same size as the thickness of the metals.*** If 1/4" thick plate is being welded, a 1/4" leg fillet is needed to properly join the members. The old saying, "If a little is good, a lot is better," may be true in some cases but not with fillet welds.

Consider again the 1/4" thick plate. If a lot of weld would be better, think of 1/2" legs on the fillet. This would result in what is termed over-welding. This weld is not just twice as large as required, but its volume is three times that required. This wastes weld metal, the welder's time, causes more distortion and may even weaken the structure because of residual stress. Figure 7.13 shows correct and incorrect fillet welds.

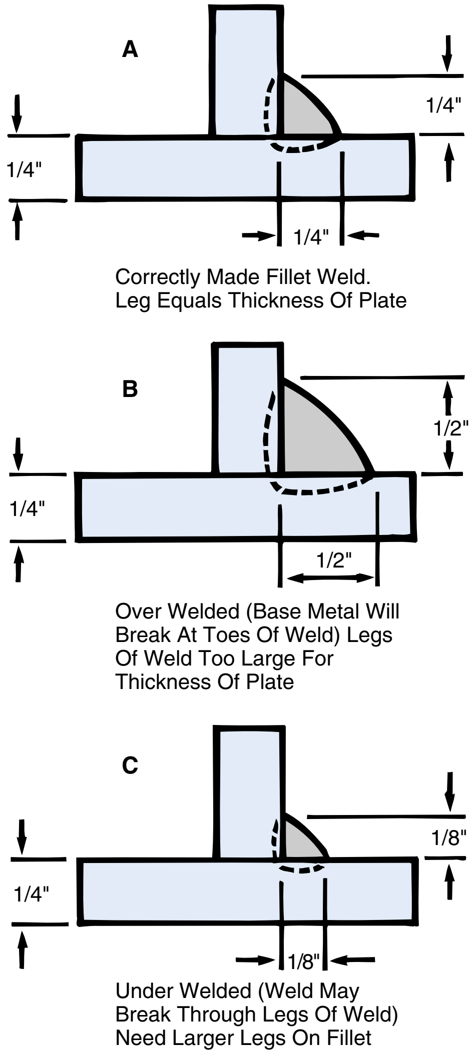

Figure 7.13 Correct/incorrect fillets.

A weld or weld joint is no stronger than its weakest point. Even though B of Figure 7.13 would appear to be much stronger, it will not support more stress than A. It may even support less stress due to the additional residual stresses built up in the joint that is over-welded.

When metals of different thicknesses are to be joined, such as welding a 1/4" thick plate onto a 1/2" thick plate in the form of a T-joint, the rule for fillet weld size is ***size of fillet weld leg should equal the thickness of the metal being welded***. Since there are two different thicknesses, the best weld results will be obtained by making an unequal leg fillet weld. Figure 7.14 shows correct and incorrect examples.

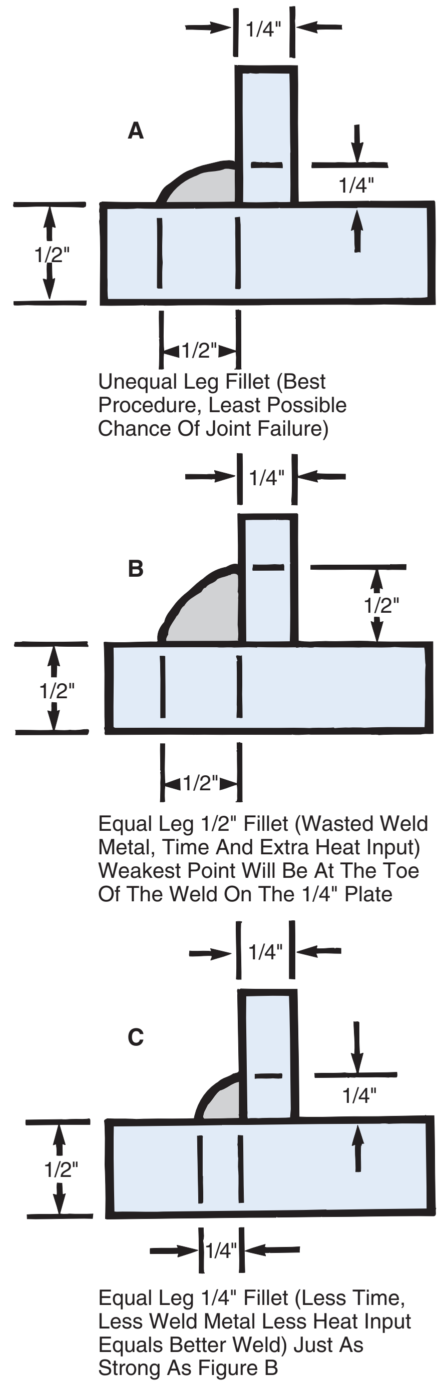

Figure 7.14 Unequal leg fillet.

The correct, unequal leg fillet weld has a 1/4" weld leg on the 1/4" plate and a 1/2" weld leg on the 1/2" plate. This would be the best way to handle this weldment. However, consider the results of making the weld with an equal leg fillet. There would then be two choices: a 1/2" fillet or a 1/4" fillet. In this instance, the 1/4" fillet would be the more practical, since a weldment is no stronger than its weakest point. The extra welds in the 1/2" fillet will also require more time, electrode wire, and induce more heat into the metal, causing more residual stress.

Groove Welds

The groove name is taken from the profile of the groove. A groove weld is made in square, V, bevel, U, J, flare-V or flare-bevel type grooves between workpieces. These are the most common type grooves to be encountered with the TIG process. Review Figure 7.4 for typical grooves found on butt type joints.

Square-Groove

A square-groove weld can be made with either a closed or an open groove. Usually if the base metal is thin (such as thin sheet metal gauge thicknesses), a square groove weld can be used. Remember the higher a gauge number, the thinner the material. In the base metal thickness range of 1/8" to 1/4", it is good to weld both sides of an open-square-groove-weld to provide proper penetration into the groove. Usually, open-square-groove-welds will not be made with groove openings of more than about 5/32". In some cases where welding is done from only one side of the joint, a temporary or permanent backup bar or strip can be used. On critical welds, a consumable insert can be used. These backings or inserts can ensure proper joint penetration, help avoid excessive melt-through, or provide a flush backing to the weld.

V-Groove

V-groove weld designs require careful preparation, yet they are quite popular. V-groove welds are usually made on medium to thicker metals, and are used quite often for pipe welding. They can provide excellent weld quality if properly completed. V-groove weld designs may or may not use permanent or temporary backups or consumable inserts, depending upon the joint design and type of joint penetration needed. Usually if backups are used, root openings can be somewhat wider.

The groove angle for a groove weld must be large enough for the torch to fit into the groove. The groove angle depends upon metal thickness, desired electrode extension and torch nozzle size. Usually V-groove welds are made on material over 1/8" to 1/4" in thickness. Adjusting the root face thickness can help control penetration.

Usually, the root pass of a weld without backing is done with some melt-through. Proper penetration and fusion of the root pass is necessary to avoid weld defects.

V-groove welds are often made on material up to about 3/8" thickness, while double V-groove welds are normally made on thicker materials up to roughly 3/4" in thickness. Double V-groove welds on thicker materials can use less deposited weld metal and limit distortion in the weld, especially if a small root face of about 1/8" is used on each member. Usually the weld passes on such a joint would be made alternating from one side of the joint to the other, helping avoid distortion.

Bevel-Groove

The bevel-groove weld also requires preparation, but in this case only one member need be beveled. The single bevel-groove can be used on material up to about 3/8", while double bevel-grooves are used on thicker material up to about 3/4". In most cases, up to 1/8" root openings are used on single and double bevels. Backing may or may not be used on single bevel-grooves, depending upon joint penetration requirements. A bevel-groove is sometimes used when welding in the horizontal position. Root faces up to about 1/8" are normally used for either single or double bevel-grooves.

U- and J-Grooves

On thicker materials, U- or J-grooves can provide good penetration. They do not use as much deposited weld metal as a V-groove or bevel-groove joint design. With thicker materials, the U- and J-grooves can be used with a smaller groove angle and still maintain proper fusion. A normal groove angle for either a U- or J-groove is about 20˚ to 25˚. This would also apply to the double U- and double J-grooves.

One disadvantage of U- and J-groove design is the preparation of the base material. Air carbon arc, plasma gouging or special mechanical cutting tools are required for preparation of the J- or U-type design. V- or bevel-grooves are easier to prepare.

Flare-V and Flare-Bevel

Flared-groove welds are named after the shape of the base members to be welded. One or both of the members have a type of rounded edge, which already forms a groove for welding. They take their shape from the curved, bent or circular material the joint is being constructed from. Usually no preparation is needed for flare type groove welds.

Groove Weld Size

When a weld is called for on a joint, the size of the weld is important for the joint to carry the load applied to it. In order to understand groove weld size, it is important to understand some of the terms applied to typical groove—such as a V-groove joint. One must have an understanding of groove angle, bevel angle, root face and root opening. These are shown in Figure 7.15.

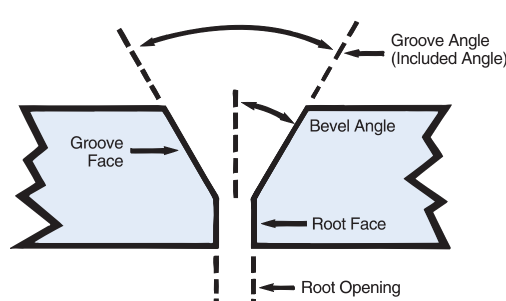

Figure 7.15 V-Groove butt joint with terms.

If a groove weld is indicated and no weld size is specified, a full size weld completely penetrating the joint should be used. If the weld size can be made smaller, indications of this should be shown on the drawing and welding symbol. Smaller weld size is referred to as a partial penetration joint and is acceptable if it will carry the applied load.

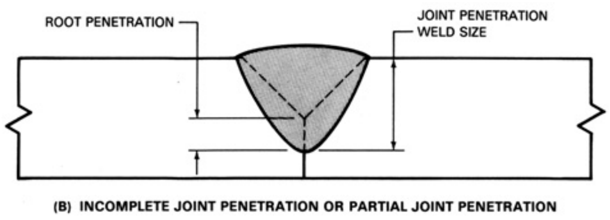

Figure 7.16 V-Groove butt joint with partial joint penetration and terms.

The groove weld size relates to how deep the weld fuses into the joint. The groove should be completely filled, excess fill called weld reinforcement should be minimal. Any extra reinforcement decreases the strength of the joint by creating extra stresses at the weld toes. In most cases, the weld size does not take any weld reinforcement into its measurement. Figure 7.17 shows a complete joint penetration groove weld.

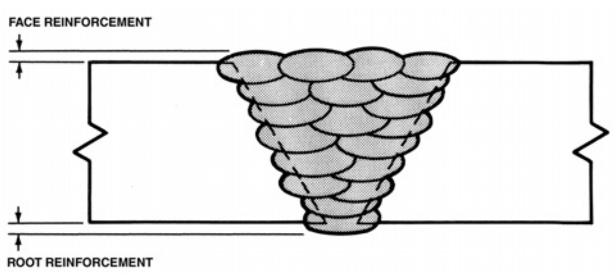

Figure 7.17 V-Groove butt joint multi-pass weld with complete joint penetration with face and root reinforcement shown.

By reducing the bevel angle and thus the groove angle, the amount of weld metal required to fill the groove is reduced. Figure 7.18 shows the great reduction in weld volume by decreasing the groove angle from 60˚ to 45˚.

