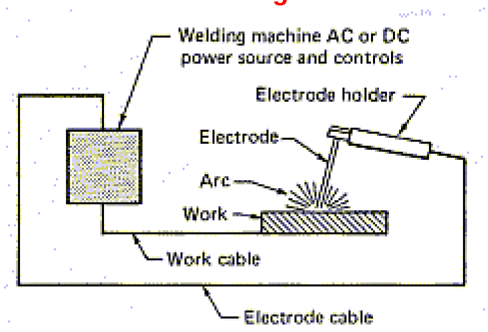
# Arc-Welding

## Introduction

Arc welding is the fusion of two pieces of metal by an electric arc between the pieces being joined – the work pieces – and an electrode that is guided along the joint between the pieces. The electrode is either a rod that simply carries current between the tip and the work, or a rod or wire that melts and supplies filler metal to the joint.

The basic arc welding circuit is an alternating current (AC) or direct current (DC) power source connected by a "work" cable to the work piece and by a "hot" cable to an electrode. When the electrode is positioned close to the work piece, an arc is created across the gap between the metal and the hot cable electrode. An ionized column of gas develops to complete the circuit.

**Basic Welding Circuit**




The arc produces a temperature of about 3600°C at the tip and melts part of the metal being welded and part of the electrode. This produces a pool of molten metal that cools and solidifies behind the electrode as it is moved along the joint.

There are two types of electrodes. Consumable electrode tips melt, and molten metal droplets detach and mix into the weld pool. Non-consumable electrodes do not melt. Instead, filler metal is melted into the joint from a separate rod or wire.

The strength of the weld is reduced when metals at high temperatures react with oxygen and nitrogen in the air to form oxides and nitrides. Most arc welding processes minimize contact between the molten metal and the air with a shield of gas, vapour or slag. Granular flux, for example, adds deoxidizers that create a shield to protect the molten pool, thus improving the weld.

## Advances in Welding Power Source Design and Efficiency

The electricity-consuming device – the key component of the arc welding apparatus – is the power source. Electrical consumption from the approximately 110 000 to 130 000 arc welding machines in use in Canada is estimated at 100 GWh a year.

In the past, power sources used transformer-rectifier equipment with large step-down transformers that made them heavy and prone to overheating. They can be used for only one function, i.e., one type of welding. In the 1990s, advances in power switching semiconductors led to the development of inverter power sources that are multi-functional, lighter, more flexible and that provide a superior arc.

Welding power sources use electricity when welding (arc-on) and when idling. Earlier transformer-rectifier equipment had energy conversion efficiencies that ranged from 40 to 60 percent and required idling power consumption of 2 to 5 kW. Modern inverter power sources have energy conversion efficiencies near 90 percent, with idling power consumption in the order of 0.1 kW.

Modern inverter power sources are gradually replacing transformer-rectifier units. They combine a quick return on investment, and, compared with transformer-rectifier units, are far more portable and easier to operate, are multi-functional rather than mono-functional, create superior arcs and combine higher-quality welds with longer arc-on time.

### The Five Most Common Arc Welding Processes

| Process | Known as | Electrodes | Shielding | Operator skill required | Popularity |
|---|---|---|---|---|---|
| Shielded metal arc welding | SMAW or stick | Rigid metal | Stick coatings | Low | Diminishing |
| Gas metal arc welding | GMAW or MIG | Solid wire | $CO_2$ gas | Low | Growing |
| Flux core arc welding | FCAW or MIG | Hollow wire | Core materials | Low | Growing |
| Gas tungsten arc welding | GTAW or TIG | Tungsten | Argon gas | High | Steady |
| Submerged arc welding | SAW | Solid wire | Argon gas | High | Steady |

Power sources produce DC with the electrode either positive or negative, or AC. The choice of current and polarity depends on the process, the type of electrode, the arc atmosphere and the metal being welded.

