PDHonline Course M514 (6 PDH)

Gas Metal Arc Welding – GMAW Best Practices

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GAS METAL ARC WELDING – GMAW
BEST PRACTICES

CONTENTS:

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INTRODUCTION:

GMAW or Gas Metal Arc Welding is also sometimes referred to by its subtypes, Metal Inert Gas (MIG) and Metal Active Gas (MAG). GMAW is a welding process in which an electric arc forms between a consumable wire electrode and the workpiece, which heats the workpiece metal(s), causing them to melt, and join. Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from contaminants in the air.

Originally developed for welding aluminum and other non-ferrous materials in the 1940s, GMAW was soon applied to steels because it provided faster welding time compared to other welding processes. The cost of inert gas limited its use in steels until several years later, when the use of semi-inert gases such as carbon dioxide became common.

Further developments during the 1950s and 1960s gave the process more versatility and as a result, it became a highly used industrial process. Today, GMAW is the **most common industrial welding process**, preferred for its versatility, speed and the relative ease for adapting to robotic automation.

Unlike welding processes that do not employ a shielding gas, such as shielded metal arc welding, it is rarely used outdoors or in other areas of air volatility. A related process, Flux Cored Arc Welding, often does not use a shielding gas, but instead employs an electrode wire that is **hollow** and **filled with flux**.

GMAW DEVELOPMENT:

The principles of Gas Metal Arc Welding began to be understood in the early 19th century, after Humphry Davy discovered the short pulsed electric arcs in 1800. Vasily Petrov independently produced the continuous electric arc in 1802 (soon followed by Davy). It was not until the 1880s that the technology became developed with the aim of industrial usage. At first, carbon electrodes were used in carbon arc welding.

By 1890, metal electrodes had been invented by Nikolay Slavyanov and C. L. Coffin. In 1920, an early predecessor of GMAW was invented by P. O. Nobel of General Electric. He used a bare electrode wire and direct current, used arc voltage to regulate the feed rate, and did not use a shielding gas to protect the weld, as developments in welding atmospheres did not take place until later that decade. In 1926 another forerunner of GMAW was released, but it was not suitable for practical use.

In 1948, GMAW was **finally developed** by the Battelle Memorial Institute. It used a smaller diameter electrode and a constant voltage power source developed by H. E. Kennedy. It offered a high deposition rate, but the high cost of inert gases limited its use to non-ferrous materials and prevented cost savings. In 1953, the use of carbon dioxide as a welding atmosphere was developed, and it quickly gained popularity in GMAW, since it made welding steel more economical.

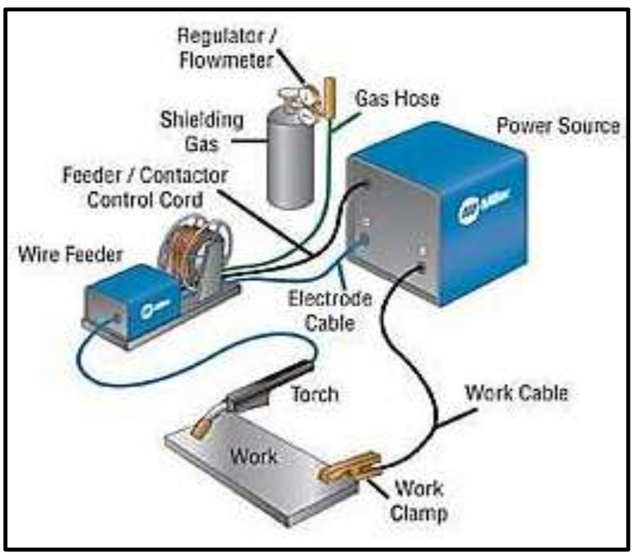
In 1958 and 1959, the short-arc variation of GMAW was released, which increased welding versatility and made the welding of thin materials possible while relying on smaller electrode wires and more advanced power supplies. It quickly became the most popular GMAW variation. The **spray-arc transfer** variation was developed in the early 1960s, when experimenters added small amounts of oxygen to inert gases. More re-cently, pulsed current has been applied, giving rise to a new method called the pulsed spray-arc variation.

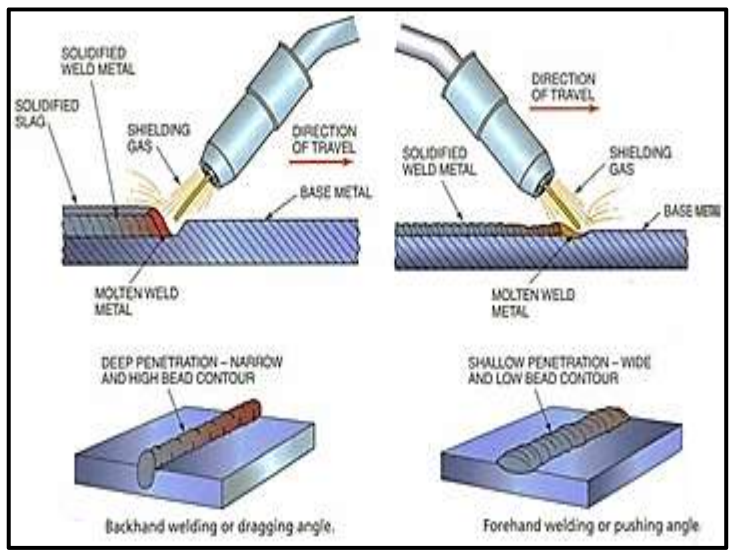
As noted, GMAW is currently one of the **most popular welding methods**, especially in industrial environments. It is used extensively by the sheet metal industry and, by extension, the automobile industry. There is also the method often used for **arc spot welding**, thereby replacing riveting or resistance spot welding. It is also popular for automated welding, in which robots handle the workpieces and the welding gun to speed up the manufacturing process.

Generally, it is **unsuitable for welding outdoors**, because the movement of the surrounding air can dissipate the shielding gas and thus make welding more difficult, while also decreasing the quality of the weld. The problem can be alleviated to some extent by increasing the shielding gas output, but this can be expensive and may also affect the quality of the weld.

In general, processes such as Shielded Metal Arc Welding (SMAW) and Flux-Cored Arc Welding (FCAW) are preferred for **welding outdoors**, making the use of GMAW in the construction industry rather limited. Furthermore, the use of a shielding gas causes GMAW to be **unpopular for underwater welding**.

The Mig welding process operates on D.C. (direct current) usually with the wire electrode positive. This is known as “reverse” polarity. The “straight” polarity is seldom used because of the poor transfer of molten metal from the wire electrode to the workpiece. Welding currents of from **50 amperes** up to more than **600 amperes** are commonly used at welding voltages from **15V to 32V**. A stable, self-correcting arc is obtained by using the constant potential (voltage) power system and a constant wire feed speed.





Continuing developments have made the Mig process applicable to the welding of all commercially important metals such as steel, aluminum, stainless steel, copper and several others. Materials **above 0.030 in. (0.76 mm) thick** can be welded in **all positions**, including flat, vertical and overhead. It is simple to choose the equipment, wire electrode, shielding gas, and welding conditions capable of producing high-quality welds at a low cost.

The basic GMAW process includes **four distinctive process** techniques: **Globular Transfer, Short-Circuiting Transfer, Spray Arc Transfer**, **Pulsed-Spray** and a **special** technique designated as **Rotational Spray Transfer** each of which has distinct properties and corresponding advantages and limitations. These techniques describe the manner in which metal is transferred from the wire to the weld pool.

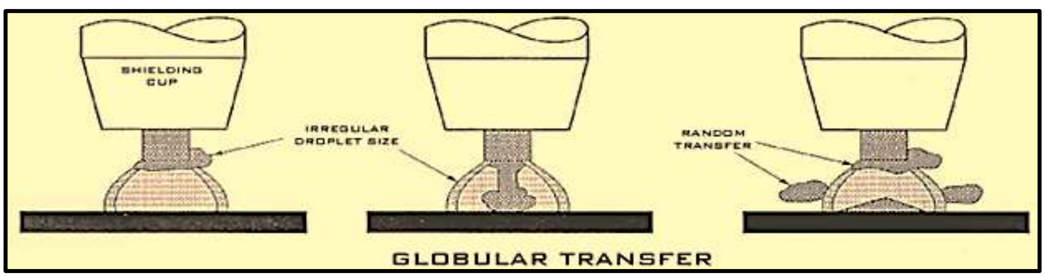
METAL TRANSFER VARIATIONS:

Globular: GMAW with globular metal transfer is considered the **least desirable** of the three major GMAW variations, because of its tendency to produce high heat, a poor weld surface, and spatter. The method was originally developed as a cost efficient way to weld steel using GMAW, because this variation uses carbon dioxide, a less expensive shielding gas than argon. Adding to its economic advantage was its high deposition rate, allowing welding speeds of up to **110 mm/s** (**250 in/min**).

Globular transfer occurs when the drops of metal are quite large and move toward the weld pool under the influence of gravity. Factors that determine the manner of metal transfer are the welding current, wire size, arc length (voltage), power supply characteristics, and shielding gas. The process can be semi-automatic or automatic. A constant voltage, direct current power source is most commonly used with GMAW, but current systems, as well as, alternating current, can be used.

This mode of transfer generally is used on carbon steel only and uses **100 % CO2** shielding gas. The method is typically used to weld in the **flat and horizontal positions** because the droplet size is large and would be more difficult to control if used in the vertical and overhead positions compared to the short-circuit arc transfer. This mode generates more spatter; however, when higher currents are used with CO2 shielding and a buried arc, spatter can be greatly reduced. You must use caution with a buried arc because this can result in excessive reinforcement if travel speed isn't controlled.