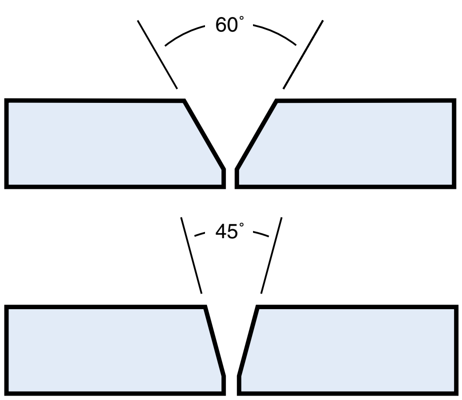

Figure 7.18 Compare joint designs.

A smaller groove angle can reduce the cost of filler metal needed to fill the joint and thus help to reduce time and labor costs. The amount of heat input to the joint is reduced, which will reduce distortion and residual stresses that could cause the weld to crack. Less scrap is produced, as less metal is removed to produce the smaller beveled angle. When changing the groove angle, the weld size must be maintained.

Joint design for various types of groove welds can be expensive, since some groove weld joints require more preparation than others. Therefore, it is helpful to know when preparation is necessary and when it can be avoided.

Weld Length

Fillet and groove welds are usually made the full length of the joint. In some cases, fillet welded joints can achieve their full strength by only welding a portion of the joint. The effective length of a fillet weld is measured as the overall length of the full-size fillet weld. The start and stop of the weld must be allowed for in the length measurement. The TIG process is very capable of making excellent starts and with crater filling to the welds full cross section. However, the weld starts and stops are not square so allowance is made when measuring the length to account for the start and stop radius.

If a specific weld length is specified, it will be shown on the print. In some cases, the fillet weld will be made at intermittent intervals. The spaces between the welds are determined by the center-to-center distance of the welds, which is called the pitch. If intermittent fillet welds are called for, the print will indicate their length and pitch.

Multiplying the weld length with the weld size equals the weld area. Area = weld size X weld length. It is important to understand that this will determine how much stress the joint can take. The design engineer is aware of the base material properties and the loads it will see in service and applies the formula. Stress = Load/Weld Area. Safety margins are built in and the designer applies the weld size and length to the print. Much weld efficiencies are lost due to over welding; follow the specifications on the print and do not over weld.

Weld Positions

When discussing groove welds a "G" is used to signify a groove weld, and a number is assigned to signify welding position. Plate weld designations are as:

1G — flat position, groove weld

2G — horizontal position, groove weld

3G — vertical position, groove weld

4G — overhead position, groove weld

Pipe welds as:

1G — flat position groove weld, pipe rotated

2G — horizontal groove weld, pipe axis is vertical

5G — multiple positions (overhead, vertical and flat) groove weld, pipe axis is horizontal and is not rotated

6G and 6GR — multiple positions groove weld, pipe axis is 45° from horizontal and is not rotated

Figure 7.19 represents a graphic view of these groove weld positions on plate and pipe.

When discussing fillet welds an "F" is used to signify a fillet weld, and a number is assigned to signify the welding position. Plate positions are designated as:

1F — flat position, fillet weld

2F — horizontal position, fillet weld

3F — vertical position, fillet weld

4F — overhead position, fillet weld

Pipe positions as:

1F — flat position, fillet weld pipe axis is 45° from the horizontal and the pipe is rotated

2F — horizontal position, fillet weld pipe axis is vertical

2FR — horizontal position, fillet weld pipe axis is horizontal and the pipe is rotated

4F — overhead position, fillet weld pipe axis is vertical

5F — multiple positions (overhead, vertical and horizontal), fillet weld pipe axis is horizontal and is not rotated

6F — multiple positions, fillet weld pipe axis is 45° from horizontal and is not rotated

Figure 7.20 represents a graphic view of these fillet weld positions on plate and pipe.

If possible, it is best to make both fillet and groove welds in the flat (1) position. This allows for proper penetration, proper wetting action and avoidance of undercut. Positioners are often used to keep welds in the flat position for the highest weld productivity. However, there are times when this is not possible and the weld must be made in the position encountered. The TIG process is very applicable to welding in all positions, as the filler metal is deposited directly in the weld pool and does not transfer across the arc as it does in other arc welding processes. Proper welding techniques must still be observed to weld in the various positions.

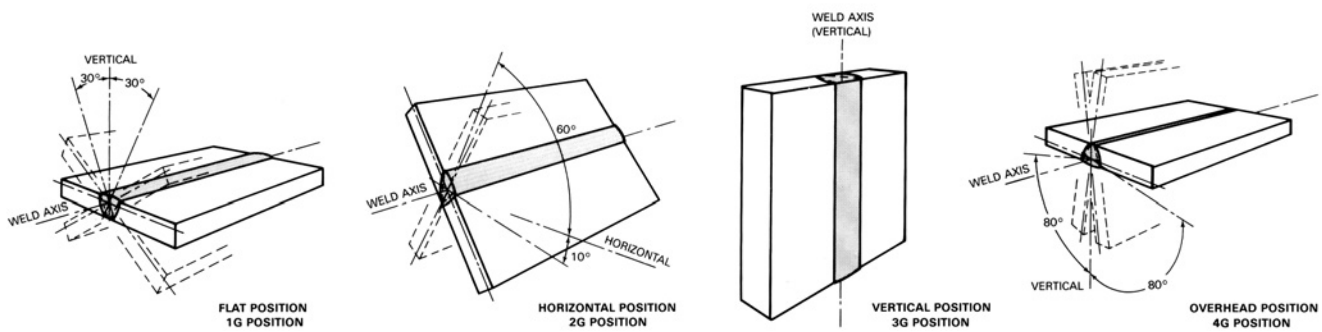

Figure 7.19 Groove weld positions.

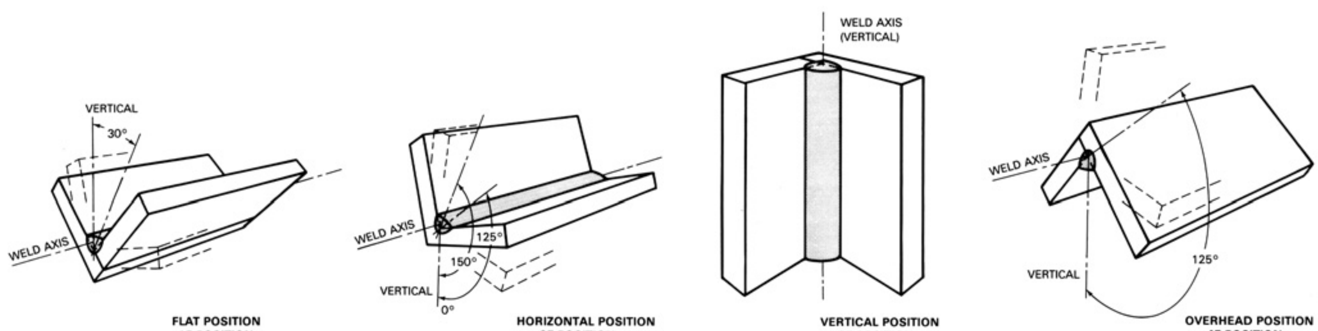

Figure 7.20 Fillet weld positions.

VIII. Techniques for Basic Weld Joints

Arc Length, Gas Cup Size, and Electrode Extension

As a rule of thumb, the arc length is normally one electrode diameter as seen in Figure 8.1. This would hold true when AC welding with a balled end on the electrode. When welding with direct current using a pointed electrode, the arc length may be considerably less than the electrode diameter. Torches held in a fixed position allow for holding a closer arc than for manually held torches.

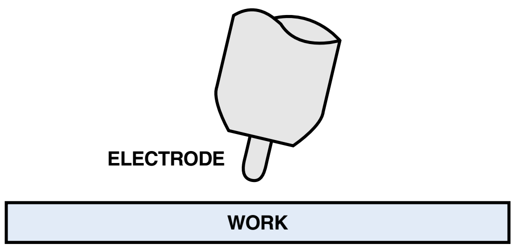

Figure 8.1 Illustration shows the relationship between electrode diameter and arc length.

The inside diameter of the gas cup should be at least three times the tungsten diameter to provide adequate shielding gas coverage. For example, if the tungsten is 1/16" in diameter, the gas cup should be a minimum of 3/16" diameter. Figure 8.2 is an example of gas cup size and torch position.

Tungsten extension is the distance the tungsten extends out beyond the gas cup of the torch. Electrode extension may vary from flush with the gas cup to no more than the inside diameter of the gas cup. The longer the extension the more likely it will accidentally contact the weld pool, filler rod being fed in by the welder, or touch the side of a tight joint. A general rule would be to start with an extension of one electrode diameter. Joints that make the root of the weld hard to reach will require additional extension.

Torch Position for Arc Starting with High Frequency

The torch position shown in Figure 8.3 illustrates the recommended method of starting the arc with high frequency when the torch is held manually. In this way the operator can position the torch in the joint area and after lowering the welding hood, close the contactor switch and initiate the arc. By resting the gas cup on the base metal there is little danger of touching the electrode to the work. After the arc is initiated, the torch can be raised to the proper angle for welding.

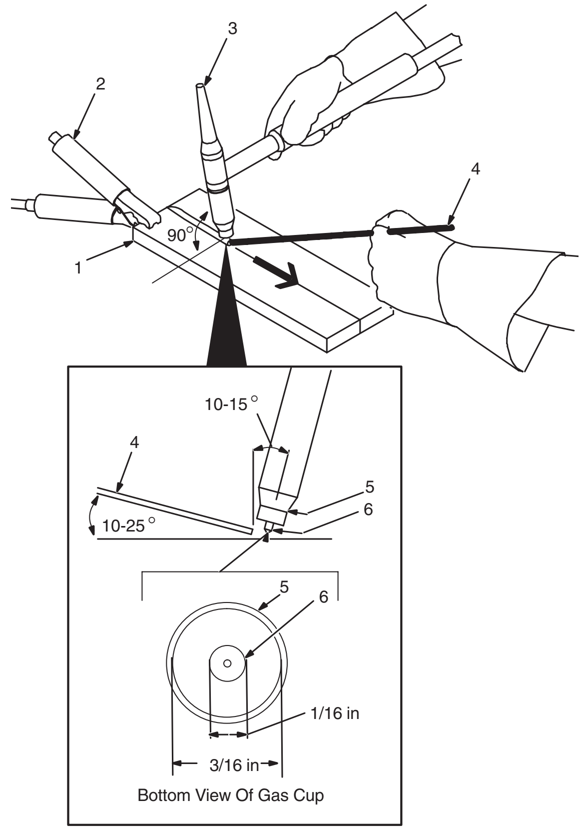

Figure 8.2 Gas cup size and torch positions. 1-Workpiece, 2-Work Clamp, 3-Torch, 4-Filler Rod (If Applicable), 5-Gas Cup, 6-Tungsten Electrode.

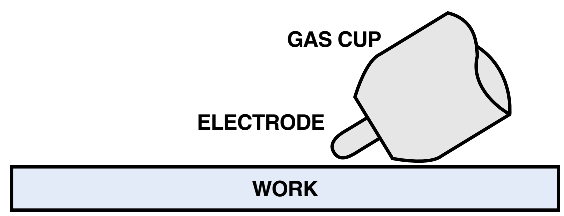

Figure 8.3 Resting the gas cup against the work in preparation for a high-frequency start.

Manual Welding Techniques

Making the Stringer Bead

The torch movement used during manual welding is illustrated in Figure 8.4. Once the arc is started, the electrode is held in place until the desired weld pool is established. The torch is then held at a 75° angle from the horizontal as shown in the illustration and is progressively moved along the joint. When filler metal is used, it is added to the leading edge of the pool.