## Energy Efficiency of the Power Source

- Modern inverter power sources have high energy-conversion efficiencies and can be 50 percent more efficient than transformer-rectifier power sources.
- Modern inverter power sources for idling power requirements are 1/20th of conventional transformer-rectifier power sources.
- Modern inverter power sources have power factors that are close to 100 percent; transformer-rectifier power source percentages are much lower, which reduces electricity consumption.
- Modern inverter power sources are four times lighter and much smaller than transformer-rectifier power sources. They are thus more portable and can be moved by one person instead of four, making it possible to bring the welding equipment to the job, not vice versa.
- Modern inverter power sources are multi-functional and can be used for GMAW, FCAW, SMAW and GTAW.

## How Much Will I Save?

### Assumptions

| | |
|---|---|
| Work time | Two shifts of eight hours for 250 days a year (4000 hours) |
| Operating factor | 40 percent |
| Arc-on time | 1600 hours per year |
| Idling time | 2400 hours per year |
| Cost per kWh | $0.12 |
| Welding process | SMAW (Shielded metal arc welding) |
| Output power | 300 amps at 32 volts – 9.6 kW |

### Inverter-Based Power Source

Weight: 34 kg

Energy conversion efficiency: 78.7%

Arc-on power: 10.4 kW

Idling power: 0.06 kW

#### Operating Electricity Cost

| | |
|---|---|
| Welding time | $1,996.80 |
| Idling time | $16.42 |

### Transformer-Rectifier Power Source

Weight: 126 kg

Energy conversion efficiency: 51.6%

Arc-on power: 18.6 kW

Idling power: 0.87 kW

#### Operating Electricity Cost

| | |
|---|---|
| Welding time | $3,571.20 |
| Idling time | $250.56 |

| | | | |
|---|---|---|---|
| Annual electricity cost | $2,013.22 | Annual electricity cost | $3,821.76 |
| Annual electricity saving | $1,808.54 | | |
| **Investment** | | **Investment** | |
| Purchase price | $5,609 | Purchase price | $4,428 |
| Price difference | $1,181 | | |
| **Payback period** | **8 months** | | |

The break-even point for investment in an inverter power source equipment occurs approximately eight months after purchase. From then on, annual energy costs will remain lower.

## Purchasing Tips

Find the lowest-powered inverter power source that is most appropriate to your application.

- If you need process flexibility, choose multi-process equipment.
- Look for a power factor of 99 percent or higher.
- Look for an energy conversion efficiency (kVA out over kVA in) near 80 percent.
- Look for idling power consumption of less than 0.1 kW.
- Buy from a reliable supplier who provides field maintenance and at least a two-year, all-parts warranty.
- Check manufacturers' Web sites for warranty information.
- Shop for competitive prices.

## Operation Tips

Arc welding requires an operator and a power source. Both the operator and the equipment have roles to play in making the welding process more energy efficient.

## Some Important Definitions

*Arc-on time:* When the welder holds an arc between the electrode and the work piece
*Idling time:* When welding equipment is ready for use but is not generating an arc
*Operating factor:* The ratio of arc-on time to the total time worked, often expressed as a percentage:

$$\text{Operating factor} = \frac{\text{Arc-on time}}{\text{Arc-on time} + \text{Idling time}} \times 100\%$$

*Work time:* Convention is to assume total annual work time of 4000 hours (two shifts).

## Power Efficiency

Welding power sources draw power when idling. Efficiency is greater when idling is reduced and the operating factor is close to 100 percent. The higher the operating factor, the more efficient the process. The following are ways to improve efficiency:

- **Use the most efficient welding process.** Use gas metal arc welding (GMAW) instead of shielded metal arc welding (SMAW). Typically, operating factors for SMAW fall between 10 to 30 percent; operating factors for GMAW fall between 30 to 50 percent.
- **Use multi-process inverter power sources.** Modern inverter power sources can be used for several welding processes and save time and effort when switching processes. For example, the Miller XTM 304 can be used for GMAW, FCAW, SMAW and GTAW.
- **Automate when possible.** Manage repetitive operations by applying advances in automation and computer programming.
- **Reduce idling time.** Cut the time spent on pre-welding tasks such as assembly, positioning, tacking and cleaning, and on follow-up operations, such as slag removal and defect repair.