Stainless steel GMAW electrodes normally aren't used in globular transfer because their nickel and chrome content (9 to 14 % nickel and 19 to 23 % chromium) creates a higher electrical resistance than carbon steel electrodes. In addition to the electrical resistance differences, the use of 100 % CO2 as a shielding gas could be detrimental to corrosion resistance of the stainless steel electrodes. Carbon steel **ER70S-3 and ER70S-6** generally are the **electrodes of choice**.



GLOBULAR TRANSFER

As a result of the large molten droplet, the process is generally limited to **flat and horizontal** welding positions. The high amount of heat generated also is a downside, because it forces the welder to use a larger electrode wire, increases the size of the weld pool, and causes greater residual stresses and distortion in the weld area. When the droplet finally detaches either by gravity or short circuiting, it falls to the workpiece, leaving an uneven surface and often causing spatter.

Short-Circuiting: With an adequate adjustment can produce excellent bead appearance and is essential for stainless steel materials. The most predominant stainless steel electrodes are **ER308L, ER 309L, and ER 316L**. These electrodes are also available in the **Si** type, such as, **308LSi.** The LSi types contain more silicon, which increases puddle fluidity and helps to weld better than the standard alloys. Further developments with GMAW led to a variation known as **short-circuit transfer** (SCT) or **short-arc welding**, in which the current is lower than the **globular** method.

The short-circuiting metal transfer, also known as "Short Arc", "Dip Transfer", and "Micro wire", metal transfer occurs when an electrical short circuit is established. This occurs as the molten metal at the end of the wire touches the molten weld pool. In spray arc welding, small molten drops of metal are detached from the tip of the wire and projected by electromagnetic forces towards the weld pool.

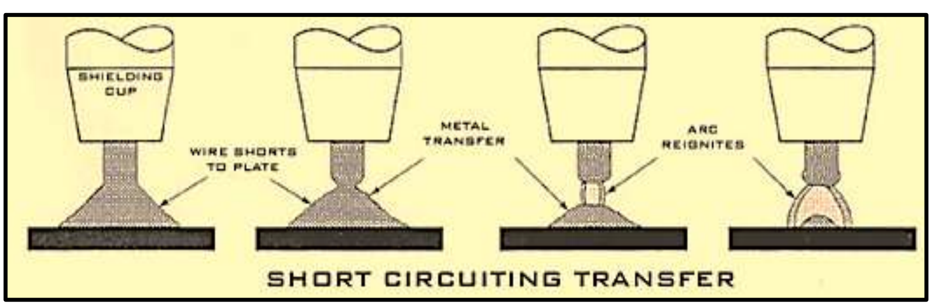
As a result of the lower current, the heat input for the short-arc variation is considerably reduced, making it possible to weld **thinner materials** while decreasing the amount of distortion and residual stress in the weld area. This mode of transfer generally calls for smaller-diameter electrodes, such as, **0.023, 0.030, 0.035, 0.040, and 0.045 in**. The welding current must be sufficient to melt the electrode, but if it is excessive, it can cause a violent separation of the short electrode leading to excessive spatter.

Using adjustable slope and inductance controls can enhance the transfer to minimize spatter and promote a flatter weld profile. Slope adjustment limits the short-circuit amperage, while inductance adjustments control the time it takes to reach maximum amperage. For carbon steel electrodes, the electrode classification dictates the silicon level, **ER70S-3 and ER70S-6** as the most used. For pipe applications, **ER70S-2, ER70S-4, and ER70S-7** are sometimes used for open-root work because they offer lower silicon levels.

The lower silicon produces a stiffer puddle and gives you more control of the back bead profile. In an open-root weld, you may use an **S-6 type electrode** with less inductance than an **S-2 type electrode** since the S-6 type has higher level of silicon and the puddle is more fluid. Maintaining a constant contact tip-to-work distance in short-circuit transfer is important to maintain a smooth transfer. The most common shielding gas and short-circuit transfer mode for carbon steel electrodes is **75 %-Ar and 25 % CO_2**.

Many other three-part shielding gas mixtures are also available for carbon steel and stainless steel using this mode of transfer. This type of metal transfer provides better weld quality and fewer spatters than the globular variation, and allows for welding in all positions, with slower deposition of weld material.

Setting the weld process parameters (volts, amps and wire feed rate) within a relatively narrow band is critical to maintaining a stable arc, generally between **100 to 200 amperes at 17 to 22 volts**, for most applications. However, using only short-arc transfer can result in lack of fusion and insufficient penetration when welding thicker materials, due to the lower arc energy and rapidly freezing weld pool. Like the globular variation, it **can only be used on ferrous metals**.



Short-Arc Welding: This welding technique is particularly useful for joining **thin materials** in any position, **thick materials** in the vertical and overhead positions, and for filling large gaps. Uses small wire in the **range of 0.030 in. (0.76 mm) to 0.045 in. (1.1 mm)** diameter and operates at **low arc** lengths (low voltages) and welding currents. Short-arc welding should also be used where minimum distortion of the workpiece is a requirement. The metal is transferred from the wire to the weld pool only when contact between the two is made, or at each short circuit.

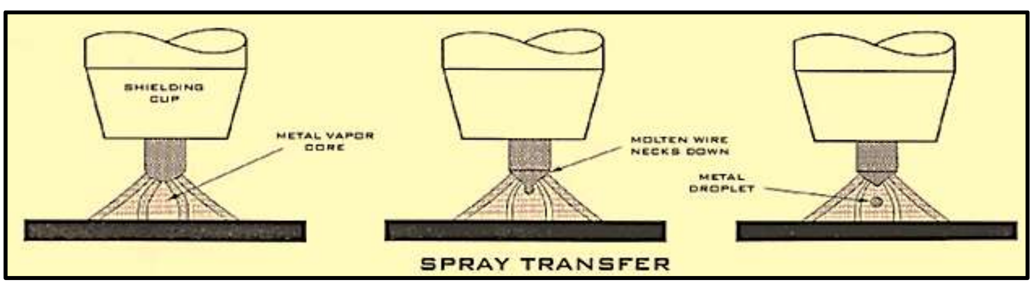
The wire short circuits to the workpiece **20 to 200 times per second**. To insure good arc stability, relatively low welding currents must be employed when using the short arc technique. The Table 1-1, below, illustrates the optimum current range for short circuiting metal transfer with several wire sizes. These ranges can be broadened, depending upon the shielding gas selected.

Table 1-1 – Optimum Short Arc Current Range for Various Steel Wires

WIRE ELECTRODE DIAM.		WELDING CURRENT (AMPS)	
IN.	mm	MINIMUM	MAXIMUM
.030	.76	50	150
.035	.89	75	175
.045	1.1	100	225

Spray Arc: Was the first metal transfer method well-suited for **welding aluminum and stainless steel** employing an inert shielding gas. In this GMAW process, the weld electrode metal is rapidly passed along the stable electric arc from the electrode to the workpiece, essentially eliminating spatter and resulting in a high-quality weld finish. As the current and voltage increases beyond the range of short circuit transfer the weld electrode metal transfer transitions from larger globules through small droplets to a vaporized stream at the highest energies.

Since this vaporized spray transfer weld process requires a **higher voltage and current**, than short circuit transfer, results in higher heat input and larger weld pool area (for a given weld electrode diameter). Generally it is used only on workpieces of thicknesses **above about 6.4 mm (0.25 in)**. Because of the large weld pool, it is often limited only to **flat and horizontal welding positions** and sometimes also used for vertical-down welds. It is generally not practical for root pass welds. When a smaller electrode is used in conjunction with lower heat input, its versatility increases. The maximum deposition rate for spray arc GMAW is relatively high, about **60 mm/s** (**150 in/min**).



By raising the welding current and voltage still further, the metal transfer will become a true spray arc. The minimum welding current at which this occurs is called the transition current. As seen in this table, the transition current depends on the metal wire diameter and shielding gas. However, if the shielding gas for welding carbon steel contains more than about **15% CO^2** there is no transition from globular transfer to spray transfer.

The molten drops from the wire are very small, affording good arc stability. Short circuiting is rare. Little spatter is associated with this welding technique. Spray-arc welding can produce high deposition rates of weld metal. This welding technique is generally used for joining materials **3/32 in. (2.4 mm)** and greater in thickness.

Except when welding aluminum or copper, the spray-arc process is generally restricted to welding in the **flat position** only because of the large weld puddle, but mild steel can be welded out of position with this technique where small weld puddles can be used; generally with a **0.035 in. (0.89 mm) or 0.045 in. (1.1 mm) diameter wires**. The Table 1-2 shows **typical values** of transition current for various **filler metals and shielding gases**.