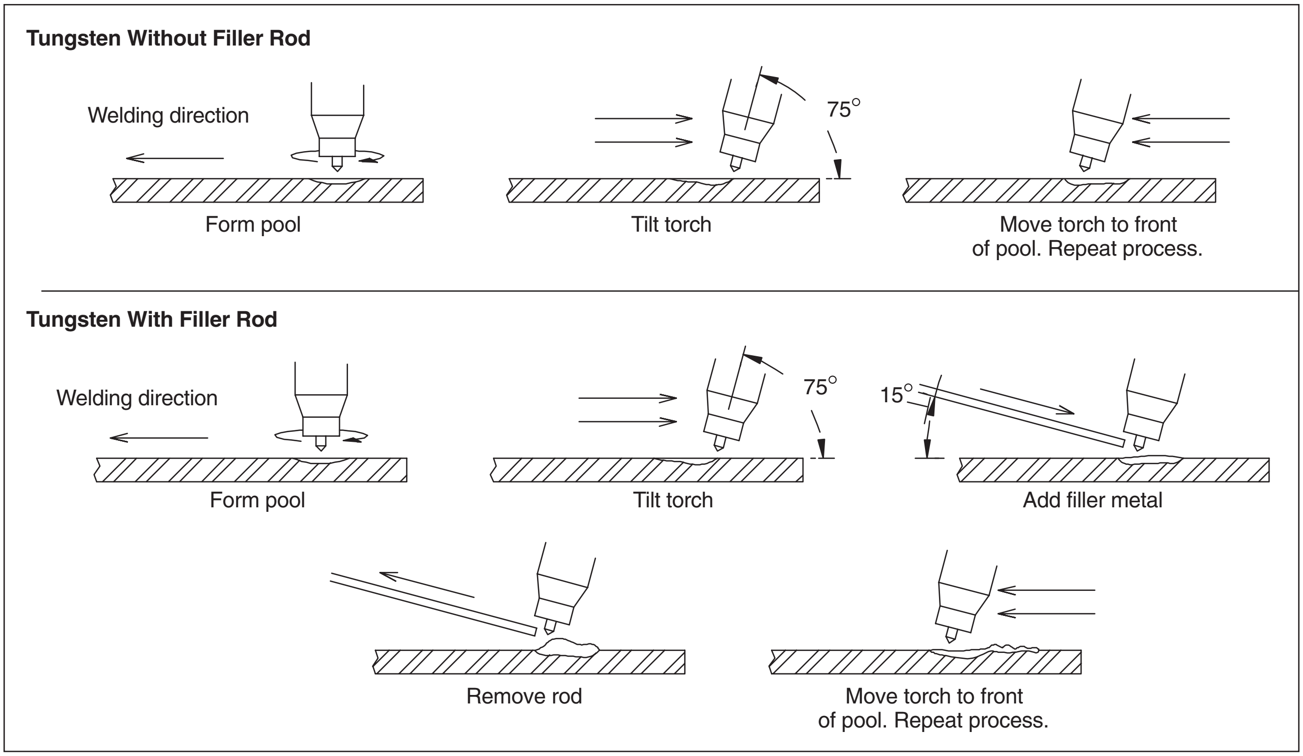

Figure 8.4 Torch movement during welding.

The torch and filler rod must be moved progressively and smoothly so the weld pool, the hot filler rod end, and the solidifying weld are not exposed to air that will contaminate the weld metal area or heat affected zone. Generally a large shielding gas envelope will prevent exposure to air.

The filler rod is usually held at about a 15° angle to the surface of the work and slowly fed into the molten pool. Or it can be dipped in and withdrawn from the weld pool in a repetitive manner to control the amount of filler rod added. During welding, the hot end of the filler rod must not be removed from the protection of the inert gas shield. When the arc is turned off, the postflow of shielding gas should not only shield the solidifying weld pool but the electrode and the hot end of the filler rod.

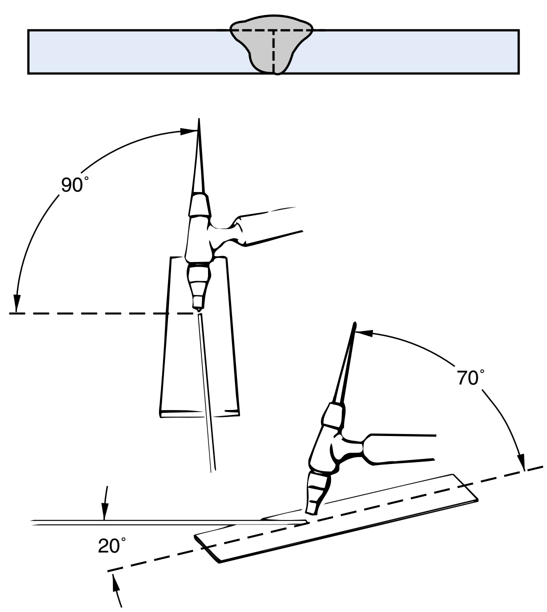

Figure 8.5 Welding the butt weld and stringer bead.

Butt Weld and Stringer Bead

Torch and Rod Position

When welding a butt joint, be sure to center the weld pool on the adjoining edges. When finishing a butt weld, the torch angle may be decreased to aid in filling the crater. Add enough filler metal to avoid an unfilled crater.

Cracks often begin in a crater and continue through the bead. A foot operated amperage control will aid in the finishing of a bead as amperage can be lowered to decrease pool size as filler metal is added.

Lap Joint

Torch and Rod Position

Having established an arc, the pool is formed so that the edge of the overlapping piece and the flat surface of the second piece flow together. Since the edge will become molten before the flat surface, the torch angle is important. The edge will also tend to burn back or undercut. This can be controlled by dipping the filler rod next to the edge as it tries to melt away. Enough filler metal must be added to fill the joint as shown in the lap joint illustration. Finish the end of the weld the same as before by filling the crater.

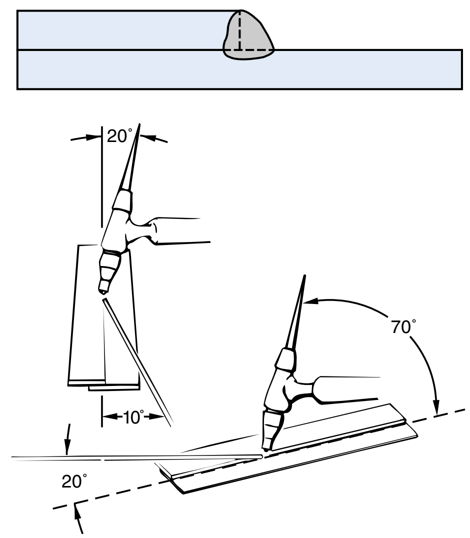

Figure 8.6 Welding the lap joint.

T-Joint

Torch and Rod Position

A similar situation exists with the T-joint as with the lap joint. An edge and a flat surface are to be joined together. The edge again will heat up and melt sooner. The torch angle illustrated will direct more heat onto the flat surface. The electrode may need to be extended further beyond the cup than in the previous butt and lap welds in order to hold a short arc. The filler rod should be dipped so it is deposited where the edge is melting away. Correct torch angle and placement of filler rod should avoid undercutting. Again, the crater should be filled to avoid excessive concavity.

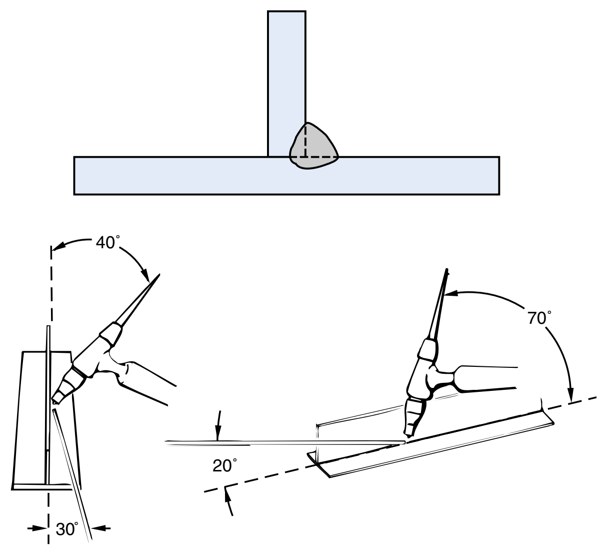

Figure 8.7 Welding the T-joint.

Corner Joint

Torch and Rod Position

The correct torch and filler rod positions are illustrated for the corner joint. Both edges of the adjoining pieces should be melted and the pool kept on the joint centerline. When adding filler metal, sufficient deposit is necessary to create a convex bead. A flat bead or concave deposit will result in a throat thickness less than the metal thickness. On thin materials, this joint design lends itself to autogenous welding or fusions welding without the addition of filler rod. Good fit-up is required for autogenous welding.

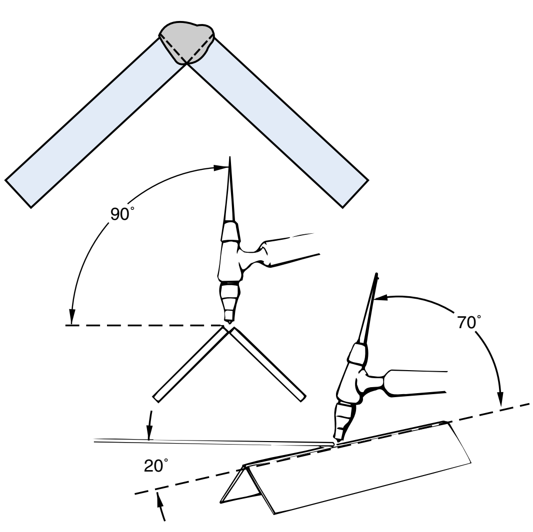

Figure 8.8 Welding the corner joint.

Techniques for Out-of-Position Weld Joints

During the welding process, all action is centered in the weld pool. The weld pool is the point at which fusion and penetration occur. With practice controlling the pool becomes quite easy while welding in the flat position. Eventually as additional experience is acquired, welding out-of-position will be much easier for the welder. Controlling the weld pool and penetration is the prime concern for all positions of welding.

There are many variables to take into consideration in out-of-position welding, such as amperage, travel speed, tungsten type and torch position. Volumes could be devoted to this subject alone. Therefore, we will try to provide a few tips and make a few general statements regarding out-of-position weld joints.

Welding in the Vertical Position

Figure 8.9 Welding in the vertical position.

Gravity is the enemy of all out-of-position welding. In the vertical position, both up and down, gravity will try to pull the molten weld pool downward and out of the joint. A good welder however, will learn to use gravity to his or her advantage.

In vertical up welding, the weld is begun at the bottom of the joint with the filler metal being added from above. Attempt to establish a "shelf" with each dab of filler metal for the next filler metal addition to rest on. If the joint is wide, work back and forth across the joint to establish this shelf.

If the joint to be welded is a V-groove, the tungsten electrode extension can be increased, and the gas cup can be rested against the edges of the joint and maneuvered back and forth. This will greatly assist in providing a steady hand, although this technique makes it difficult to actually see the weld pool.

Vertical down welding makes use of both surface tension and arc force to hold the molten weld pool in the joint. Mastery of the vertical down technique is useful when welding on thin material. Practicing the vertical up and down techniques on a flat sheet or plate will greatly assist the welder who desires to move on to pipe welding because nearly all pipe beads are accomplished with the same techniques. However, vertical down is rarely used when TIG welding thicker sections of plate or pipe.

Welding in the Overhead Position

Figure 8.10 Welding in the overhead position.

Welding in the overhead position is thought by most welders to be the most difficult of all positions. The welder who can consistently produce high quality overhead welds is much sought after by industry.

As with vertical welding techniques, gravity is the enemy of overhead welding. Unlike the vertical position, overhead welding cannot rely on the building of shelves on which to place consecutive beads. Instead, it relies on surface tension of the pool, arc force, and a combination of lower amperage and higher travel speeds.