- **Position the work to allow down-hand welding.** Experience has shown that down-hand (vertical high to low) welding is faster, easier on the operator and more error-free than other techniques.
- **Train the welder.** Well-trained welders work better and faster and are usually conscious of energy savings opportunities.

### Power Source Performance

Certain characteristics determine the energy efficiency of power sources:

- **Power factor:** Power factor is the ratio of “real” electrical power made available by the welding power source for producing a welding arc (the power you can use) to the "apparent" electrical power supplied by the utility (the power you pay for). The older technology of transformer-rectifier power sources can have power factors in the order of 75 percent; modern inverter power sources have power factors close to 100 percent.
- **Arc-on power and idling power:** Transformer-rectifier power sources use more power in arc-on and idling modes than modern inverter power sources do with the same output.

The following table shows that the average annual electrical energy required by a typical transformer-rectifier source is five to nine times the energy required by an inverter power source for the same job. In other words, the inverter source uses only 10 to 20 percent of the power needed by a transformer-rectifier source.

| Power Source | Process | Apparent Arc-On Power (kW) | Apparent Idling Power (kW) | Operating Factor (OF) | Annual Energy Required (kWh) |
|---|---|---|---|---|---|
| Transformer – rectifier | SMAW (stick) | 10.26<br>10.26 | 4.86<br>4.86 | 10%<br>30% | 18 600<br>25 920 |
| Inverter | SMAW (stick) | 3.91<br>3.91 | 0.12<br>0.12 | 10%<br>30% | 1 996<br>5 028 |

To compare the performance of power sources use the following formula:

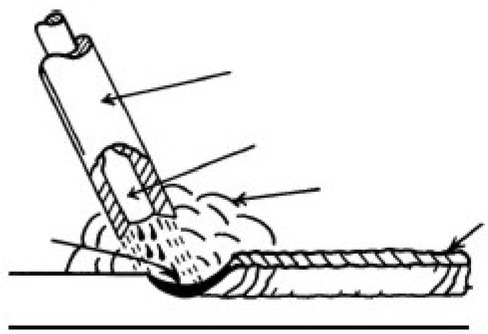
$$\text{Energy conversion efficiency} = \frac{\text{Volt-ampere output}}{\text{Volt-ampere input}}$$

The kVA input and output values for power sources at rated outputs can be found in manufacturers' equipment data sheets.

## COMMON ELECTRIC ARC WELDING PROCESSES

### Shielded metal arc welding:

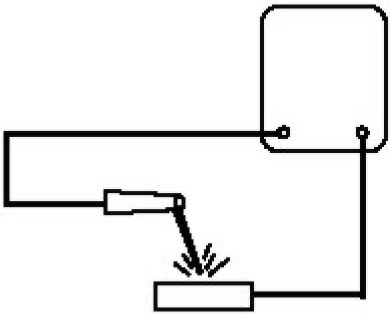
Shielded Metal Arc Welding, also known as manual metal arc welding, stick welding, or electric arc welding, is the most widely used of the various arc welding processes. Welding is performed with the heat of an electric arc that is maintained between the end of a coated metal electrode and the work piece (See Figure below).



The heat produced by the arc melts the base metal, the electrode core rod, and the coating. As the molten metal droplets are transferred across the arc and into the molten weld puddle, they are shielded from the atmosphere by the gases produced from the decomposition of the flux coating. The molten slag floats to the top of the weld puddle where it protects the weld metal from the atmosphere during solidification.

Other functions of the coating are to provide arc stability and control bead shape. More information on coating functions will be covered in subsequent lessons.

**Equipment & Operation** - One reason for the wide acceptance of the SMAW process is the simplicity of the necessary equipment. The equipment consists of the following items. (See Figure below)



1. Welding power source
2. Electrode holder
3. Ground clamp
4. Welding cables and connectors
5. Accessory equipment (chipping hammer, wire brush)
6. Protective equipment (helmet, gloves, etc.)