Table 1-2 – Minimum Current for Spray Arc Welding

WIRE ELECTRODE TYPE	WIRE ELECTRODE DIAMETER IN.	mm	SHIELDING GAS	MINIMUM SPRAY ARC CURRENT (AMP)
MILD STEEL	.030	.76	98% ARGON-2% OXY	150
MILD STEEL	.035	.89	98% ARGON-2% OXY	165
MILD STEEL	.045	1.1	98% ARGON-2% OXY	220
MILD STEEL	.052	1.3	98% ARGON-2% OXY	240
MILD STEEL	.062	1.6	98% ARGON-2% OXY	275
STAINLESS STEEL	.035	.89	99% ARGON-1% OXY	170
STAINLESS STEEL	.045	1.1	99% ARGON-1% OXY	225
STAINLESS STEEL	.062	1.6	99% ARGON-1% OXY	285
ALUMI NUM	.030	.76	ARGON	95
ALUMIN UM	.046	1.19	ARGON	135
ALUMINUM	.062	1.6	ARGON	180
DEOXI DIZED COPPER	.035	.89	ARGON	180
DEOXIDIZED COPPER	.045	1.1	ARGON	210
DEOXIDIZED COPPER	.062	1.6	ARGON	310
SILICON BRONZE	.035	.89	ARGON	165
SILICON BRONZE	.045	1.1	ARGON	205
SILICON BRONZ E	.062	1.6	ARGON	270

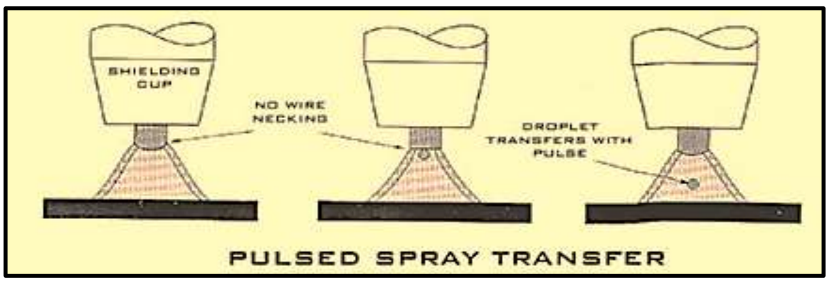
Pulsed-spray: Is a variation of the **spray transfer mode**, based on the same principles, but using a **pulsing current** to melt the filler wire and allow one small molten droplet to fall with each pulse. The pulses allow the average current to be lower, decreasing the overall heat input and thereby decreasing the size of the weld pool and heat-affected zone while making it possible to weld **thin workpieces**.

The pulse provides a **stable arc and no spatter**, since no short-circuiting takes place and makes the process suitable for nearly all metals, then, **thicker** electrode wires can be used, as well. The low level of current is below the transition current while the high level is well into the spray arc region. Metal is only transferred to the work during the period of high current. Usually one droplet is transferred during each high current pulse. The peak current is in the spray arc region arc stability is similar to that of conventional spray arc welding. The period of low current maintains the arc and serves to reduce the average current.

The smaller weld pool gives the variation greater versatility, making it possible to weld in all positions. In comparison with short arc GMAW, this method has a somewhat slower maximum speed **(85 mm/s or 200 in/min)** and the process also requires that the shielding gas be primarily argon with a low carbon dioxide concentration. Additionally, it requires a special power source capable of providing current pulses with a frequency between **30 and 400 pulses** per second.

The electrodes you can use include all the standard **carbon steel and stainless steel types**, along with some of the specialty alloys such as **Inconel (625), duplex (2209), and super duplex (2509)**. With a programmable pulse power supply, most solid-wire alloys can be used with a customized pulse waveform. With all modes of transfer, the wire type will have some effect on the machine settings. Manufacturers use different types of arc stabilizers on the wire surface to enhance a smooth transfer.

However, the method has gained popularity, since it requires lower heat input and can be used to weld thin workpieces, as well as nonferrous materials. Thus, the **pulse spray technique** will produce a spray arc at **lower average current** levels than are required for conventional spray arc welding. The lower average current makes it possible to weld thinner gauge materials with spray type transfer using larger sized wire electrodes than otherwise possible. Pulsed spray arc welding can also be used for out-of-position welding of heavier sections.

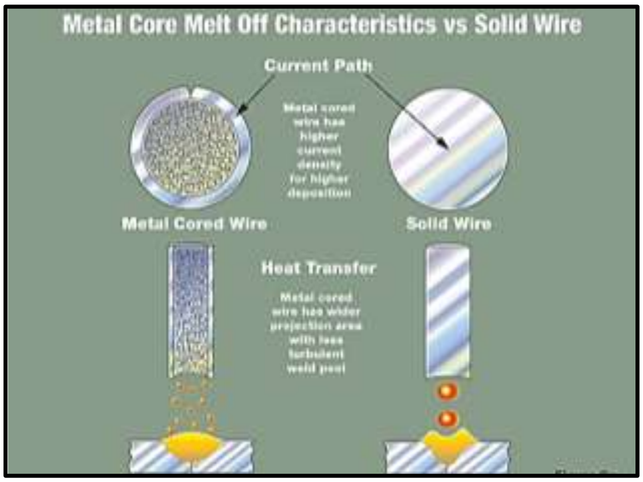


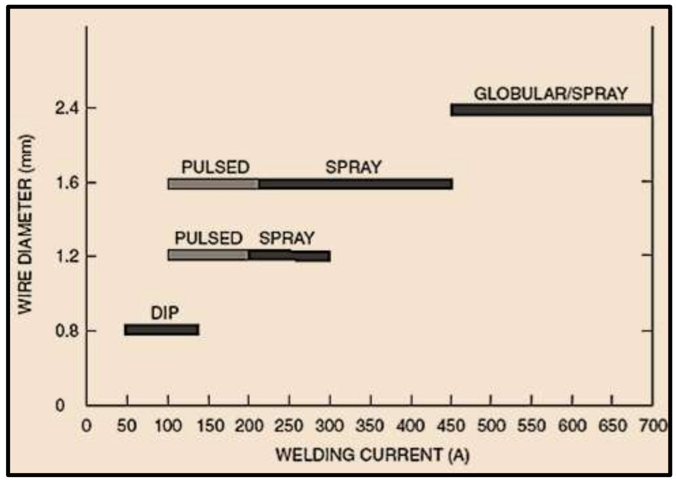
Rotational Spray Transfer: This transfer occurs when a **solid wire** is used with a **long electrode extension** of **7/8 to 1 1/2 in. (22 - 38 mm)** and the shielding gas is a mixture of argon-carbon dioxide-oxygen or argon-oxygen. The long electrode creates resistance heating of the electrode that causes the end to become molten. Electromechanical forces make the molten end of **the electrode rotate** in a helical pattern. The shielding gas mixtures affect the surface tension of the molten end assisting the rotational transfer. Deposition rates of **18 to 30 lb/h** are attainable with this transfer mode.

The **rotational phenomenon** will be inhibited by high thermal conductivity in the shielding gas and an increase in the surface tension at the tip of the molten electrode. This can occur when the gas mixture is high in carbon dioxide or helium is incorporated into the mix. This condition will increase the size of the droplets and decrease the transfer rate. The arc plasma becomes narrower than in the rotational mode, but the transfer is similar to an axial spray. Joint penetration increases when the arc becomes more concentrated.

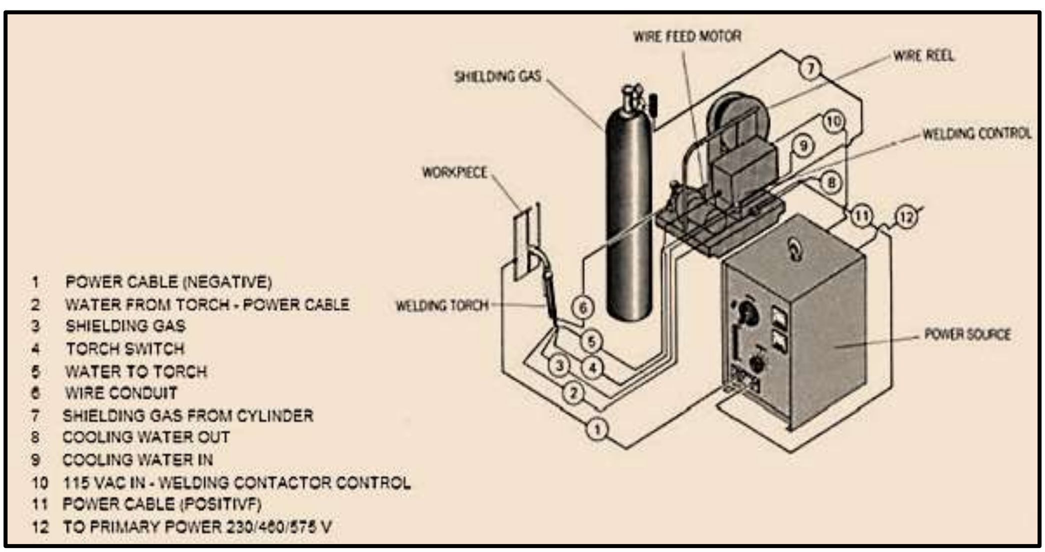
Flux-Cored Electrode: Is a continuous, GMAW **tubular electrode wire**, with a sheath of low carbon, mild steel and core containing deoxidizers, slag formers and arc stabilizers in powder form. Both strip and core materials are carefully monitored to conform to rigorous specifications. Automatic controls during production provide a uniform, high quality product. Flux-cored wires are specifically designed to weld **mild steel** using either **CO_2 gas or Argon-Co_2** gas mixtures.

Flux-cored arc welding offers many inherent **advantages** over **stick electrode** welding. Higher deposition rates (typically double) and increased duty cycles (no electrode changing) mean savings in labor costs. The **deeper penetration** achieved with cored wire also permits less joint preparation, yet provides quality welds **free from lack of fusion and slag** entrapment. See below, the most used GMAW processes and respective wire diameters and welding currents:



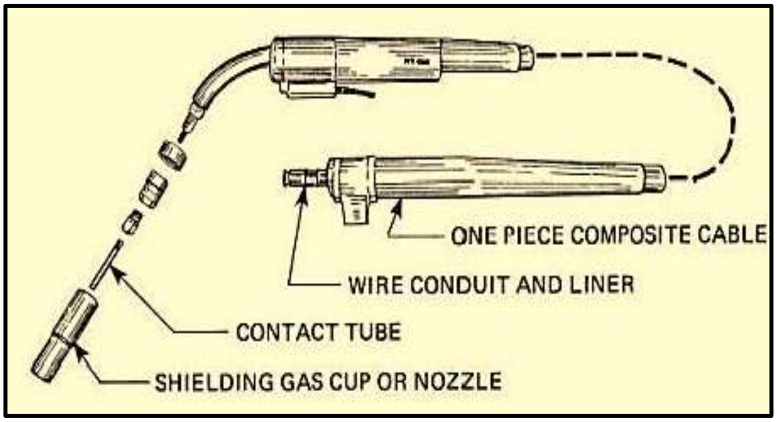


Manual Welding: A manual welding station is simple to install. Because arc travel is performed by the welder, only three major elements are necessary, as shown below:



WELDING TORCHES AND ACCESSORIES:

The **welding torch** brings welding power to the wire, guides the wire and shielding gas into the weld zone. Different types of welding torches have been designed to provide maximum welding utility for different types of applications. They range from heavy duty torches for high current work to lightweight torches for low current and out-of-position welding. In types, **water or air cooling** and curved or straight front ends are available. Figure below, shows a cross-sectional view of a typical **air cooled** curved-front-end torch with the necessary accessories.