One of the techniques used in vertical welds that can be utilized in the overhead position is extending the tungsten electrode and resting the gas cup against one or both sides of the joint to be welded. This procedure is usually used only in groove welds and some fillet welds. When the welder is putting in fill passes he can extend a few fingers on either the torch hand or the filler rod hand and actually rest them on the plate to be welded. This will help steady the hand.

Figures 8.11 and 8.12 Demonstrations of two common methods of grasping the torch for pipe welding. There is no single "correct" method of doing this and each welder is encouraged to experiment with several different methods until one is found that is most comfortable, and results in satisfactory welds.

Heat input to the overhead weld pool is extremely important. Generally speaking, the heat input of an overhead joint would be less than the amount used for a comparable weld in the horizontal or flat position. This keeps the pool size small and thereby prevents sagging or the weld pool from falling out of the joint.

The possibility of falling molten metal makes the need of proper protective clothing and equipment absolutely essential. Never attempt to make this type of weld without all safety gear in place.

No doubt the overhead position is difficult. It is extremely fatiguing for the welder to accomplish, making it a slow process and increasing the time needed to accomplish the job. This is one of the major reasons industrial use of overhead welding is kept to a minimum.

Techniques for Pipe Welding

Pipe welding with the GTAW process requires a great deal of skill, and should only be attempted when the welder has mastered the principles of GTAW welding on plate.

GTAW produces the highest quality pipe weld of all the arc processes and with a minimum of distortion.

As with our previous segments on out-of-position welding, the different combinations of metals, positions, tungstens, gases and so on make this a subject to which an entire book, or even library, could be devoted. Therefore this segment will be limited to a few helpful hints and tips.

Consumable inserts are items often used in pipe welding. Consumable inserts are composed of the same type of material that is being welded and are used to keep root passes uniform. The consumable insert is melted into the root pass and becomes an integral part of the weld bead.

Because most pipe joints require a gapped joint, protection of the weld bead in the form of gas coverage inside the pipe is necessary. This coverage can be accomplished by covering the ends of the pipe with pipe caps made for that purpose, or by simply covering the ends with paper and tape, and then inserting a shielding gas hose.

GTAW pipe welding also requires a special treatment of the tungsten electrode tip. A common electrode would be a 1.5% lanthanated or 2% thoriated tungsten. Once the tip is ground to a point, the very tip is flattened to a width of about .020. This small flat spot helps to distribute the arc evenly at the joint edges.

One of the most popular techniques for GTAW welding of pipe joints is the walking-the-cup technique. This technique utilizes a specific manner of manipulating the torch, along with a series of increasingly larger gas cups to produce consistently good welds with a minimum of fatigue.

Figure 8.13 Demonstration of how the torch and filler rod are held to accomplish the "walking-the-cup" method of pipe welding.

The two sections of pipe to be welded should be gapped slightly less than the diameter of the filler rod to be used. The filler rod should rest in the groove without slipping through. For the root pass, rest the gas cup in the groove contacting both sides and aimed slightly to either the right or left of the joint. The cup is then rocked slowly back and forth and slight pressure is applied to the torch so that it travels forward along the groove at the same time.

The filler rod is not dipped in and out of the pool, but remains in contact with the leading edge at all times. When the root pass is completed, a larger cup is then placed on the torch so that it now contacts both sides of the groove as well as the surface of the root pass. The torch is now rocked back and forth in the joint pivoting on the surface of the root pass while being guided by the sides of the groove. The filler rod is kept at the leading edge of the pool without dipping in and out. The third and all remaining passes are accomplished in the same manner except that increasingly larger gas cups are used. Make sure the tungsten extension is adjusted so that it does not dip into the weld pool, but remains close enough for proper control.

Arc Starting Procedures

The arc starting requirements of the material to be welded will have a great impact on the choice of welding power sources.

Scratch Start — This method of arc initiation is utilized by GTAW power sources with no added arc starting capability. The arc is started by briefly placing the tungsten electrode in contact with the work and then quickly withdrawing it as the arc is established. The advantage of this method is simplicity of operation. This starting method is not acceptable for critical applications since small tungsten particles may become embedded in the workpiece and contaminate the weld. It is not advisable to use this method with inverter-type power sources equipped with touch start.

Figure 8.14 This welder (who happens to be left handed) demonstrates still another style of torch and filler rod manipulation used to accomplish a pipe weld.

Lift-Arc™ — This type of arc starting method was developed to eliminate tungsten contamination associated with the scratch start method. With touch start the tungsten is brought into contact with the workpiece. When this occurs, the power source senses a short circuit and establishes a low voltage current in the weld circuit. This voltage and current are not great enough to establish an arc, but do contribute to heating the electrode. When the electrode is lifted from the workpiece, the power source senses the absence of the short circuit condition and automatically switches to the current set on the machine. The fact that the electrode has been pre-heated assists in arc initiation.

Carbon Start — In this method, the tungsten is placed close to the work, then the resulting gap is momentarily bridged with a carbon rod or block. Once the arc has begun, the carbon rod or block is removed or the arc is moved to the beginning point of the weld. This method is also unacceptable in critical weld applications because carbon particles may easily become entrapped in the work. The application of the carbon rod may be frequently impractical.

Pilot Arc — A small current is maintained between the electrode and the gas nozzle to provide a conductive path for the main weld current. This is a method used often with the GTAW spot welding process and when the process is used for machine or automatic welding applications.

Hot Tungsten Arc — The tungsten is resistively heated to a cherry red. At this temperature, the shielding gas in the area of the tungsten becomes ionized and therefore will conduct electricity. The presence of the power sources open circuit voltage under these circumstances is enough for the arc to establish itself between the electrode and the work. The necessity of heating the electrode and the resulting preheating of the work are considered disadvantages of this method.

Capacitor Discharge (CD) — In this method, the arc is initiated with a momentary burst of high voltage (normally provided by a bank of capacitors) between the electrode and the work. This high-energy spark creates an ionized path through which the weld current starts flowing. This method is generally used with DC power supplies in machine or automatic welding applications.

High-Frequency Start — Perhaps the most common of all arc starting methods, high frequency can be used with DC or AC power sources for manual through automatic applications. This method uses the ionizing capability of a high-frequency voltage superimposed over the welding current to provide a path for the arc to become established. Some power sources discontinue the high frequency once the arc is established and some feature continuous high frequency to take advantage of the stabilizing control it has on the arc. Special precautions must be taken to prevent the high frequencies electromagnetic interference (EMI) from radiating too much energy and causing interference with communication systems and computerized equipment.

Impulse Arc Start—Used when a noncontact, TIG arc starting method is required. A single pulse of high-frequency (HF) voltage is superimposed from the electrode to the workpiece to initiate the arc. Impulse arc starting can be used for DC TIG or AC TIG using the Advanced Squarewave power source. The main advantage to impulse arc starting is the electromagnetic interference (EMI) generated by the welding power source is significantly reduced. Thus, the chance of causing other electronic equipment in the immediate vicinity to malfunction or be damaged is diminished.

Arc Assist—Utilizes a high voltage DC spike that is induced into the weld circuit to assist starts and provide stabilization during AC welding. These high voltage spikes are present only when the output voltage is greater than 30 volts. In DC welding, as the welder brings the electrode close enough to the work, the pulses jump start the arc, the weld circuit voltage drops to its normal 14 or so volts, and the arc assist circuitry drops out. In AC welding, the voltage passes through the zero point twice each cycle and the arc will tend to go out. Because the voltage increases during these arc outages, the Arc Assist circuitry is automatically engaged for that part of the cycle only, thereby providing a stabilizing effect.

GTAW Arc Starting Tips

The following list is developed from the experiences of welding engineers, welding technicians, welding instructors, and others employed in the welding field. They were asked to provide tips and techniques they have used for the sometimes difficult task of starting the gas tungsten arc. The list of arc starting “hints and tips” are in no particular order of importance, and are submitted in the interest of taking advantage of the many years of experience of welding professionals.

- Use the smallest diameter tungsten possible.
- Buy the highest quality tungsten available (of the proper alloy).
- Use the shortest length torch possible.
- Use premium quality cable for torch and work leads.
- Keep torch and work leads as short as possible. Move the power source as close as possible to the work. If the power source cannot be moved closer and a high-frequency arc starter is being used, move it closer to the weld.
- Attach work lead as close as possible to the weld.
- Avoid long cable runs over bare concrete floors, or insulate cables from floor by laying them on boards.
- If the welding machine is being used for both GTAW welding and for Stick electrode welding, make sure the Stick electrode holder is detached from the machine when GTAW welding.
- Check and tighten all connections.
- Keep the torch cable from contacting any grounded metal such as work benches, steel floor plates, and the machine case.
- Use 100% argon shielding gas if possible.
- Check the secondary current path and tighten all connections.
- If the machine has adjustable high-frequency spark gaps, increase gap to manufacturer’s recommended maximum.
- Check for mineral deposit build up in water-cooled torches to avoid high-frequency shunting back to ground through deposit material.
- Increase intensity adjustment if available.

Tips for Automatic Applications

- Check all of the above, they still apply.
- Mount the torch in a non-metallic holder or clamp.
- Use a metallic gas cup on the torch. Attach a 6000 volt lead with a .001 mfd mica-capacitor between gas cup and ground.

IX. Cost Considerations of the GTAW Process

It is important to take into consideration all the facts that relate to a welding situation when attempting to attach a cost to a foot of weld. Not only do direct costs such as filler wire, shielding gas, equipment, and labor have a bearing, but indirect costs such as overhead and training of personnel have an affect as well.

Training should be considered in the cost since GTAW is generally considered a more advanced process and will require time by the welder to familiarize with the technical and manipulative aspects of the process.

The cost of proper equipment to efficiently accomplish the job at hand is of great importance. Manual GTAW equipment in a production setup can run into thousands of dollars. If there are many repetitive welds, automatic equipment should be considered, and those costs can run into the tens of thousands of dollars.

A cost evaluation of a welding process should include:

1. Labor and overhead cost per foot of weld.
2. Filler wire cost per foot of weld.
3. Gas cost per foot of weld.
4. Power cost per foot of weld.

Computing these figures on a chart or proposal will show the economics of a particular process.

Standard formulas for cost estimating as presented in this book (Figure 9.1) are a reasonable measure for computing data for cost comparison.

The formulas as presented have no “plug-in” numerical values. The values will vary with each application and each company.

Formulas to Figure Total Welding Cost

1. Labor = $$\frac{\text{Welder Rate in \$ Per Hour}}{\text{Weld Travel Speed (IPM)} \times \text{Duty Cycle} \times \frac{60\ \text{min./hr.}}{12\text{"/ft.}}} = \text{Cost per ft.}$$

2. Overhead = $$\frac{\text{Overhead Rate}}{\text{Weld Travel Speed (IPM)} \times \text{Duty Cycle} \times \frac{60\ \text{min./hr.}}{12\text{"/ft.}}} = \text{Cost per ft.}$$

3. $$\frac{\text{Filler Metal Cost}}{\text{Foot of Weld}} \qquad \frac{\text{Weight of Deposit} \times \text{Filler Metal Cost}}{\text{Deposition Efficiency}}$$

4. Gas = $$\frac{\text{Cost of Gas/cu. ft.} \times \text{Flow Rate (cfh)}}{\text{Weld Travel Speed (IPM)} \times \frac{60\ \text{min./hr.}}{12\text{"/ft.}}} = \text{Cost per ft.}$$

5. Power = $$\frac{\text{Volts} \times \text{amps} \times \text{power cost/kw. hr.}}{\text{Weld Travel Speed (IPM)} \times \text{Machine Efficiency} \times \frac{60\ \text{min./hr.}}{12\text{"/ft.}} \times 1000} = \text{Cost per ft.}$$

6. Total = Total of Above Applying Formulas x Total Length of Weld = Total Cost

*The factor 5 will appear in some of the formula examples: This was derived from the ratio of: $\frac{60\ \text{min./hr.}}{12\text{"/ft.}}$

Figure 9.1 Formulas for cost considerations.