**Welding Power Sources** - Shielded metal arc welding may utilize either alternating current (AC) or direct current (DC), but in either case, the power source selected must be of the constant current type. This type of power source will deliver a relatively constant amperage or welding current regardless of arc length variations by the operator. The amperage determines the amount of heat at the arc and since it will remain relatively constant, the weld beads produced will be uniform in size and shape. Whether to use an AC, DC, or AC/DC power source depends on the type of welding to be done and the electrodes used. The following factors should be considered:

**Electrode Selection** - Using a DC power source allows the use of a greater range of electrode types. While most of the electrodes are designed to be used on AC or DC, some will work properly only on DC.

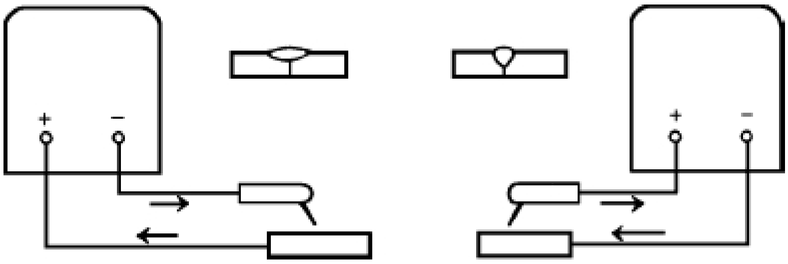
**Metal Thickness** - DC power sources may be used for welding both heavy sections and light gauge work. Sheet metal is more easily welded with DC because it is easier to strike and maintain the DC arc at low currents.

**Distance from Work** - If the distance from the work to the power source is great, AC is the best choice since the voltage drop through the cables is lower than with DC. Even though welding cables are made of copper or aluminum (both good conductors), the resistance in the cables becomes greater as the cable length increases. In other words, a voltage reading taken between the electrode and the work will be somewhat lower than a reading taken at the output terminals of the power source. This is known as voltage drop.

**Welding Position** - Because DC may be operated at lower welding currents, it is more suitable for overhead and vertical welding than AC. AC can successfully be used for out-of-position work if proper electrodes are selected.

**Arc Blow** - When welding with DC, magnetic fields are set up throughout the weldment. In weldments that have varying thickness and protrusions, this magnetic field can affect the arc by making it stray or fluctuate in direction. This condition is especially troublesome when welding in corners. AC seldom causes this problem because of the rapidly reversing magnetic field produced. Combination power sources that produce both AC and DC are available and provide the versatility necessary to select the proper welding current for the application. When using a DC power source, the question of whether to use electrode negative or positive polarity arises. Some electrodes operate on both DC straight and reverse polarity, and others on DC negative or DC positive polarity only. Direct current flows in one direction in an electrical circuit and the direction of current flow and the composition of the electrode coating will have a definite effect on the welding arc and weld bead.

Figure below shows the connections and effects of straight and reverse polarity.




While polarity affects the penetration and burn-off rate, the electrode coating also has a strong influence on arc characteristics. Performance of individual electrodes will be discussed in succeeding lessons.

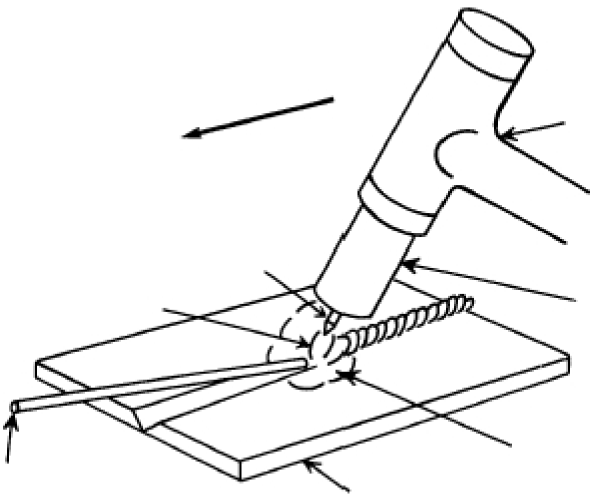
**Electrode Holder** - The electrode holder connects to the welding cable and con- ducts the welding current to the electrode. The insulated handle is used to guide the electrode over the weld joint and feed the electrode over the weld joint and feed the electrode into the weld puddle as it is consumed. Electrode holders are available in different sizes and are rated on their current carrying capacity.