Typical Mig Welding Torch

The wire guide tube, also called “contact tube”, is made of copper and is used to bring welding power to the wire as well as direct the wire toward the work. The torch (and guide tube) is connected to the welding power source by the power cable. Because the wire must feed easily through the guide tube and also make good electrical contact, the bore diameter of the tube is important. The tube, which is a replaceable part, must be firmly locked to the torch and centered in the shielding gas cup.

The shielding gas cup directs a protective mantle of gas to the welding zone. **Large** cups are used for high current works where the weld puddle is large. **Smaller** cups are used for low-current welding. The wire conduit and its liner are connected between the torch and wire drive (feed) rolls. They direct the wire to the tor-ch and into the contact tube. Uniform wire feeding is necessary for arc stability. When not properly supported by the conduit and liner, the wire may jam.

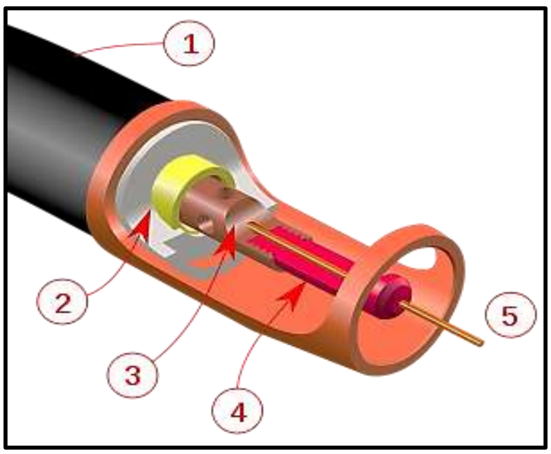
The liner may be either an integral part of the conduit or supplied separately. In both case, the inner diameter and material of the liner are important. Using steel wire electrodes, a steel spring liner is recommended. **Nylon** and other **plastic liners** should be used for aluminum wire. The literature supplied with each torch, lists the recommended conduits and liners for each wire size and material. The typical GMAW welding gun has a number of key parts, a control switch, a contact tip, a power cable, a gas nozzle, an electrode conduit and liner, and a gas hose.

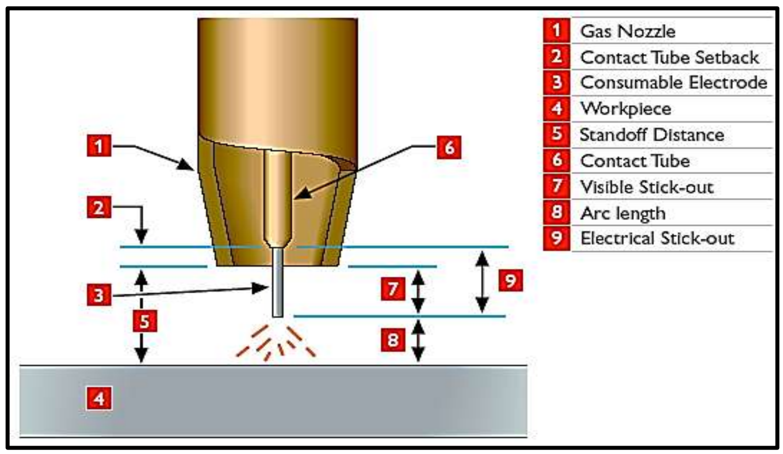
The control switch, or trigger, when pressed by the operator, initiates the wire feed, electric power, and the shielding gas flow, causing an electric arc to be struck. The contact tip, normally made of copper and chemically treated to reduce spatter, is connected to the welding power source through the power cable and transmits the electrical energy to the electrode while directing it to the weld area. It must be firmly secured and properly sized, since it must allow the electrode to pass while maintaining electrical contact.

On the way to the contact tip, the wire is protected and guided by the electrode conduit and liner, which help prevent buckling and maintain an uninterrupted wire feed. The gas nozzle directs the shielding gas evenly into the welding zone. Inconsistent flow may not adequately protect the weld area. Larger nozzles provide greater shielding gas flow, which is useful for high current welding operations that develop a larger molten weld pool. A gas hose from the tanks of shielding gas supplies the gas to the nozzle.

Sometimes, a water hose is also built into the welding gun, cooling the gun in high heat operations. The wire feed unit supplies the electrode to the work, driving it through the conduit and on to the contact tip. Most models provide the wire at a constant feed rate, but more advanced machines can vary the feed rate in response to the arc length and voltage. Some wire feeders can reach feed rates to **30.5 m/min (1200 in/min)**, but feed rates for semi-automatic GMAW typically range from **2 to 10 m/min (75 - 400 in/min)**.

Electrode Holder: The top electrode holders may be semiautomatic air-cooled holder. In the **first** electrode holder, **compressed air** circulates through it to maintain moderate temperatures. It is used with lower current levels for welding lap or butt joints. The **second** most common type of electrode holder is semiautomatic **water-cooled**, and uses higher current levels for **T** welding or corner joints. The **third** typical holder type is a water cooled automatic electrode holder, which is typically used with automated equipment.





1) Torch handle;
2) Molded phenolic dielectric (shown in white) and threaded metal nut insert (yellow);
3) Shielding gas diffuser;
4) Contact tip;
5) Nozzle output face.

WELDING CONTROL AND WIRE-FEEDING:

Are often supplied in one package (wire feeder). Their main function is to pull the welding wire from the spool and feed it to the arc. The control maintains pre-determined wire-feed speed at a rate appropriate to the application. The control not only maintains the set speed independent of load, but also regulates starting and stopping of wire feed on signal from the torch switch.

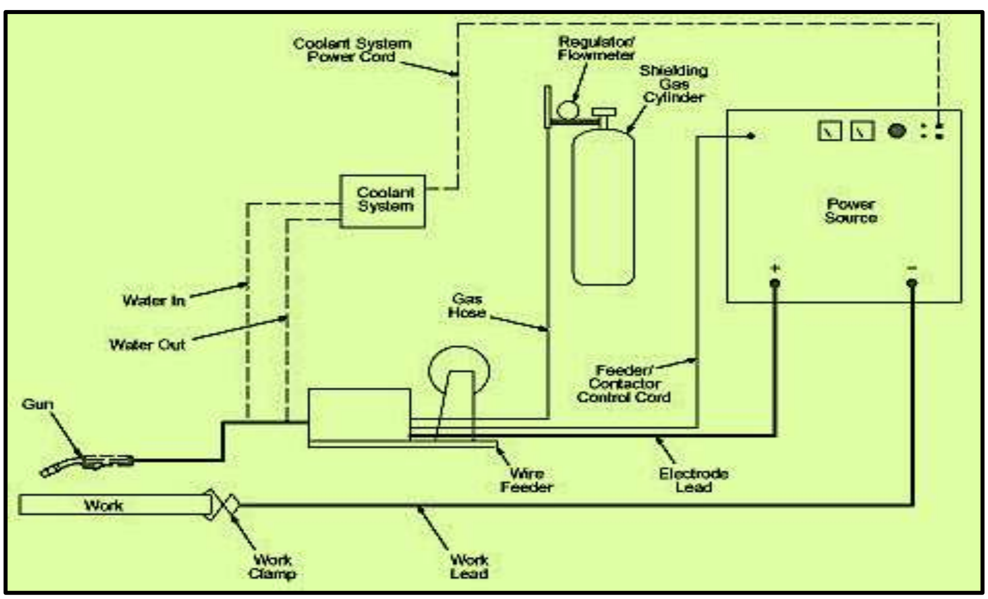
Shielding gas, water, and welding power are usually delivered to the torch through the control box. Through the use of solenoids, gas and water flow are coordinated with flow of weld current. The control determines the sequence of gas flow and energizing of the power supply contactor. It also allows some gas to flow before and after arc operation.

Power Source: Almost all mig welding is done with reverse polarity. The positive (+) lead is connected to the torch while the negative (–) lead is connected to the workpiece. Since wire feed speed and, hence, current, is regulated by the welding control, the basic adjustment made through the power source is arc length. Arc length is set by adjusting the power source voltage.

Power source may also have one or two additional adjustments for other welding applications. Most power sources require either **240V or 480V AC input power**. The only other connection to the power source is a multi-connector cable from the control, to have the power in sequence with other control functions, as most applications of GMAW use a **constant voltage** power supply. Then, any change in arc length (which is directly related to voltage) results in a large change in heat input and current.

A shorter arc length causes a much greater heat input, which makes the wire electrode melt more quickly and thereby restore the original arc length. This helps operators keep the arc length consistent even when manually welding with hand-held welding guns. To achieve a similar effect, sometimes a constant current power source is used in combination with an arc voltage-controlled wire feed unit.