X. GTAW Troubleshooting

When troubleshooting Gas Tungsten Arc Welding process and equipment problems, it is ideal to isolate and classify them as soon as possible into one of the following categories:

1. Electrical
2. Mechanical
3. Process

The data collected here discusses some of the common problems of the TIG welding processes.

The assumption of this data is that a proper welding condition has been achieved and has been used until trouble developed. In all cases of equipment malfunction, the manufacturer's recommendations should be strictly adhered to and followed.

PROBLEM 1: Burning Through Tungsten Fast	
PROBABLE CAUSES	SUGGESTED REMEDY
1. Inadequate gas flow.	Check to be sure hose, gas valve, and torch are not restricted or the tank is not out of gas. Gas flow should typically be set at 15 to 20 cfh.
2. Operation on electrode positive (DCEP).	Switch to electrode negative (DCEN).
3. Improper size tungsten for current used.	General purpose tungsten size is 3/32" diameter at a maximum of 220 amps.
4. Excessive heating in torch body.	Air-cooled torches do get very warm. If using a water-cooled torch, coolant flow may be restricted or coolant may be low.
5. Tungsten oxidation during cooling.	Keep shielding gas flowing 10–15 seconds after arc stoppage. 1 second for each 10 amps of weld current.
6. Use of gas containing oxygen or CO_2.	Use argon gas.
7. Tungsten melting back into cup (AC).	If using pure tungsten, change to ceriated or lanthanated. If machine has Balance Control, adjust setting towards maximum penetration (70-90). Tungsten diameter may be too small for the amount of current being used. Increase tungsten size.

PROBLEM 2: Tungsten Contamination	
PROBABLE CAUSES	SUGGESTED REMEDY
1. Tungsten melting into weld puddle.	Use less current or larger tungsten. Use ceriated (AC), thoriated (DC), or lanthanated tungsten.
2. Touching tungsten to weld puddle.	Keep tungsten from contacting weld puddle. Raise the torch so that the tungsten is off of the work piece 1/8" to 1/4".

PROBLEM 3: High-Frequency Present — No Arc Power	
PROBABLE CAUSES	SUGGESTED REMEDY
1. Incomplete weld circuit.	Check work connection. Check all cable connections.
2. No shielding gas.	Check for gas flow at end of torch. Check for empty cylinder or closed shut-off valve. Gas flow should typically be set at 15 to 20 cfh.

PROBLEM 4: Porosity and Poor Weld Bead Color	
PROBABLE CAUSES	SUGGESTED REMEDY
1. Condensation on base metal.	Blow out all air and moisture condensation from lines. Remove all condensation from base metal before welding. Metals stored in cold temperatures will condensate when exposed to warm temperatures.
2. Loose fittings in torch or hoses.	Tighten fittings on torch and all hoses.
3. Inadequate gas flow.	Adjust flow rate as necessary. Gas flow should typically be set at 15 to 20 cfh.
4. Defective gas hose or loose connection.	Replace gas hose and check connections for leaks, cuts, or pin holes.
5. Contaminated or improper filler metal.	Check filler metal type. Remove all grease, oil, or moisture from filler metal.
6. Base metal is contaminated.	Remove paint, grease, oil, and dirt, including mill scale from base metal.

PROBLEM 5: Yellow Powder or Smoke on Cup—Tungsten Discolor	
PROBABLE CAUSES	SUGGESTED REMEDY
1. Shielding gas flow rate too low.	Increase flow rate. Gas flow should typically be set at 15 to 20 cfh.
2. Incorrect shielding gas or mixture.	Use argon gas.
3. Inadequate post flow.	Increase post flow time. Set at 10 to 15 seconds.
4. Improper tungsten size or cup size.	Match tungsten size and cup size to joint being welded. General purpose tungsten size is 3/32" diameter and #8 cup.

PROBLEM 6: Unstable Arc	
PROBABLE CAUSES	SUGGESTED REMEDY
While AC Welding	
1. Excessive rectification in base metal.	Increase travel speed. Increase balance control toward more penetration. Add filler metal.
2. Improper shielding gas.	In some cases, when welding on 3/8" to 1/2" thick aluminum, argon/helium is used.
3. Incorrect arc length.	Use correct arc length. Adjust the torch so that the tungsten is off of the work piece 1/8" to 1/4".
4. Tungsten is contaminated.	Remove 1/2" of contaminated tungsten and repoint tungsten.
5. Base metal is contaminated.	Remove paint, grease, oil, and dirt, including mill scale from base metal.
6. Frequency set too low.	On welders with adjustable AC frequency, increase frequency to give proper arc stability and direction. 100 to 180 Hertz is acceptable.
7. Improperly prepared tungsten.	With Squarewave and inverter machines, use pointed tungsten. Point will eventually round off after welding.

PROBLEM 6: Unstable Arc	
PROBABLE CAUSES	SUGGESTED REMEDY
While DC Welding	
1. Weld circuit polarity is incorrect.	Check polarity switch on welder. Select DCEN (Direct Current Electrode Negative).
2. Tungsten is contaminated.	Remove 1/2" of contaminated tungsten and repoint tungsten.
3. Arc too long.	Shorten arc length. Lower torch so that the tungsten is off of the work piece no more than 1/8" to 1/4".
4. Base metal is contaminated.	Remove paint, grease, oil, and dirt, including mill scale from base metal.

PROBLEM 7: Arc Wanders	
PROBABLE CAUSES	SUGGESTED REMEDY
While DC Welding	
1. Improper arc length/tungsten in poor condition.	Lower the torch so that the tungsten is off of the work piece 1/8" to 1/4". Clean and sharpen tungsten.
2. Improperly prepared tungsten.	Grind marks should run lengthwise with tungsten, not circular. Use proper grinding method and wheel.
3. Light gray frosted appearance on end of tungsten.	Remove 1/2" of tungsten and repoint tungsten.
4. Improper gas flow.	Gas flow should typically be set at 15 to 20 cfh.
While AC Welding	
1. Improper tungsten preparation.	With Squarewave and inverter machines, use pointed tungsten. Point will eventually round off after welding.
2. Tungsten is contaminated.	Remove 1/2" of contaminated tungsten and repoint tungsten.
3. Base metal is contaminated.	Remove paint, grease, oil, and dirt, including mill scale from base metal.
4. Incorrect balance control setting.	Increase balance toward more penetration. Normal Balance Control setting is 70 - 90.
5. Improper tungsten size and type.	Select proper size and type. General purpose tungsten size is 3/32" diameter and ceriated or thoriated.
6. Excessive rectification in base metal.	Increase travel speed. Increase balance setting toward more penetration. Add filler metal.
7. Improper shielding gas flow.	Gas flow should typically be set at 15 to 20 cfh.
8. Frequency set too low.	Increase AC frequency on machines so equipped to stabilize and direct the arc. The higher the frequency, the narrower and deeper the penetration.

PROBLEM 8: Arc Will Not Start or is Difficult to Start	
PROBABLE CAUSES	SUGGESTED REMEDY
While DC Welding	
1. No shielding gas.	Gas flow should typically be set at 15 to 20 cfh.
2. Incorrect power supply switch positions.	Place switches in proper positions, either HF impulse or start HF.
3. Improper tungsten electrode.	Use ceriated or thoriated tungsten.
4. Loose connections.	Tighten all cable and torch connections.
5. Incomplete weld circuit.	Make sure work clamp is connected.
6. Improper tungsten size.	Use smallest tungsten possible. Most common tungsten size is 3/32" diameter.
While AC Welding	
1. Incomplete weld circuit.	Check work clamp to assure it is securely fastened to work.
2. Incorrect cable installation.	Check circuit breakers and fuses. Check and tighten all cable connections.
3. No shielding gas.	Check for gas flow at end of torch. Check for empty cylinder or closed shut-off valve. Gas flow should typically be set at 15 to 20 cfh.
4. Loss of high frequency.	Check torch and cables for cracked insulation or bad connections. Check spark gaps and adjust if necessary.
5. Improper tungsten size.	Use smallest tungsten possible. Most common tungsten size is 3/32" diameter.
6. Incorrect tungsten type.	Use ceriated, thoriated, or lanthanated tungsten.

XI. Tables

Table 1

Types of Tungsten Electrodes				
AWS Classification	**Type of Tungsten (Alloy)**	**Color Code**	**Available Finish***	**Remarks**
EWP	Pure	Green	Cleaned and ground	Provides good arc stability for AC welding. Reasonably good resistance to contamination. Lowest current carrying capacity. Least expensive. Maintains a clean balled end.
EWCe-2	Ceria CeO_2 1.8% to 2.2%	Orange	Cleaned and ground	Similar performance to thoriated tungsten. Easy arc starting, good arc stability, long life. Possible nonradioactive replacement for thoria.
EWLa-1	Lanthana La_2O_3 0.9% to 1.2%	Black	Cleaned and ground	Similar performance to thoriated tungsten. Easy arc starting, good arc stability, long life, high current capacity. Possible nonradioactive replacement for thoria.
EWLa-1.5	Lanthana La_2O_3 1.3% to 1.7%	Gold	Cleaned and ground	Similar performance to thoriated tungsten. Easy arc starting, good arc stability, long life, high current capacity. Possible nonradioactive replacement for thoria.
EWLa-2	Lanthana La_2O_3 1.8% to 2.2%	Blue	Cleaned and ground	Similar performance to thoriated tungsten. Easy arc starting, good arc stability, long life, high current capacity. Possible nonradioactive replacement for thoria.
EWTh-1	Thoria ThO_2 0.8% to 1.2%	Yellow	Cleaned and ground	Easier arc starting. Higher current capacity. Greater arc stability. High resistance to weld pool contamination. Difficult to maintain balled end on AC.
EWTh-2	Thoria ThO_2 1.7% to 2.2%	Red	Cleaned and ground	Easier arc starting. Higher current capacity. Greater arc stability. High resistance to weld pool contamination. Difficult to maintain balled end on AC.
EWZr-1	Zirconia ZrO_2 0.15% to 0.40%	Brown	Cleaned and ground	Excellent for AC welding due to favorable retention of balled end, high resistance to contamination, and good arc starting. Preferred when tungsten contamination of weld is intolerable.
EWG	Specify	Gray		Contains other rare earths or a combination of oxides.

*Clean finish designates electrodes that are chemically cleaned and etched. Ground finish designates electrodes with a centerless ground finish to provide maximum smoothness and consistency.

Centerless ground tungsten electrodes are used where minimum resistance loss at the collet-electrode contact point is desired.