**Ground Clamp** - The ground clamp is used to connect the ground cable to the work piece. It may be connected directly to the work or to the table or fixture upon which the work is positioned. Being a part of the welding circuit, the ground clamp must be capable of carrying the welding current without overheating due to electrical resistance.

**Welding Cables** - The electrode cable and the ground cable are important parts of the welding circuit. They must be very flexible and have a tough heat-resistant insulation. Connections at the electrode holder, the ground clamp, and at the power source lugs must be soldered or well crimped to assure low electrical resistance. The cross-sectional area of the cable must be sufficient size to carry the welding current with a minimum of voltage drop. Increasing the cable length necessitates increasing the cable diameter to lessen resistance and voltage drop.

**Coated Electrodes** - Various types of coated electrodes are used in shielded metal arc welding. Electrodes used for welding mild or carbon steels are quite different than those used for welding the low alloys and stainless steels. Details on the specific types will be covered in subsequent lessons.

Gas Tungsten Arc Welding is a welding process performed using the heat of an arc established between a nonconsumable tungsten electrode and the work piece.

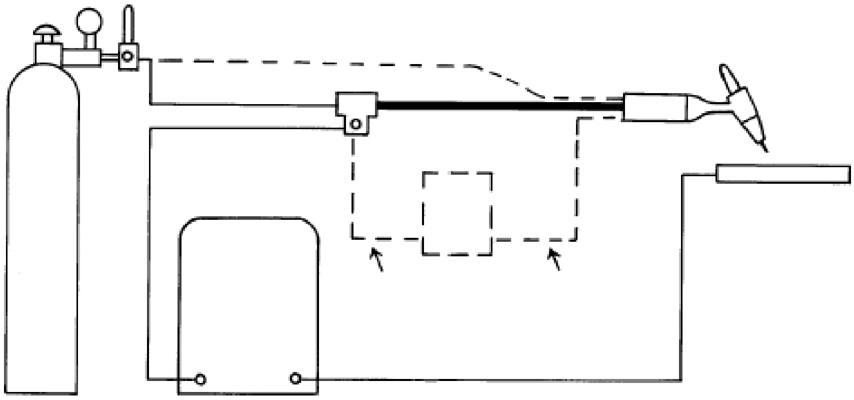


The electrode, the arc, and the area surrounding the molten weld puddle are protected from the atmosphere by an inert gas shield. The electrode is not consumed in the weld puddle as in shielded metal arc welding. If a filler metal is necessary, it is added to the leading the molten puddle. Gas tungsten arc welding produces exceptionally clean welds no slag is produced, the chance inclusions in the weld metal is and the finished weld requires virtually no cleaning. Argon and Helium, the primary shielding gases employed, are inert gases. Inert gases do not chemically combine with other elements and therefore, are used to exclude the reactive gases, such as oxygen and nitrogen, from forming compounds that could be detrimental to the weld metal. Gas tungsten arc welding may be used for welding almost all metals — mild steel, low alloys, stainless steel, copper and copper alloys, aluminum and aluminum alloys, nickel and nickel alloys, magnesium and magnesium alloys, titanium, and others. This process is most extensively used for welding aluminum and stainless steel alloys where weld integrity is of the utmost importance. Another use is for the root pass (initial pass) in pipe welding, which requires a weld of the highest quality. Full penetration without an excessively high inside bead is important in the root pass, and due to the ease of current control of this process, it lends itself to control of back-bead size. For high quality welds, it is usually necessary to provide an inert shielding gas inside the pipe to prevent oxidation of the inside weld bead.