In this case, a change in arc length makes the wire feed rate adjust to maintain a relatively constant arc length. In rare circumstances, a constant current power source and a constant wire feed rate unit might be coupled, especially for the welding of metals with high thermal conductivities, such as aluminum. This concedes the operator additional control over the heat input into the weld, but requires significant skill to perform successfully.



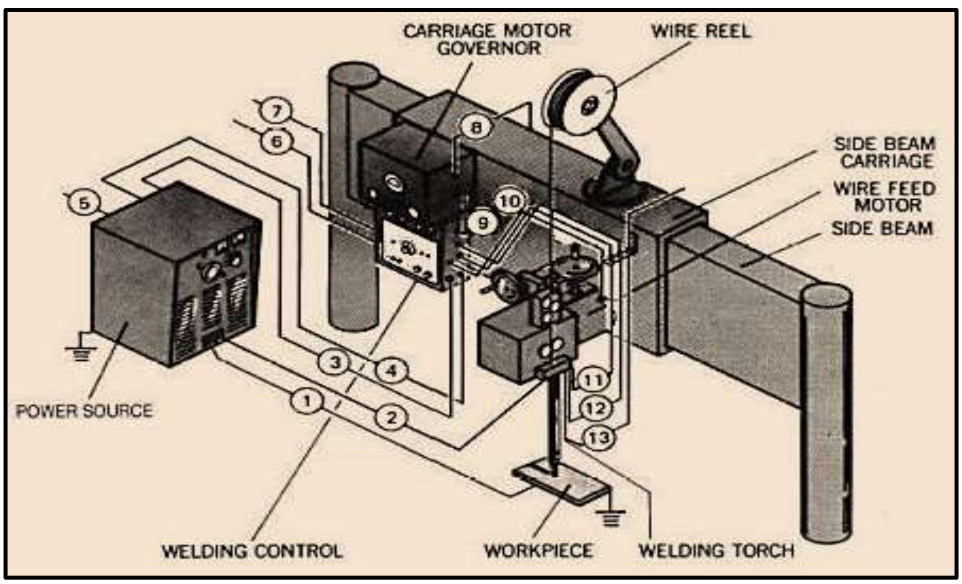
Alternating Current: Is rarely used with GMAW, instead, direct current is employed and the electrode is generally positively charged. Since the anode tends to have a greater heat concentration, this result in faster melting of the feed wire, which increases weld penetration and welding speed. The polarity can be reversed only when special emissive-coated electrode wires are used, but since these are not popular, a negatively charged electrode is rarely employed.

Direct current: Are used for most Mig welding with constant potential (voltage) and contrasts with Tig and Stick electrode welding which use constant current power sources. The Mig power source provides a relative constant voltage to the arc during welding, which determines the arc length. When there is a sudden change in wire-feed speed, or a momentary change in arc length, the power source abruptly increases or decreases the current (and thereby the wire burn off rate) depending on the arc length change.

The rate of wire changes automatically and restores the original arc length. As a result, a permanent change in arc length is made by adjusting the output voltage of the power source. The wire-feed speed selected by the operator, prior to welding, determines the arc current. It can be changed over a considerable range before the arc length changes enough to cause stubbing to the workpiece or burning back to the guide tube.

Mechanized Welding Station: A mechanized station is used when the work can more easily be brought to the welding station or where a great deal of repetitive welding justifies special fixtures. Arc travel is automatic and controlled by the fixture travel speed. Weld speed is usually increased and weld quality improved. As shown below, the welding equipment in a mechanized fixture is much the same as in a manual station, except:

1) The torch is mounted directly under the wire feed motor, eliminating the need for a wire conduit.
2) The welding control is mounted away from the wire feed motor. Remote control boxes can be used.
3) Other equipment may be used to provide automatic fixture travel, as side-beam carriages and turning fixtures. The welding control also coordinates carriage travel with the weld start and stop.

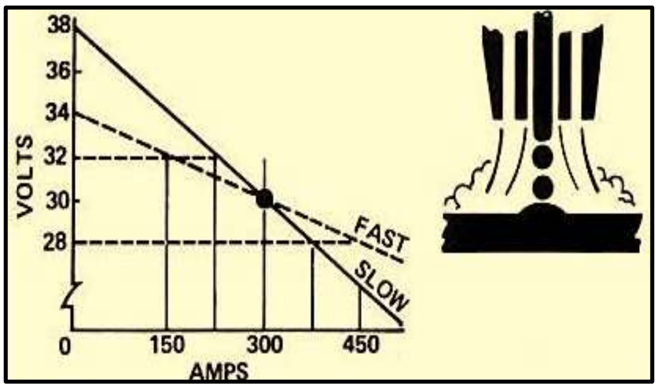


1 POWER CABLE (NEGATIVE)
2 POWER CABLE (POSITIVE)
3 WELDING VOLTAGE & CURRENT DETECTION
4 115 VAC IN
5 TO PRIMARY POWER 230/460/575 V
6 COOLING WATER IN
7 SHIELDING GAS IN
8 TO CARRIAGE DRIVE MOTOR
9 115 VAC IN TRAVEL START/STOP
10 WIRE FEED MOTOR
11 SHIELDING GAS IN
12 COOLING WATER IN
13 COOLING WATER OUT

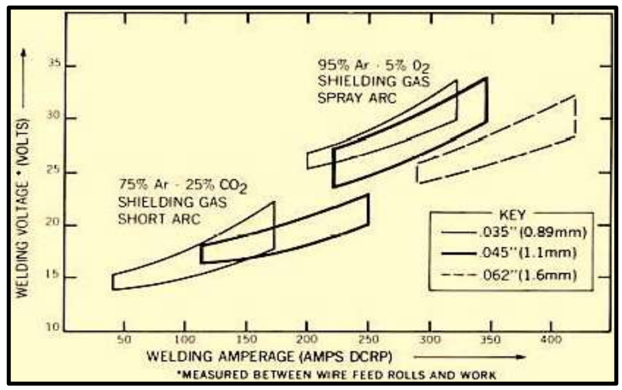
Automatic Welding Installation.

Power Source Variables: The self-correcting arc length feature of the constant voltage welding system is very important in producing stable welding conditions. Specific electrical characteristics are needed to control the arc heat, spatter, etc. These include voltage, slope, and inductance. Arc voltage is the voltage between the end of the wire and the workpiece. Because of voltage drops encountered in the welding system, the arc voltage cannot be directly read on the power source voltmeter.

Welding Voltage: Has an **important effect** on the type of metal transfer desired (arc length). Short arc welding requires relatively low voltages while spray arc requires higher voltages. It should be noted, too, as welding current and wire burn off are increased, the welding voltage must also be increased somewhat to keep the stability. The figure below shows a relationship of arc voltage to welding current for the most common shielding gases employed for mig welding carbon steel. The arc voltage is increased with increasing current to provide the best operation.



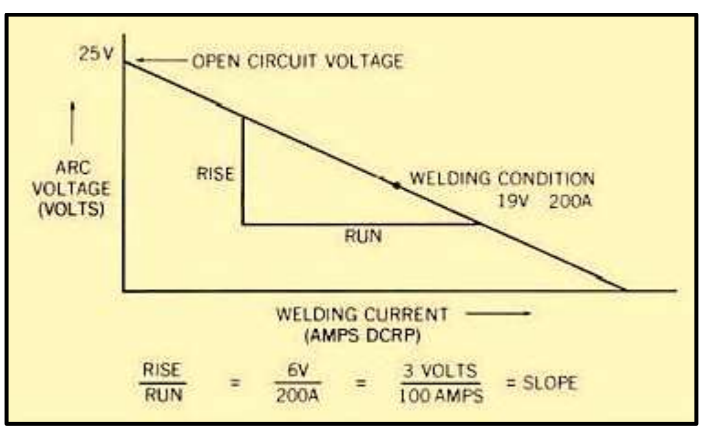
Wire Feed Speed



Arc Voltage-Welding Current Relationship

Slope: Is the volt-ampere characteristic of the Mig power source and refers to the **reduction** in output voltage with increasing current. Thus, a "constant voltage" power source with a slope may not really provide constant voltage for reasons to be considered, as shown in below example. The **slant** from horizontal of the curve, in this graph is referred to as the **"**slope**"** of the power source.

Example of Slope: Suppose an open circuit voltage is set at 25V and the welding condition is 19V and 200 amps. The voltage **decreases** from **25V** to **19V** with **200 amps**, then, the slope is **3V/100 amps**, as can be shown below. The slope of the power source by itself, as specified by the manufacturer and measured at its output terminals, is not the total slope of the arc system.

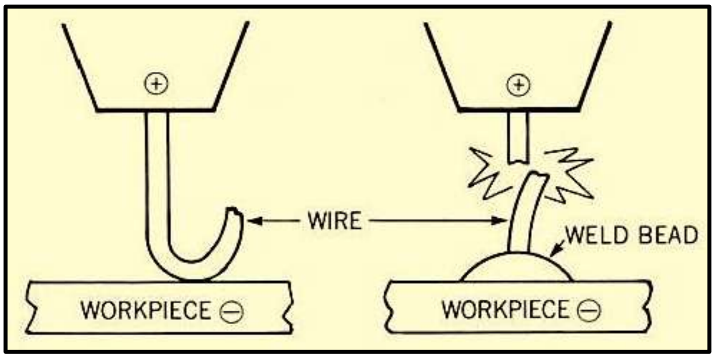


Slope Calculation of a Welding System

Anything which adds resistance to the welding system adds some slope and increases the voltage drop at a given welding current. Power cables, connections, loose terminals, dirty contacts, etc., all are added to the slope. Therefore, in a welding system, the slope should be measured at the arc.