Table 2

Typical Current Ranges for Tungsten Electrodes*						
		Direct Current, DC	Alternating Current, AC			
		DCEN	70% Penetration		(50/50) Balanced Wave A	
Tungsten Diameter	Gas Cup Inside Diameter	Ceriated Thoriated Lanthanated	Pure	Ceriated Thoriated Lanthanated	Pure	Ceriated Thoriated Lanthanated
.040	#5 (3/8 in)	15 – 80	20 – 60	15 – 80	10 – 30	20 – 60
.060 (1/16 in)	#5 (3/8 in)	70 – 150	50 – 100	70 – 150	30 – 80	60 – 120
.093 (3/32 in)	#8 (1/2 in)	150 – 250	100 – 160	140 – 235	0 – 130	100 – 180
.125 (1/8 in)	#8 (1/2 in)	250 – 400	150 – 200	225 – 325	100 – 180	160 – 250

*All values are based on the use of Argon as a shielding gas. Other current values may be employed depending on the shielding gas, type of equipment, and application.
DCEN = Direct Current Electrode Negative (Straight Polarity)

Table 3

Recommended Types of Current, Tungsten Electrodes and Shielding Gases for Welding Different Metals[1]				
Types of Metal	**Thickness**	**Type of Current**	**Electrode[2]**	**Shielding Gas**
Aluminum	All	AC	Pure or zirconium	Argon or argon-helium
	All	AC Advanced Squarewave	Lanthanated, cerium thoriated	Argon or argon-helium
	over 1/4"	DCEN	Lanthanated, cerium thoriated	100% Helium
Copper, copper alloys	All	DCEN	Lanthanated, cerium thoriated	Helium
Magnesium alloys	All	AC	Pure or zirconium	Argon
	All	AC Advanced Squarewave	Lanthanated, cerium thoriated	Argon
Nickel, nickel alloys	All	DCEN	Lanthanated, cerium thoriated	Argon, argon-helium, argon-hydrogen (5% max)
Plain carbon, low-alloy steels	All	DCEN	Lanthanated, cerium thoriated	Argon or argon-helium
Stainless steel	All	DCEN	Lanthanated, cerium thoriated	Argon or argon-helium
Titanium, zirconium, hafnium[3]	All	DCEN	Lanthanated, cerium thoriated	Argon
Refractory Metals[3]	All	DCEN	Lanthanated, cerium thoriated	Argon

[1]These recommendations are general guidelines based on methods commonly used in industry.
[2]Where thoriated electrodes are recommended, lanthanated, ceriated or rare earth containing electrodes should be used.
[3]A glove box is often required to prevent atmospheric contamination.

Table 4

AWS Specifications for Filler Metals, Shielding Gases and Electrodes Suitable for Gas Tungsten Arc Welding	
Specification Number	**Title**
A 5.7	Copper and Copper Alloy Bare Welding Rods and Electrodes
A 5.9	Stainless Steel Bare Welding Rods and Electrodes
A 5.10	Aluminum and Aluminum Alloy Welding Rods and Bare Electrodes
A 5.12	Tungsten and Tungsten Alloy Electrodes
A 5.13	Surfacing Welding Rods and Electrodes
A 5.14	Nickel and Nickel Alloy Bare Welding Rods and Electrodes
A 5.16	Titanium and Titanium Alloy Bare Welding Rods and Electrodes
A 5.18	Carbon Steel Filler Metals for Gas Shielded Arc Welding
A 5.19	Magnesium-Alloy Welding Rods and Bare Electrodes
A 5.21	Composite Surfacing Welding Rods and Electrodes
A 5.24	Zirconium and Zirconium Alloy Bare Welding Rods and Electrodes
A 5.28	Low Alloy Steel Filler Metal for Gas Shielded Arc Welding
A 5.30	Consumable Inserts
A 5.32	Welding Shielding Gases

Table 5

Welding Position Designations	
Plate Welds	
Groove Welds	
1G	Flat position
2G	Horizontal position
3G	Vertical position
4G	Overhead position
Fillet Welds	
1F	Flat position
2F	Horizontal position
3F	Vertical position
4F	Overhead position
Pipe Welds	
Groove Welds	
1G	Flat position, pipe axis horizontal and rotated
2G	Horizontal position, pipe axis vertical
5G	Multiple positions, (overhead, vertical and flat) pipe axis horizontal and is not rotated (fixed)
6G	Multiple positions, (overhead, vertical and horizontal) pipe axis in inclined 45° from horizontal and is not rotated (fixed)
6GR	Multiple positions, (overhead, vertical and horizontal) pipe axis in inclined 45° from horizontal and is not rotated (fixed), with restriction ring
Fillet Welds	
1F	Flat position, pipe axis is 45° from the horizontal and the pipe is rotated
2F	Horizontal position, pipe axis is vertical
2FR	Horizontal position, weld pipe axis is horizontal and the pipe is rotated
4F	Overhead position, pipe axis is vertical
5F	Multiple positions, (overhead, vertical and horizontal) pipe axis is horizontal and is not rotated
6F	Multiple positions, (overhead, vertical and flat) pipe axis is 45° from horizontal and is not rotated

Table 6

Welding Process Comparison Based on Quality and Economics			
	All Positions		
Applications	GTAW	GMAW	SMAW
Carbon steel plate (over 3/16")	G	E	E
Carbon steel sheet (to 3/16")	E	E	G
Carbon steel structural	F	F	E
Carbon steel pipe — 3" IPS and under	E	F	F
Carbon steel pipe — over 4" IPS	G	G	G
Stainless steel plate (over 3/16")	G	E	G
Stainless steel sheet (to 3/16")	E	G	F
Stainless steel pipe — 3" IPS and under	E	F	F
Stainless steel pipe — over 4" IPS	G	G	F
Aluminum plate (over 3/16")	G	E	NR
Aluminum sheet (to 3/16")	E	G	NR
Aluminum structural	E	G	NR
Aluminum pipe — 3" IPS and under	E	NR	NR
Aluminum pipe " over 4" IPS	E	F	NR
Nickel and nickel alloy sheet	E	F	F
Nickel and nickel alloy tubing	E	NR	NR
Nickel and nickel alloy pipe — 3" IPS and under	E	F	NR
Nickel and nickel alloy pipe — over 4" IPS	E	F	NR
Reflective metals, titanium — sheet, tubing, and pipe	E	NR	NR
Refractory metals, TA and Cb — sheet, tubing	E	NR	NR

GTAW — Gas Tungsten Arc (TIG)
GMAW — Gas Metal Arc (MIG)
SMAW — Shielded Metal Arc (Stick)

E — Excellent
G — Good
F — Fair
NR — Not recommended on basis of cost, usability, or quality.

Table 7

Cost Information			
Weld Process	Approximate Equipment Cost	Average Gas and Power Cost Per Hour	Relative Labor Cost
GTAW	$1,500 – 10,000	7.00	Medium
GMAW	$2,000 – 10,000	8.00	Low
SMAW	$500 – 2,000	1.50	Low/Medium

Table 8

Guide for Shade Numbers				
Operation	**Electrode Size 1/32 in. (mm)**	**Arc Current (A)**	**Minimum Protective Shade**	**Suggested* Shade No. (Comfort)**
Shielded Metal Arc Welding	Less than 3 (2.5)	Less than 60	7	—
	3 – 5 (2.5 – 4)	60 – 160	8	10
	5 – 8 (4 – 6.4)	160 – 250	10	12
	More than 8 (6.4)	250 – 550	11	14
Gas Metal Arc Welding and Flux Cored Arc Welding		Less than 60	7	—
		60 – 160	10	11
		160 – 250	10	12
		250 – 550	10	14
Gas Tungsten Arc Welding		Less than 50	8	10
		50 – 150	8	12
		150 – 500	10	14
Air Carbon	(Light)	Less than 500	10	12
Arc Cutting	(Heavy)	500 – 1000	11	14
Plasma Arc Welding		Less than 20	6	6 to 8
		20 – 100	8	10
		100 – 400	10	12
		400 – 800	11	14
Plasma Arc Cutting	(Light)**	Less than 300	8	9
	(Medium)**	300 – 400	9	12
	(Heavy)**	400 – 800	10	14
Torch Brazing		—	—	3 or 4
Torch Soldering		—	—	2
Carbon Arc Welding		—	—	14
Plate thickness				
Gas Welding				
Light	Under 1/8"	Under 3.2 mm		4 or 5
Medium	1/8 to 1/2"	3.2 to 12.7 mm		5 or 6
Heavy	Over 1/2"	Over 12.7 mm		6 or 8
Oxygen Cutting				
Light	Under 1"	Under 25 mm		3 or 4
Medium	1 to 6"	25 to 150 mm		4 or 5
Heavy	Over 6"	Over 150 mm		5 or 6

*As a rule of thumb, start with a shade that is too dark to see the weld zone. Then go to a lighter shade which gives sufficient view of the weld zone without going below the minimum. In oxyfuel gas welding or cutting where the torch produces a high yellow light, it is desirable to use a filter lens that absorbs the yellow or sodium line in the visible light of the (spectrum) operation.

**These values apply where the actual arc is clearly seen. Experience has shown that lighter filters may be used when the arc is hidden by the workpiece.

Table 9

Conversion Table
U.S. Customary Units to International System of Units (SI) — Metric System

Property	Convert From	To	Multiply By
Measurement	Inches (in)	Millimeters (mm)	25.4
	Inches (in)	Meters (m)	0.0254
	Feet (ft)	Millimeters (mm)	304.8
	Feet (ft)	Meters (m)	0.3048
Area	in^2	mm^2	645.16
	in^2	m^2	0.000645
	ft^2	m^2	0.0929
Current Density	Amperes/in^2	Amperes/mm^2	0.00155
Deposition Rate	Pounds (lb)/hour (h)	Kilograms (kg)/hour (h)	0.0454
Flow Rate	ft^3/h	Litre/minute	0.472
Pressure, Tensile Strength	Pounds /sq in (psi)	Pascals (Pa)	6895.0
Travel Speed,	in/min	mm/s	0.423
Wire Feed Speed	in/min	cm/m	2.54
Weight, Mass	lb	Kg	0.454
Temperature	Fahrenheit (F˚), t_F	Celsius (C˚) (centigrade)	$\frac{t_F - 32}{1.8}$
	Celsius (C˚) (centigrade), t_C	Fahrenheit (F˚)	t_C x 1.8 + 32
Impact Strength	ft lbs	Joules	1.356

Table 10

Control Symbols Found on GTAW Machines			
Functional Area	**Control**	**Wordage/Abbrev.**	**Symbol**
Power	ON	ON	
	OFF	OFF	
Polarity	Electrode Positive	Electrode Positive/DCEP	
	Electrode Negative	Electrode Negative/DCEN	
	Alternating Current	Alternating Current/AC	
Process	SMAW	Stick	
	GTAW	TIG	
Start Mode	Off	Off	
	Lift Arc	Lift Arc	
	HF Start Only	HF Start	
	HF Continuous	HF Cont.	
	Impulse	Impulse	
Output	On	On	
	Remote	Remote	
Trigger	Two Step Maintained	Standard/STD	
	Two Step Momentary	2T Trigger Hold/2T	
	Four Step Momentary	4T Trigger Hold/4T	
Amperage	Panel	Current Panel/A PNL	
	Remote	Current Remote/ARMT	
Gas	Preflow Time	Preflow	
	Postflow Time	Postflow	
	Gas Inlet	Gas In	
	Gas Outlet	Gas Out	
AC Waveshaping	Balance Phase Control	Balance/BAL	
	AC Frequency	Frequency/AC f	
	Maximum Cleaning	Maximum Cleaning/MAX CLEAN	
	Maximum Penetration	Maximum Penetration/MAX PEN	
	Electrode Positive Amperage	Electrode Positive Amperage/EP AMPS	
	Electrode Negative Amperage	Electrode Negative Amperage/EN AMPS	
Arc Force	Percentage Arc Force	DIG	
Sequencing	Initial Amperage	Initial Amperage/INITIAL A	
	Initial Time	Initial Time/INITIAL t	
	Initial Slope Time	Initial Slope	
	Spot Time	Spot Time/SPOT t	•••• t
	Weld Time	Weld Time/WELD t	None
	Final Slope	Final Slope	
	Final Amperage	Final Amperage/FINAL A	
	Final Time	Final Time/FINAL t	
Pulsing	Pulse Frequency	Pulses Per Seconds/PPS	
	Percent Peak Time	Peak Time/PK t	
	Percent Background Amperage	Background Amperage/BKGND A	
	Pulser	Pulser	
Coolant	Coolant Inlet	Coolant In	
	Coolant Outlet	Coolant Out	

XII. Glossary

Advanced Squarewave: The advanced AC output available from certain types of power sources. The wave is much more square than the conventional Squarewave power source. It also has expanded balance control to 90% electrode negative (max penetration) and the ability to control arc frequency (arc direction). Some have the additional ability to adjust the amount of current in the electrode negative and electrode positive cycles independently.