Gas tungsten arc welding lends itself to both manual and automatic operation. In manual operation, the welder holds the torch in one hand and directs the arc into the weld joint. The filler metal is fed manually into the leading edge of the puddle. In automatic applications, the torch may be automatically moved over a stationary work piece or the torch may be stationary with the work moved or rotated in relation to the torch. Filler metal, if required, is also fed automatically.

**Equipment and Operation** - Gas tungsten arc welding may be accomplished with relatively simple equipment, or it may require some highly sophisticated components. Choice of equipment depends upon the type of metal being joined, the position of the weld being made, and the quality of the weld metal necessary for the application. The basic equipment consists of the following:

1. The power source
2. Electrode holder (torch)
3. Shielding gas
4. Tungsten electrode
5. Water supply when necessary
6. Ground cable
7. Protective equipment



**Power Sources** - Both AC and DC power sources are used in gas tungsten arc welding. They are the constant current type with a drooping volt-ampere curve. This type of power source produces very slight changes in the arc current when the arc length (voltage) is varied.

The choice between an AC or DC welder depends on the type and thickness of the metal to be welded. Distinct differences exist between AC and DC arc characteristics, and if DC is chosen, the polarity also becomes an important factor. The effects of polarity in GTAW are directly opposite the effects of polarity in SMAW. In SMAW, the distribution of heat between the electrode and work, which determines the penetration and weld bead width, is controlled mainly by the ingredients in the flux coating on the electrode. In GTAW where no flux coating exists, heat distribution between the electrode and the work is controlled solely by the polarity. The choice of the proper welding current will be better understood by analyzing each type separately.

**Direct current electrode_negative (DCEN)** is produced when the electrode is connected to the negative terminal of the power source. Since the electrons flow from the electrode to the plate, approximately 70% of the heat of the arc is concentrated at the work, and approximately 30% at the electrode end. This allows the use of smaller tungsten elec- trodes that produce a relatively narrow concentrated arc. The weld shape has deep penetra- tion and is quite narrow. Direct current electrode negative is suitable for weld- ing most metals. Magnesium and aluminum have a refractory oxide coating on the surface that must be physically removed immediately prior to welding if DCSP is to be used.

**Direct current electrode positive (DCEP)** is produced when the electrode is connected to the positive terminal of the welding power source. In this condition, the electrons flow from the work to the electrode tip, concentrating approximately 70% of the heat of the arc at the electrode and 30% at the work. This higher heat at the electrode necessitates using larger diameter tungsten to prevent it from melting and contaminating the weld metal. Since the electrode diameter is larger and the heat is less concentrated at the work, the resultant weld bead is relatively wide and shallow.

Direct current electrode positive is rarely used in gas-tungsten arc welding. Despite the excellent oxide cleaning action, the lower heat input in the weld area makes it a slow process, and in metals having higher thermal conductivity, the heat is rapidly conducted away from the weld zone. When used, DCEP is restricted to welding thin sections (under 1/8") of magnesium and aluminum.

**Alternating current** is actually a combination of DCEN and DCEP and is widely used for welding aluminum. In a sense, the advantages of both DC processes are combined, and the weld bead produced is a compromise of the two. Remember that when welding with 60 Hz current, the electron flow from the electrode tip to the work reverses direction 120 times every second. Thereby, the intense heat alternates from electrode to work piece, allowing the use of an intermediate size electrode. The weld bead is a compromise having medium penetration and bead width. The gas ions blast the oxides from the surface of aluminum and magnesium during the positive half cycle.