Use of the Slope: Is used during short arc welding to limit the short circuit current, so that **spatter** is reduced when short circuits between the wire electrode and workpiece are cleared. The greater the slope, the lower the short circuit currents and within limits, the lower the spatter. The amount of short circuit current must be high enough (but not too high) to detach the molten drops from the wire.

When **little or no slope** is present in the welding circuit, the short circuit current rises to a very high level, and a violent, but miniature, reaction takes place. **This cause spatter**. When a short circuit current is limited to excessively **low values** by use of **too much slope**, the wire electrode can carry the full current and the short circuit will not clear itself. In that case, the wire piles up on the workpiece or may stub to the puddle occasionally and flash off, as schematically is shown below (Effect of Too Much Slope):



When the short circuit current is at the **correct value**, the parting of the molten drop from the wire is smooth, with very little spatter. The Table 1-3, below, shows some typical short circuit currents required for metal transfer and the best arc stability.

Table 1-3 – Typical Circuit Currents Required for Metal Transfer:

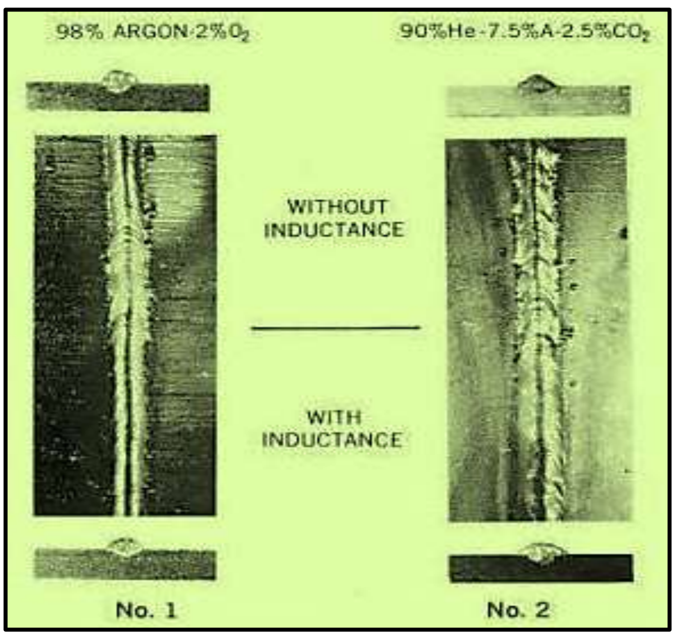
Gas	Wire Diameter	Amps	Volts	Wire Feed Speed m/min	Transfer Mode
$Ar + O_2 + CO_2$	1.0mm	152	22.5	7.8	Spray
	1.0mm	48	16.1	2.4	Pulsed
	1.0mm	83	16	3.6	Dip
$Ar + He + CO_2$	1.0mm	178	27	8.7	Spray
	1.0mm	50	17.9	2.9	Pulsed
	1.0mm	47	16.2	2.1	Dip
$Ar + O_2$	1.0mm	147	22	6.9	Spray
	1.0mm	49	15.9	2.5	Pulsed
	1.0mm	73	16.7	3.2	Dip

Inductance: Since power sources do not respond instantly to load changes, the current takes a finite time to attain a new level. Inductance in the circuit is responsible for this time lag. Inductance controls the rate of rise of short circuit current. The rate can be slowed so that the short current may clear with minimum spatter. The inductance also stores energy. It supplies this energy to the arc after the short has cleared and causes a longer arc. In “short arc” welding, an increase in inductance also increases the “arc on” time.

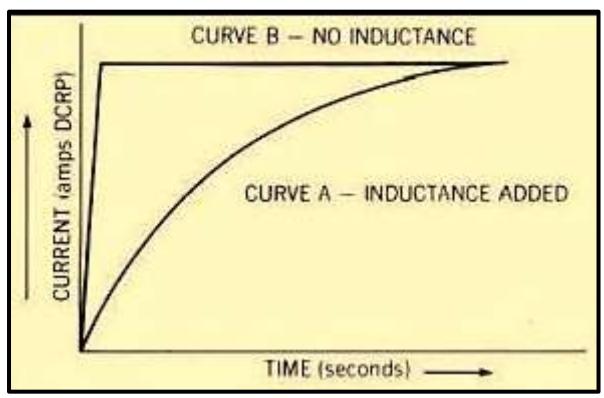
Photos below, shows the influence of inductance on the appearance of “short-arc” welds made both with an argon-oxygen gas mixture and with a helium-argon-carbon dioxide mixture. The **weld No. 1** was made with a mixture of **98% argon and 2% oxygen** shielding gas and **no inductance in the half above** and **spatter is clear.** In the **half below** the sample, **inductance** of about **500 micro-henries** was added. Freeze lines are not as prominent, and the bead remains convex.

The **weld No. 2**, was made with the **He-Ar-Co$_2$ mixture** is also convex, but spatter on the plate is excessive, however, when the **inductance** is introduced in the **half below of the sample**, the **reduction in spatter** is dramatic. The bead becomes flat and the cross-section on the bottom right shows penetration of the weld bead into the workpiece has increased. In spray arc welding, the addition of some inductance to the power source will produce a better arc start.

This, in turn, makes the puddle more fluid, resulting in a flatter, smoother weld bead. The opposite is true when the inductance is decreased. The effect of inductance is shown in the curve appearing aside the photos of two samples. The **curve “A”** shows a typical current-time curve with inductance present as the current rises from zero to a final value, while the **curve “B”** shows the path which the current would have taken, if there were no inductance in the circuit.



Effect of Inductance on Weld Appearance



Change in Current Rise Due to Inductance

Too much inductance will result in erratic starting. When conditions of both correct shorting current and correct rate of current rise exist, spatter is minimal. The power source adjustments required for minimum spatter conditions vary with the electrode material and size. As a general rule, both the amount of **short circuit current** and the **amount of inductance** needed for ideal operation are increased, as the **electrode diameter** is also increased.

SHIELDING GASES – BEST PRACTICES:

Shielding gases are necessary for GMAW to **protect the welding area** from atmospheric gases, such as **nitrogen and oxygen**, which can cause fusion defects, porosity, and weld metal embrittlement, when in contact with the electrode, the arc, or the welding metal. This problem is common to all arc welding processes, for example, in the older Shielded-Metal Arc Welding process (SMAW), the electrode is **coated** with a **solid flux** which evolves a protective cloud of carbon dioxide when melted by the arc.

In GMAW, the electrode wire does not have a **flux coating**, and a separate shielding gas is employed to protect the weld. This eliminates slag, but the hard residue from the flux that builds up after welding must be chipped off to reveal the completed weld. The **choice** of a shielding gases depends on several factors, most importantly the type of material being welded and the process variation being used.

Pure inert gases such as **argon (Ar) and helium (He)** are only used for **nonferrous welding.** These gases, for welding steel, cannot provide adequate weld penetration (argon) or cause an erratic arc and encourage spatter (with helium). Pure **carbon dioxide (CO_2)**, on the other hand, allows deep penetration welds, but encourages **oxide** formation, which adversely affect the mechanical properties of the weld. Its low cost makes it an attractive choice, but because of the reactivity of the arc plasma, spatter is unavoidable and **welding thin** materials is difficult.

As a result, argon (Ar) and carbon dioxide (CO_2) are **frequently mixed** in a **75%/25% to 90%/10% mixture**. Generally, in short circuit GMAW, higher carbon dioxide content increases the weld heat and energy when all other weld parameters (volts, current, electrode type and diameter) are held the same. However, as the carbon dioxide content increases **over 20%,** the spray transfer in GMAW becomes problematic, especially with **smaller electrode** diameters.

Argon is also commonly **mixed with other gases**, oxygen, helium, hydrogen, and nitrogen. The addition of up to 5% oxygen (like the higher concentrations of carbon dioxide mentioned above) can be helpful in welding **stainless steel**, however, in most applications carbon dioxide (CO_2) is preferred. Increasing oxygen makes the shielding gas **oxidize** the electrode, which can lead to **porosity** in the deposit if the electrode does not contain sufficient deoxidizers.

Excessive oxygen, especially when used in not prescribed application, can lead to **brittleness** in the heat affected zone. **Argon-helium** mixtures are **extremely inert**, and can be used on **nonferrous** materials. A **helium** concentration of **50%–75%** raises the required voltage and increases the heat in the arc, due to helium's higher ionization temperature.

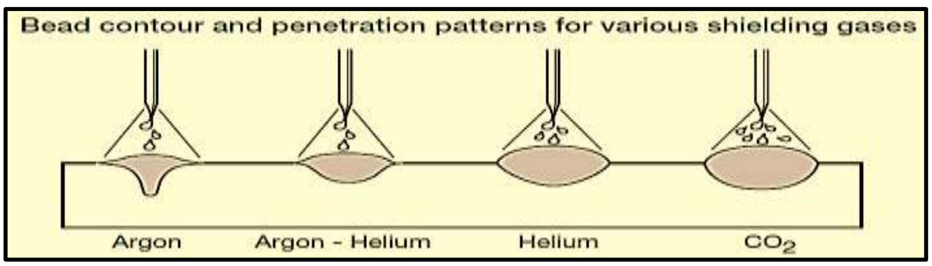
Hydrogen is sometimes added to **argon** in small concentrations (up to about 5%) for welding nickel and thick **stainless steel** workpieces. In higher concentrations (up to 25% hydrogen), it may be used for welding conductive materials such as **copper**, however, **should not be used** on steel, aluminum or magnesium because it can cause porosity and hydrogen embrittlement.