Air Carbon Arc Cutting: A cutting process by which metals are melted by the heat of an arc using a carbon electrode. Molten metal is forced away from the cut by a blast of forced air.

Alternating Current (AC): An electrical current that reverses its direction at regular intervals, such as 60 cycles alternating current (AC), or 60 hertz (Hz).

Amperage: The measurement of the amount of electricity flowing past a given point in a conductor per second. Current is another name for amperage.

Annealing: The opposite of hardening. A heat treating process used to soften a metal and relieve internal stresses.

Anodize: To anodize aluminum is to coat the metal by either chemical or electrical means. The coating provides improved corrosion and wear resistance. The thickness of this coating depends upon the length of the treatment. This coating is often removed from the area to be welded. This coating can be reapplied after welding.

Arc: The physical gap between the end of the electrode and the base metal. The physical gap causes heat due to resistance of current flow and arc rays.

Arc Length: Distance or air space between the tip of the electrode and the work.

Arc Voltage: Measured across the welding arc between the electrode tip and the surface of the weld pool.

Asymmetric Waveform: The output waveform of a welding power source that has the ability to modify both the amplitude and duration of the positive and negative half cycles of alternating current.

Autogenous Weld: When a TIG weld is made without the addition of filler metal.

Automatic Welding (AU): Uses equipment which welds without the constant adjusting of controls by the welder or operator. Equipment controls joint alignment by using an automatic sensing device.

Axis of Weld: Can be thought of as an imaginary line through the center of a weld, lengthwise.

Back Gouging: The removal of weld metal and base metal from the other side (root side) of a weld joint. When this gouged area is welded, complete penetration of the weld joint is assured.

Balanced Wave: An alternating current waveform that has equal negative and positive polarity current values.

Bevel Angle: An angle formed between a plane, perpendicular to the surface of the base metal and the prepared edge of the base metal. This angle refers to the metal that has been removed.

Butt Joint: A weldment where the material surfaces and joining edges are in or near the same plane.

Carbide Precipitation: Occurs when austenitic stainless steel is heated within a temperature range of 800˚–1600˚ F, 427˚– 870˚ C for a critical period of time. Carbon moves from a solid solution to grain boundaries and combines with chromium. The metal adjacent to the grain boundaries is left with less chromium and is said to be sensitized. Corrosion resistance is therefore reduced in the grain boundary region. See Figure 12.1.

Carbon Arc Gouging: A cutting process by which metals are melted by the heat of an arc using a carbon electrode. Molten metal is forced away from the cut by a blast of forced air.

Cerium Tungsten: GTAW tungsten electrode with small amount of the rare earth and nonradioactive ceria added. Improves arc starting and provides for use of wider current range.

Characteristics: Special qualities or properties. For instance, some welding machines have certain internal characteristics which allow a welder to perform more welding applications than with other welding machines.

Circuit: The complete path or route traveled by the electrical current. A circuit for GTAW can include the welding machine, weld cables, torch assembly, arc, base metal and work clamp with cable.

Cold Lap: See preferred term Incomplete Fusion.

Conductor: An electrical path where current will flow with the least amount of resistance. Most metals are good electrical conductors.

Constant Current (CC) Welding Machine: These welding machines have limited maximum short circuit current. They have a negative volt-amp curve and are often referred to as “droopers”. The voltage will change with different arc lengths while only slightly varying the amperage, thus the name constant current or variable voltage.

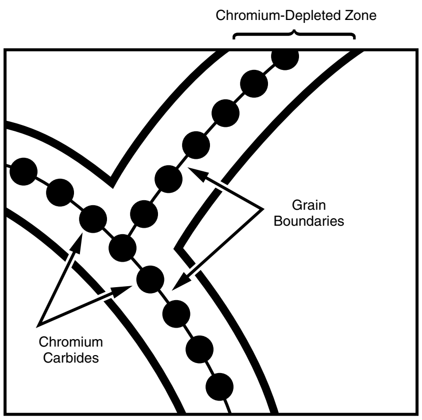

Figure 12.1 Carbide precipitation.

Constant Voltage (CV), Constant Potential (CP) Welding Machine: "Potential" and "voltage" are basically the same in meaning. This type of welding machine output maintains a relatively stable, consistent voltage regardless of the amperage output. It results in a relatively flat volt-amp curve as opposed to the drooping volt-amp curve of a typical GTAW (TIG) welding machine.

Consumable Insert: Preplaced filler metal that is completely fused into the joint root and becomes part of the weld.

Contactor: An electrical switch that is used to energize or de-energize output terminals of a welding machine. In some types of welding machines they can be of solid state design, with no moving parts and thus no arcing of contact points.

Corner Joint: Produced when the weld members meet at approximately 90˚ to each other in the shape of an "L".

Crater: A depression at the end of a weld bead.

Current: Another name for amperage. The amount of electricity flowing past a point in a conductor every second.

Current Density: The amount of current per square inch of cross-sectional area in an electrode. For any electrode diameter, find the current density by dividing the current value by the electrode cross-sectional area in square inches.

Cycle: One cycle equals 360 electrical degrees. For alternating current, current flow is in one direction through a circuit for 180˚ and in the opposite direction for the other 180˚. For 60 cycle power, a cycle is repeated 60 times per second. Some welding machines, especially outside the United States, require 50 cycle (hertz) power. Hertz stands for cycles per second.

Defect: One or more discontinuities that exceed the acceptance criteria as specified for a weld.

Depth of Fusion: The depth or distance that deposited weld metal extends into the base metal or the previous pass.

Direct Current: Flows in one direction and does not reverse its direction of flow as does alternating current.

Direct Current Electrode Negative (DCEN): The specific direction of current flow through a welding circuit when the electrode lead is connected to the negative terminal and the work lead is connected to the positive terminal of a DC welding machine.

Direct Current Electrode Positive (DCEP): The specific direction of current flow through a welding circuit when the electrode lead is connected to a positive terminal and the work lead is connected to a negative terminal to a DC welding machine.

Discontinuity: Any change in a metal's typical structure. It is the lack of consistence in mechanical, metallurgical or physical characteristics. Discontinuities are found in all metals and welds because they have some degree of inconsistency in them. However, this is acceptable as long as the discontinuities do not exceed the acceptance criteria of the weld or metal in question. If a discontinuity exceeds the acceptance criteria, they are defects and must be repaired.

Distortion: The warpage of a metal due to the internal residual stresses remaining after welding from metal expansion (during heating), and contraction (during cooling).

Duty Cycle: The number of minutes out of a 10-minute time period an arc welding machine can be operated at maximum rated output. An example would be 60% duty cycle at 300 amps. This would mean that at 300 amps the welding machine can be used for 6 minutes and then must be allowed to cool with the fan motor running for 4 minutes. (Some imported welding machines are based on a 5-minute cycle).

Edge Joint: A joint that occurs when the surfaces of the two pieces of metal to be joined are parallel or nearly parallel, and the weld is made along their edges.

Electrode Extension: While welding, the length of electrode extending beyond the end of the gas cup. Also referred to as electrical stickout.

Electron: A very small atomic particle which carries a negative electrical charge. Electrons can move from one place to another in atomic structures. It is electrons that move when electrical current flows in an electrical conductor.

Etching: When a weld specimen is cut through a weld, an acid or similar solution can be applied to the weld area to bring out the features of the weld. These include the deposited weld metal, heat affected zone, penetration and weld profile. Many different etching solutions and techniques exist for the various kinds of metals.

Excessive Melt-Through: A weld defect occurring in a weld joint when weld metal no longer fuses the base metals being joined. Rather, the weld metal falls through the weld joint or "burns through". Also referred to as excess penetration.

Face: The surface of the weld as seen from the side of the joint on which the weld was made.

Face Rotation: Can be thought of as an imaginary line from the axis of the weld through the center of the welds face. This face rotation angle along with the axis angle determine the actual welding position. Face rotation is measured in a clockwise direction starting from the 6 o'clock position. A weld with the face rotation at 12 o'clock would have the face rotation at 1800.

Ferrous: Refers to a metal that contains primarily iron, such as steel, stainless steel and cast iron.

Filler Metal: The metal added when making a welded, brazed, or soldered joint.

Fillet Weld: A weld that is used to join base metal surfaces that are approximately 90˚ to each other, as used on T-joint, corner joint or lap joint. The cross sectional shape of a fillet weld is approximately triangular.

Fit-Up: Often used to refer to the manner in which two members are brought together to be welded, such as the actual space or any clearance or alignment between two members to be welded. Proper fit-up is important if a good weld is to be made. Tacking, clamping or fixturing is often done to ensure proper fit-up. Where it applies, base metal must be beveled correctly and consistently. Also, any root openings or joint angles must be consistent for the entire length of a joint. An example of poor fit-up can be too large of a root opening in a V-groove butt weld.

Flat Position: When welding is done from the top side of a joint, it is in the flat position if the face of the weld is approximately horizontal. Sometimes referred to as downhand welding. The axis angle can be from 0˚–15˚ in either direction from a horizontal surface. Face rotation can be from 150˚–210˚.

Flux Cored Arc Welding (FCAW): An arc welding process which melts and joins metals by heating them with an arc between a continuous, consumable tubular electrode wire (consumable) and the workpiece. Shielding is obtained from a flux contained within the electrode's tubular core. Depending upon the type of flux-cored wire, added shielding may or may not be provided from externally supplied gas or gas mixture.

Freeze Lines: The lines formed across a weld bead. They are the result of the weld pool freezing. In appearance they sometimes look as if one tiny weld was continuously laid upon another.

Frequency: The number of double directional changes made by an alternating current in one second. Usually referred to as "hertz per second" or "cycles per second". In the United States, the frequency or directional change of alternating current is usually 60 hertz. Some Advanced Squarewave power sources allow the arc frequency to be adjusted. As arc frequency is increased the arc becomes more directional.

Gas Metal Arc Welding (GMAW): An arc welding process which joins metals by heating them with an arc. The arc is between a continuously fed solid filler wire (consumable) electrode and the workpiece. Externally supplied gas or gas mixtures provide shielding for GMAW. Sometimes called MIG welding (Metal Inert Gas) or MAG welding (Metal Active Gas).

Gas Nozzle: That part of the GTAW torch that directs the shielding gas flow over the weld area. Made of ceramic, glass, or metal in various styles.

Gas Tungsten Arc Welding (GTAW): Sometimes called TIG welding (Tungsten Inert Gas), it is a welding process which joins metals by heating them with a tungsten electrode which should not become part of the completed weld. Filler metal is sometimes used and argon inert gas or inert gas mixtures are used for shielding.

Groove Angle: When a groove is made between two materials to be joined together, the groove angle represents the total size of the angle between the two beveled edges and denotes the amount of material that is to be removed.

Ground Connection: A safety connection from a welding machine frame to the earth. Often used for grounding an engine driven welding machine where a cable is connected from a ground stud on the welding machine to a metal stake placed in the ground. See Work Connection for the difference between work connection and ground connection.

Ground Lead: When referring to the connection from the welding machine to the work, see preferred term Work Lead.

Heat Affected Zone (HAZ): The portion of a weldment that has not melted, but has changed due to the heat of welding. The HAZ is between the weld deposit and the unaffected base metal. The physical makeup or mechanical properties of this zone are different after welding.