**DC constant current power sources** - Constant current power sources, used for shielded metal arc welding, may also be used for gas-tungsten arc welding. In applications where weld integrity is not of utmost importance, these power sources will suffice. With machines of this type, the arc must be initiated by touching the tungsten electrode to the work and quickly withdrawing it to maintain the proper arc length. This starting method contaminates the electrode and blunts the point which has been grounded on the electrode end. These conditions can cause weld metal inclusions and poor arc direction. Using a power source designed for gas tungsten arc welding with a high frequency stabilizer will eliminate this problem. The electrode need not be touched to the work for arc initiation. Instead, the high frequency voltage, at very low current, is superimposed onto the welding current. When the electrode is brought to within approximately 1/8 inch of the base metal, the high frequency ionizes the gas path, making it conductive and a welding arc is established. The high frequency is automatically turned off immediately after arc initiation when using direct current.

**AC Constant Current Power Source** - Designed for gas tungsten arc welding, always incorporates high frequency, and it is turned on throughout the weld cycle to maintain a stable arc. When welding with AC, the current passes through 0 twice in every cycle and the must be reestablished each time it does so. The oxide coating on metals, such as aluminum and magnesium, can act much like a rectifier.. The positive half-cycle will be eliminated if the arc does not reignite, causing an unstable condition. Continuous high frequency maintains an ionized path for the welding arc, and assures arc re- ignition each time the current changes direction. AC is extensively used for welding aluminum and magnesium.

**AC/DC Constant Current Power Sources** - Designed for gas tungsten arc welding, are available, and can be used for welding practically all metals. The gas tungsten arc welding process is usually chosen because of the high quality welds it can produce. The metals that are commonly welded with this process, such as stainless steel, aluminum and some of the more exotic metals, cost many times the price of mild steel; and therefore, the power sources designed for this process have many desirable features to insure high quality welds. Among these are:

**1. Remote current control**, which allows the operator to control welding amperage with a hand control on the torch, or a foot control at the welding station.

**2. Automatic soft-start**, which prevents a high current surge when the arc is initiated.

**3. Shielding gas and cooling water solenoid valves**, which automatically control flow before, during and for an adjustable length of time after the weld is completed.

**4. Spot-weld timers**, which automatically control all elements during each spot-weld cycle. Other options and accessories are also available.

Power sources for automatic welding with complete programmable output are also available. Such units are used extensively for the automatic welding of pipe in position. The welding current is automatically varied as the torch travels around the pipe. Some units provide a pulsed welding current where the amperage is automatically varied between a low and high several times per second. This produces welds with good penetration and improved weld bead shape.

**Torches** - The torch is actually an electrode holder that supplies welding current to the tungsten electrode, and an inert gas shield to the arc zone. The electrode is held in a collet-like clamping device that allows adjustment so that the proper length of electrode pro- trudes beyond the shielding gas cup. Manual torches are designed to accept electrodes of 3 inch or 7 inch lengths. Torches may be either air or water-cooled. The air-cooled types actually are cooled to a degree by the shielding gas that is fed to the torch head through a compos- ite cable. The gas actually surrounds the copper welding cable, affording some degree of cooling. Water-cooled torches are usually used for applications where the welding current exceeds 200 amperes. The water inlet hose is connected to the torch head. Circulating around the torch head, the water leaves the torch via the current-in hose and cable assembly. Cooling the welding cable in this manner allows the use of a smaller diameter cable that is more flexible and lighter in weight.

The gas nozzles are made of ceramic materials and are available in various sizes and shapes. In some heavy duty, high current applications, metal water-cooled nozzles are used.

A switch on the torch is used to energize the electrode with welding current and start the shielding gas flow. High frequency current and water flow are also initiated by this switch if the power source is so equipped. In many installations, these functions are initiated by a foot control that also is capable of controlling the welding current. This method gives the operator full control of the arc. The usual welding method is to start the arc at a low current, gradually increase the current until a molten pool is achieved, and welding begins. At the end of the weld, current is slowly decreases and the arc extinguished, preventing the crater that forms at the end of the weld when the arc is broken abruptly.

**Shielding Gases** - Argon and helium are the major shielding gases used in gas tungsten arc welding. In some applications, mixtures of the two gases prove advantageous. To a lesser extent, hydrogen is mixed with argon or helium for special applications.