Shielding gas **mixtures of three or more gases** are also available. Mixtures of argon, carbon dioxide and oxygen are marketed for welding steels. Other mixtures add a small amount of helium to argon-oxygen combinations, these mixtures are claimed to allow higher arc voltages and welding speed. Helium also sometimes serves as the base gas, with small amounts of argon and carbon dioxide added.

However, because it is less dense than air, **helium is less effective** at shielding the weld than **argon**, which is denser than air. It also can lead to arc stability and penetration issues, and increased spatter, due to its much more energetic arc plasma. Helium is also substantially **more expensive** than other shielding gases. Other specialized and often proprietary gas mixtures claim even greater benefits for specific applications.

The **desirable rate** of shielding-gas flow depends primarily on weld geometry, speed, current, the type of gas, and the metal transfer mode. Welding **flat** surfaces requires higher flow than welding **grooved** materials, since gas disperses more quickly. Faster welding speeds, in general, mean that more gas must be supplied to provide adequate coverage. Additionally, higher current requires greater flow, and generally, more helium is required to provide adequate coverage, than if argon is used.

Perhaps most importantly, the four primary variations of GMAW have differing shielding gas flow requirements. About **10 l/min (20 ft³/h)** is generally suitable for **small weld** pools using short-circuiting and pulsed-spray modes, whereas for globular transfer, around **15 l/min (30 ft³/h)** is preferred. The **spray** transfer variation normally requires **more shielding-gas flow** because of its higher heat input and thus larger weld pool. Typical gas-flow amounts are approximately **20–25 l/min (40–50 ft³/h)**.



Air in the weld zone is displaced by a shielding gas, in order to prevent contamination of the molten weld puddle. This **contamination** is caused mainly by **nitrogen, oxygen and water vapor** present in the atmosphere. As an example, **nitrogen** in solidified steel reduces the ductility and impact strength of the weld causing **cracking,** and in large amounts, can also cause weld **porosity**. Excess oxygen in steel combines with carbon to form the carbon monoxide (CO) and this gas, can be also be trapped in the metal, causing **porosity**.

In addition, excess oxygen can combine with other elements in steel and form compounds that produce inclusions in the weld metal. When **hydrogen**, present in **water vapor and oil**, combines with either iron or aluminum, porosity will result and an “under bead” weld metal **cracking** always occur. To avoid these problems associated with contamination of the weld puddle, **three main gases** are used for shielding, **argon, helium and carbon dioxide**.

In addition, small amounts of **oxygen, nitrogen and hydrogen** have proven beneficial for some applications. Of these gases, only argon and helium are inert gases. Compensation for the oxidizing tendencies of other gases is made by special wire electro deformulations. Argon, helium and carbon dioxide **can be used alone**, in combinations or mixed with others to provide defect free welds in a variety of weld applications and weld processes.

Properties of Gases: The basic properties of shielding gases that affect the performance of the welding process include:

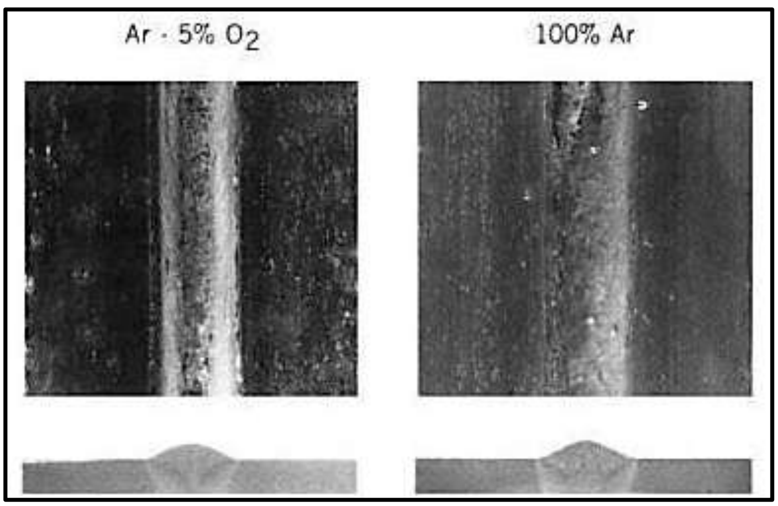
1) Thermal properties at elevated temperatures.
2) Chemical reaction of the gas with the various elements in the base plate and welding wire.
3) Effect of each gas on the mode of metal transfer. The thermal conductivity of the gas at arc temperatures influences the arc voltage, as well as, the thermal energy delivered to the weld.

As thermal conductivity increases, greater welding voltage is necessary to sustain the arc. For example, the thermal conductivity of **helium (He) and CO_2** is much higher than argon, because delivers more heat to the weld. Therefore, helium and CO_2 require **more welding voltage** and power to maintain a stable arc. The welder must find the compatibility of each gas with wire and base metal, to determine the suitability of the various gas combinations.

Carbon dioxide (CO_2) and most oxygen (O_2) shielding gases **should not be used** for welding **aluminum**, as aluminum oxide will form. However, **CO_2 and O_2** are useful at times and even essential, when welding **steels**. They promote arc stability and good fusion between the weld puddle and base material. Oxygen is a great deal more oxidizing than CO_2.

Oxygen additions to argon are generally less than 12% by volume. However, 100% CO can be used for GMAW mild steels. Steel wire electrodes must contain strong **deoxidizing elements** to prevent porosity when used with CO, particularly mixtures with high percentages of CO_2 or O_2 and especially 100% CO_2.

Shielding gases also determine the mode of metal transfer and the depth to which the workpiece is melted (depth of penetration). Spray transfer is not obtained, when the gas is rich in CO_2. For example, mixtures containing **more than about 20% CO_2** do not exhibit **true spray transfer**. Rather, mixtures up to **30% CO_2** can have a **"spray-like"** shape to the arc at high current level but are unable to maintain the arc stability of lower CO_2 mixtures. Spatter levels will also tend to increase when mixtures are rich in CO_2.



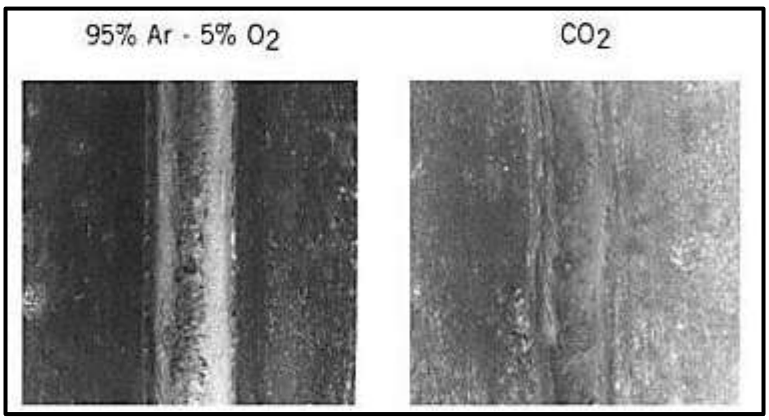
Effect of Oxygen Additions to Argon

Argon: Argon is an **inert gas** which is used both pure and in combination with other gases to achieve desired arc characteristics for welding of both **ferrous** and **non-ferrous** metals. Pure argon is used singularly on **non-ferrous materials** such as aluminum, nickel based alloys, copper alloys and **reactive metals** which include zirconium, titanium, and tantalum. Argon provides **excellent spray** arc welding stability, penetration and bead shape on these materials. Some short circuiting arc welding of thin materials is also practiced. Almost all welding processes can use **argon or mixtures** to achieve good weldability, mechanical properties, arc characteristics and productivity.

When welding **ferrous materials**, argon is **always mixed** with other gases such as oxygen, helium, hydrogen, carbon dioxide and/or nitrogen. The low ionization potential of argon creates an excellent current path and superior arc stability. Argon produces a constricted arc column at a high current density which causes the arc energy to be concentrated in a small area. The result is a deep penetration profile having a distinct "finger like" shape.

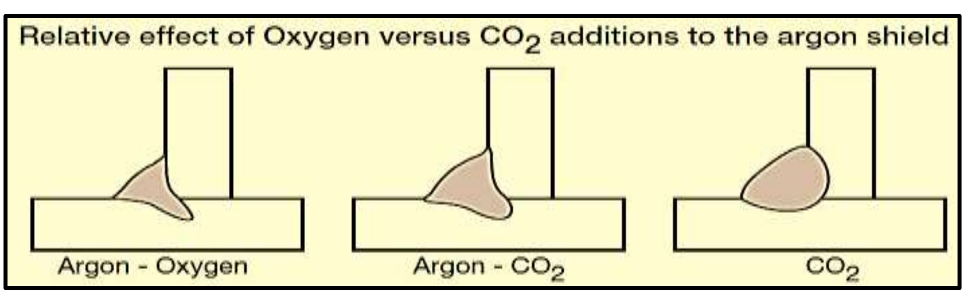
Carbon Dioxide (CO_2): Pure carbon dioxide is not an **inert gas**, but is an **active gas,** widely used for the **welding of ferrous materials,** producing an oxidizing effect. Sound welds can be consistently and easily achieved, free of porosity and defects, and because the heat the arc breaks down the CO_2 into carbon monoxide and free oxygen. The oxygen will combine with elements transferred across the arc, forming oxides which are released from the weld puddle in the form of slag and scale.

The popularity of carbon dioxide is due to the common **availability** and **quality weld** performance, as well as, its low cost and simple installation. It should be mentioned that low cost per unit of gas does not automatically translate to lower cost per foot of weld and is greatly dependent on the welding application. Factors such as lower deposition efficiency for **CO_2** caused by spatter loss, influence the final weld cost.