Heat Sink: A good weld needs a certain amount of base metal to absorb the high heat input from the welding arc area. The more base metal, or the thicker the base metal, the better heat sink effect. If this heat sink is not present, too much heat will stay in the weld area, and defects can occur.

High Frequency: Covers the entire frequency spectrum above 50,000 Hz. Used in GTAW welding for arc ignition and stabilization.

Horizontal Position: Occurs when the axis of the weld is from 0˚–15˚ from the horizontal, and the face rotation is from either 80˚–150˚ or 210˚–280˚ for groove welds, or from either 125˚–150˚ or 210˚–235˚ for fillet welds.

Impedance: In electricity, impedance will slow down, but not stop, amperage flowing in a circuit. It is the resistance in an alternating current circuit. Impedance is the combination of the natural resistance to current flow in any conductor and the inductive or capacitive reactance in an electric circuit. It is brought about by the building and collapsing field of alternating current. This building and collapsing induces a counter electro motive force (CEMF) (voltage) that holds back, but does not stop, current flow.

Included Groove Angle: See preferred term Groove Angle.

Incomplete Fusion: Molten filler metal rolling over a weld edge but failing to fuse to the base metal. Also referred to as cold lap.

Inductance: Inductance (an inductor) will slow down the changes in current, as if the electrons were sluggish.

Inert Gas: A gas that will not combine with any known element. At present 6 are known; argon, helium, xenon, radon, neon, and krypton. Only argon and helium are used as shielding gases for welding.

Inverter: Power source which increases the frequency of the incoming primary power, thus providing for a smaller size machine and improved electrical characteristics for welding, such as faster response time and more control for waveshaping and pulse welding.

Joint Design: A cross-sectional design and the given measurements for a particular weld. Generally includes included angles, root opening, root face, etc.

Joint Root: That part of a joint that comes closes together where the weld is to be made. This maybe an area of the joint or just a line or point of that joint.

Lanthanum Tungsten: GTAW tungsten electrode with small amount of the rare earth and nonradioactive lanthana added. Improves arc starting and provides for use of wider current range.

Lap Joint: A joint that is produced when two or more members of a weldment overlap one another.

Lift Arc: An arc starting method built into the GTAW power source to allow contact type starts. Tungsten contamination is virtually eliminated.

Load Voltage: Measured at the output terminals of a welding machine while a welder is welding. It includes the arc voltage (measured while welding), and the voltage drop through connections and weld cables.

Machine Welding (ME): Uses equipment which welds with the constant adjusting and setting of controls by a welder or operator.

Microprocessor: One or more integrated circuits that can be programmed with stored instructions to perform a variety of functions.

Nonferrous: Refers to a metal that contains no iron, such as aluminum, copper, bronze, brass, tin, lead, gold, silver, etc.

Open Circuit Voltage (OCV): As the name implies, no current is flowing in the circuit because the circuit is open. The voltage is impressed upon the circuit, however, so that when the circuit is completed, the current will flow immediately. For example, a welding machine that is turned on but not being used for welding at the moment will have an open circuit voltage applied to the cables attached to the output terminals of the welding machine.

Output Control: An electrical switch that is used to energize or de-energize output terminals of a welding machine. In some types of welding machines they can be of solid state design, with no moving parts and thus no arcing of contact points.

Overhead Position: When the axis angle is from 0˚ – 80˚ and the face rotation is from 0˚ – 80˚ or 280˚ – 360˚ for groove welds or from 0˚ – 125˚ or 235˚ – 360˚ for fillet welds, the weld position is considered to be in the overhead position.

Parameters: The welding settings on a welding machine such as voltage and amperage, normally read on a volt meter and an amp meter. It may also include things as travel speed, electrode size, torch angle, electrode extension and weld joint position and preparation.

Penetration: The nonstandard term used to describe the following:

Depth of Fusion: The distance from the surface melted during welding to the extent of the fusion into the base metal or previous weld bead.

Joint Penetration: The depth that a weld extends from the weld face into the joint, minus reinforcement. Joint penetration may include root penetration.

Root Penetration: The depth that a weld extends into the root of a joint.

Complete Joint Penetration: Occurs when the "filler" metal completely fills the groove, and good fusion to the base metal is present.

Incomplete Joint Penetration: A condition in the root of a groove weld when the weld metal does not extend through the joint thickness. This is generally considered a defect when the joint by design was to have complete joint penetration.

Partial Joint Penetration: A condition in the root of a groove weld when the weld metal does not extend through the joint thickness. By design this is acceptable and not a defect, because it will carry the load for which it was intended.

Plasma: The electrically charged, heated ionized gas which conducts welding current in a welding arc.

Plug Welding: A weld made by filling (or partially filling) a hole in one member of a joint, fusing that member to another member.

Pool: The weld pool is the liquid state of a weld prior to its becoming solid weld metal. It indicates no limit to depth as the nonstandard term puddle tends to note a shallower depth.

Porosity: A cavity type discontinuity formed by gas entrapment during solidification.

Positioner: A device which moves the weldment when a stationary arc is used. Positioners include turning rolls, head and tail stocks and turntables.

Pounds Per Square Inch (psi): A measurement equal to a mass or weight applied to one square inch of surface area.

Primary Power: Often referred to as the input line voltage and amperage available to the welding machine from the shop's main power line. Often expressed in watts or kilowatts (kw), primary input power is AC and may be single- or three-phase. Welding machines with the capability of accepting more than one primary input voltage and amperage must be properly connected for the incoming primary power being used.

Puddle: More properly referred to as molten weld pool, the weld puddle is the liquid state of a weld prior to its becoming solid weld metal.

Pulsing: Varying the current from a high peak amperage level to a lower background amperage level at regular intervals. Pulse controls also adjust for the number of pulses per second and the percent of time spent at the peak amperage level. Pulsing is used to control heat input and allow for improved weld profile.

Purging: Cleaning, purifying or removing something from a container. Such as applying shielding gas to the inside of a piping structure prior to welding it with the GTAW process.

Quenching: The dipping of a heated metal into water, oil or other liquid to obtain necessary hardness.

Rectifier: An electrical device that allows the flow of electricity in basically only one direction. Its purpose is to change alternating current (AC) to direct current (DC).

Residual Stress: The stress remaining in a metal resulting from thermal or mechanical treatment or both. When welding, stress results when the melted material expands and then cools and contracts. Residual stresses can cause distortion as well as premature weld failures.

Resistance: The opposition to the flow of electrical current in a conductor. This opposition to current flow changes electric energy into heat energy. Resistance is measured in ohms with an ohm meter.

Resistance Spot Welding (RSW): A process in which two pieces of metal are joined by passing current between electrodes positioned on opposite sides of the pieces to be welded. There is no arc with this process, and it is the resistance of the metal to the current flow that causes the fusion.

Reverse Polarity: An old nonstandard term denoting electron flow from the workpiece to the electrode.

Root: A nonstandard term to denote joint root or weld root.

Root Opening: The separation of the members to be welded together at the root of the joint.

SCR: Silicon Controlled Rectifier. Used to change AC current to DC. Functions as an output control device for regulating the current/voltage and arc off-on ability.

Secondary Power: Refers to the actual power output of a welding machine. This includes the load voltage while welding, measured at the output terminals and the current (amperage) flowing in the circuit outside the welding machine. Secondary amperage can be measured at any point along the secondary circuit.

Sensitization: The changing of a stainless steel's physical properties when being exposed to a temperature range of 800˚ – 1600˚ F, 427˚ – 870˚ C for a critical period of time. See also Carbide Precipitation.

Sequencing: The control over all aspects of the weld. This would include the weld start, initial current, initial current time, upslope time, weld current level, weld current time, final slope, final current level and final current time.

Shielded Metal Arc Welding (SMAW): An arc welding process which melts and joins metals by heating them with an arc, between a covered metal electrode and the workpiece. Shielding gas is obtained from the electrodes outer coating, often called flux. Filler metal is primarily obtained from the electrodes core.

Shielding Gas: Protective gas used to prevent atmospheric contamination of the weld pool.

Single-Phase: When an electrical circuit produces only one alternating cycle within a 360˚ time span, it is a single-phase circuit.

Slot Welding: A weld made by filling (or partially filling) an external hole (slot) in one member of a joint, fusing that member to another member. The hole (slot) may be completely enclosed, or it may be open at one end of the metal.

Solenoid: An electrical device which either stops or permits the flow of gas used to shield the weld pool and arc or the flow of water used to cool a welding torch.

Spatter: Metal particles blown away from the welding arc. These particles do not become part of the completed weld.

Squarewave: The AC output of a power source that has the ability to rapidly switch between the positive and negative half cycles of alternating current. Advanced Squarewave is an enhanced version of this output waveform.

Stabilizer: A device used in AC welding to assist re-ignition of the arc as current passes through the sine wave zero point.

Straight Polarity: An old nonstandard term denoting electron flow from the electrode to the workpiece.

Submerged Arc Welding (SAW): A process by which metals are joined by an arc or arcs between a bare solid metal electrode or electrodes and the work. Shielding is supplied by a granular, fusible material usually brought to the work from a flux hopper. Filler metal comes from the electrode and sometimes from a second filler wire or strip.

T-Joint: A joint produced when two members are located approximately 90˚ to each other in the shape of a "T".

Thoriated Tungsten: GTAW tungsten electrode with small amount of thorium added. Improves arc starting and provides for use of wider current range.

Three-Phase: When an electrical circuit delivers three cycles within a 360˚ time span, and the cycles are 120 electrical degrees apart, it is a three-phase circuit.

TIG: The abbreviation for Tungsten Inert Gas. A shop term for the Gas Tungsten Arc Welding process.

Torch: A device used in the GTAW process to control the position of the electrode, to transfer current to the arc, and to direct the flow of shielding gas.

Transverse: A measurement made across an object, or basically at or near a right angle to a longitudinal measurement.

Travel Angle: The angle at which the torch is positioned from the perpendicular as the weld progresses. Travel angles are usually 5˚ to 15˚.

Tungsten: Rare metallic element with extremely high melting point (3410˚ C). Used in manufacturing GTAW electrodes.

Undercut: A groove melted into the base metal usually along the toes of a weld. Undercut can also occur on either side of the first pass of a full penetration weld, such as an open groove butt weld. Undercutting produces a weak spot in the weld, if it exceeds the acceptance criteria for undercut it is considered a defect, and must be repaired. GTAW is an excellent process used for dressing this type of defect.

Vertical Position: When the axis of the weld is between 15˚– 80˚ and the face rotation is between 80˚– 280˚ for groove welds or 125˚– 235˚ for fillet welds, the weld position is considered to be in the vertical position. When the axis angle is increased to between 80˚– 90˚, the face rotation can be any angle from 0˚– 360˚ for both groove and fillet welds.

Voltage: The pressure or force that pushes the electrons through a conductor. Voltage does not flow, but causes amperage or current to flow. Voltage is sometimes termed electro-motive force (EMF) or difference in potential.

Weld Metal: The filler wire and base metal that was melted while welding was taking place. This forms the welding bead.

Weld Root: When looking at the weld profile or cross section, it is the deepest point or points the weld fused into the joint root.

Welder: A person who performs manual or semiautomatic welding. Sometimes incorrectly used to describe a welding machine.

Welding Operator: A person who operates a machine or automatic welding equipment.

Workpiece Connection: A means to fasten the work lead (work cable) to the work (metal to be welded on). Also, the point at which this connection is made. One type of work connection is made with an adjustable clamp.

Workpiece Lead: The conductor cable or electrical conductor between the arc welding machine and the work.

Zirconiated Tungsten: GTAW tungsten electrode which combines desirable effects of pure tungsten and starting characteristics of thoriated tungsten.