Argon and helium are colorless, odorless, tasteless and nontoxic gases. Both are inert gases, which means that they do not readily combine with other elements. They will not burn nor support combustion. Commercial grades used for welding are 99.99% pure. Argon is .38% heavier than air and about 10 times heavier than helium. Both gases ionize when present in an electric arc. This means that the gas atoms lose some of their electrons that have a negative charge. These unbalanced gas atoms, properly called positive ions, now have a positive charge and are attracted to the negative pole in the arc. When the arc is positive and the work is negative, these positive ions impinge upon the work and remove surface oxides or scale in the weld area.

Argon is most commonly used of the shielding gases. Excellent arc starting and ease of use make it most desirable for manual welding. Argon produces a better cleaning action when welding aluminum and magnesium with alternating current. The arc produced is relatively narrow. Argon is more suitable for welding thinner material. At equal amperage, helium produces a higher arc voltage than argon. Since welding heat is the product of volts times amperes, helium produces more available heat at the arc. This makes it more suitable for welding heavy sections of metal that have high heat conductivity, or for automatic welding operations where higher welding speeds are required.

Argon-helium gas mixtures are used in applications where higher heat input and the desirable characteristics of argon are required. Argon, being a relatively heavy gas, blankets the weld area at lower flow rates. Argon is preferred for many applications because it costs less than helium. Helium, being approximately 10 times lighter than argon, requires flow rates of 2 to 3 times that of argon to satisfactorily shield the arc.

**Electrodes** - Electrodes for gas tungsten arc welding are available in diameters from .010" to 1/4" in diameter and standard lengths range from 3" to 24". The most commonly used sizes, however, are the .040", 1/16", 3/32", and 1/8" diameters.

The shape of the tip of the electrode is an important factor in gas tungsten arc welding. When welding with DCEN, the tip must be ground to a point. The included angle at which the tip is ground varies with the application, the electrode diameter, and the welding current. Narrow joints require a relatively small included angle. When welding very thin material at low currents, a needlelike point ground onto the smallest available electrode may be necessary to stabilize the arc. Properly ground electrodes will assure easy arc starting, good arc stability, and proper bead width.

When welding with AC, grinding the electrode tip is not necessary. When proper welding current is used, the electrode will form a hemispherical end. If the proper welding current is exceeded, the end will become bulbous in shape and possibly melt off to contaminate the weld metal.

The American Welding Society has published Specification AWS A5.12-80 for tungsten arc welding electrodes that classifies the electrodes on the basis of their chemical composition, size and finish. Briefly, the types specified are listed below:

**1) Pure Tungsten (AWS EWP)** Color Code: Green Used for less critical applications. The cost is low and they give good results at relatively low currents on a variety of metals. Most stable arc when used on AC, either balanced wave or continuous high frequency.

**2) 1% Thoriated Tungsten (AWS EWTh-1) Color Code: Yellow** Good current carrying capacity, easy arc starting and provide a stable arc. Less susceptible to contamination. Designed for DC applications of nonferrous materials.

**3) 2% Thoriated Tungsten (AWS EWTh-2) Color Code: Red** Longer life than 1% Thoriated electrodes. Maintain the pointed end longer, used for light gauge critical welds in aircraft work. Like 1%, designed for DC applications for nonferrous materials.

**4) 5% Thoriated Tungsten (AWS EWTh-3) Color Code: Blue** Sometimes called "striped" electrode because it has 1.0-2.0% Thoria inserted in a wedge-shaped groove throughout its length. Combines the good properties of pure and thoriated electrodes. Can be used on either AC or DC applications.

**5) Zirconia_Tungsten_(AWS_EWZr) Color Code: Brown** Longer life than pure tungsten. Better performance when welding with AC. Melts more easily than thoriam-tungsten when forming rounded or tapered tungsten end. Ideal for applications where tungsten contamination must be minimized.


**Reference:**

www.oee.nrcan.gc.ca
http://www.esabna.com