Comparison of Ar-5% O_2 and CO_2 Shielding Gas

Carbon dioxide will not spray transfer; therefore, the arc performance is **restricted to short circuiting and globular transfer**. The advantage of **CO_2** is fast welding speeds and **deep penetration**. The major drawbacks of **CO** are a harsh globular transfer and high weld spatter levels. The weld surface resulting from pure **CO_2 shielding** is usually heavily oxidized.



A welding wire having higher amounts of deoxidizing elements is sometimes needed to compensate for the reactive nature of the gas. Overall, good mechanical properties can be achieved with **CO_2**. **Argon** is often **mixed with CO_2** to off-set pure CO_2 performance characteristics. If **impact properties** have to be maximized, a **CO_2 + argon mixture** is recommended.

Helium: Helium is an inert gas which is used on weld applications requiring higher heat input for improved wetting, deeper penetration and higher travel speed. Compared to argon, helium has a higher thermal conductivity and voltage gradient and yields a broader and shallower penetration pattern, however, in GMAW it does not produce a stable arc.

Aluminum Welding with Pure Helium: Does not give the cleaning action that pure argon experiences but is beneficial and sometimes recommended for welding thick aluminum. The helium arc column is wider than argon which reduces current density. The higher voltage gradient causes increased heat inputs over argon thus promoting higher puddle fluidity and subsequent bead wetting.

This is an advantage when welding aluminum, magnesium and copper alloys. **Helium is often mixed** with various percentages of argon to take advantage of the good characteristics of both gases. The argon improves arc stability and cleaning action, in the case of aluminum and magnesium, while the helium improves wetting and weld metal coalescence.

BINARY SHIELDING GAS MIXTURES:

Argon-Oxygen: Small amounts of O_2 to Ar greatly stabilizes the weld arc, increasing the filler metal droplet rate, lowers the spray arc transition current, and improves wetting and bead shape. The weld puddle is more fluid allowing the metal to flow out on the tip of the weld, reducing undercutting and flatten the weld bead. Small O_2 additions may be used on non-ferrous applications, as was reported by **NASA that 0.1% oxygen** is useful for arc stabilization, when **welding** very clean **aluminum** plate.

Argon-1% O_2: This mixture is primarily used for **spray transfer on stainless steels** and only 1.0 % oxygen is sufficient to stabilize the arc, improve droplet rate, provide coalescence and improve appearance.

Argon-2% O_2: This mixture is used for **spray arc welding on carbon steels**, low alloy steels and stainless steels. It provides additional wetting action over the 1% O_2 mixture. Mechanical properties and corrosion re-sistance of welds made in the 1 and 2% O_2 additions are equivalent.

Argon-5% O_2: This mixture provides a more fluid weld pool. It is the most commonly used argon-oxygen mixture for **general carbon steel welding**. The additional oxygen also permits **higher travel speeds**.

Argon-8-12% O_2: Originally popularized in Germany, this mixture has recently surfaced in the U.S. in both the 8% and 12% types. The higher oxidizing potential of these gases must be taken into consideration with respect to the wire alloy chemistry. The higher puddle fluidity and lower spray arc transition current of these mixtures could have some advantage on some weld applications.

Argon-12-25% O_2: Mixtures with very high O_2 levels have been used on a limited basis. Extreme puddle fluidity is characteristic of this gas. A heavy slag/scale layer over the bead surface can be expected which is difficult to remove. Sound welds can be made at the 25% O_2 level with little or no porosity.

Argon-Carbon Dioxide Mixtures: Are mainly used on **carbon and low alloy steels** and limited application on **stainless steels**. Ar-CO_2 decreases the spatter levels usually experienced with pure CO_2 mixtures, and the difference is mostly in the higher spray arc transition currents of Ar-CO_2 mixtures. Additions of 20% CO_2 for spray transfer become unstable and random short circuiting and globular transfer occurs.

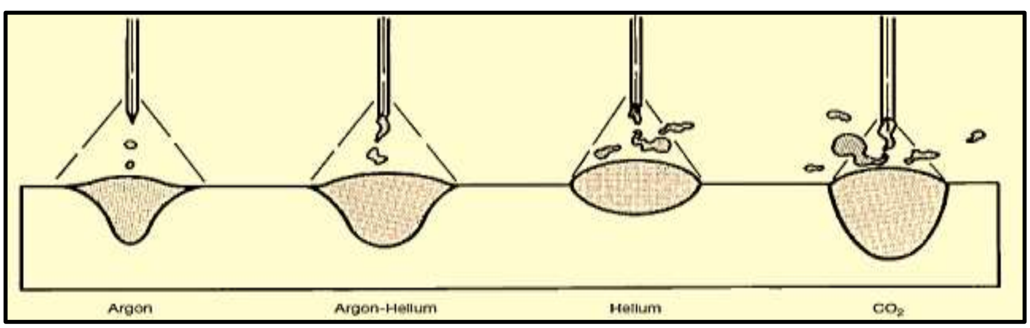
Argon-3-10% CO_2: These mixtures are used for **spray arc and short circuiting** transfer on a variety of **carbon steel** thicknesses. A 5% mixture is very commonly used for pulsed GMAW of heavy section low alloy steels being welding out-of-position. The welds are generally less oxidizing than those with 98 Ar-2% O_2. From 5 to 10% CO_2 the arc column becomes very stiff and defined. The strong arc forces that develop give these mixtures more tolerance to mill scale and a very controllable puddle.

Argon-11-20% CO_2: This mixture range has been used for various narrow gap, out-of-position sheet metal and high speed GMAW applications. Most applications are on carbon and low alloy steels. The lower CO_2 percentages also improve deposition efficiency by lowering spatter loss.

Argon-21-25% CO_2 (C-25): This range is **universally known** as the gas used for GMAW with short circuiting transfer on **mild steel**. It was originally formulated to maximize the short circuit frequency on **0.030 and 0.035-in**. diameter solid wires, but through the years has become the standard, and commonly used with flux cored wires.

Argon-50% CO_2: This mixture is used where **deep penetration** is needed, with material thicknesses above 1/8 in. and welds can be made out-of-position. This mixture is **very popular for pipe welding**, using the short circuiting transfer. When welding at high current levels, the metal transfer is more like welding in pure CO_2 than previous mixtures but some reduction in spatter loss can be realized due to the argon addition.

Argon-75% CO_2: This mixture is commonly used on **heavy wall pipe** and is the optimum in good sidewall fusion and **deep penetration**. The argon constituent aids in arc stabilization and reduced spatter.



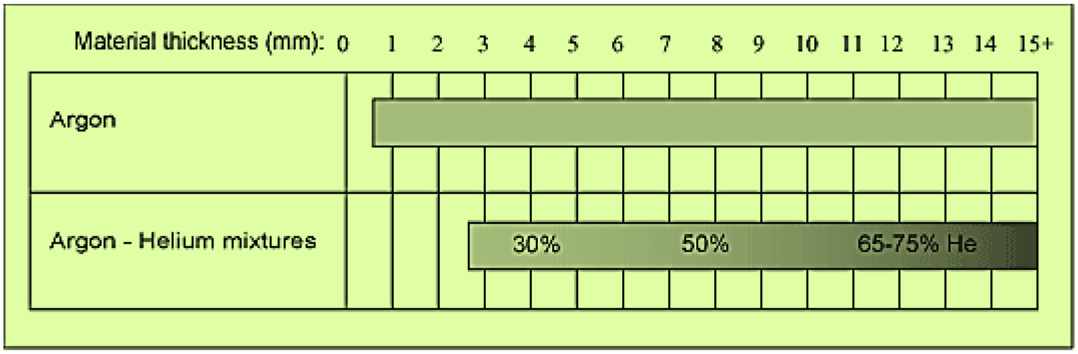
Additions to Argon and Effect of CO_2

Argon-Helium: Used for **non-ferrous materials** such as aluminum, copper, nickel alloys and reactive metals. Small percentages, such as **10%**, affect the arc and the mechanical properties of the weld. As He percentages increase, the arc voltage, spatter and penetration also increase, minimizing porosity. Argon must be, at least, **20%** when mixed with helium, to produce and maintain a stable spray arc.

Argon-25% He (HE-25): This little used mixture is sometimes recommended for welding aluminum, where increase in penetration is sought and bead appearance is of primary importance.

Argon-75% He (HE-75): This commonly used mixture is widely employed for mechanized welding of aluminum greater than one inch thick in the flat position. HE-75 also increases the heat input and reduces porosity of welds in 1/4 and 1/2 in., thick conductivity copper.

Argon-90% He (HE-90): This mixture is used for welding copper over 1/2 in. thick and aluminum over 3.0 in. thick. It has an increased heat input which improves weld coalescence and provides good X-ray quality. It is also used for short circuiting transfer with high nickel filler metals.



Mixtures for MIG welding of aluminium, magnesium, titanium, nickel and copper alloys.

Argon-Nitrogen: Small amounts of **nitrogen** were added to **Ar-1% O_2** for austenitic microstructure in **type 347** stainless steel. Nitrogen concentrations in the range of **1.5 to 3%** have been used, but quantities above 10% produced sound but welds. Additions greater than **2% N_2** produced porosity in single pass. For carbon steel, additions less than **1/2%** caused porosity in multipass welding. A few attempts have been made to utilize N_2 argon mixtures for welding of copper and its alloys, but spatter percentage is high.

Argon-Chlorine: Chlorine is sometimes **bubbled through molten aluminum to remove hydrogen** from ingots or castings. Since this degassing operation is successful, it follows that chlorine might **remove hydrogen from aluminum weld metal**. Some claims were made that Ar-$C1_2$ mixtures eliminated porosity in GMAW, but fabricators have not been able to achieve consistent results. However, chlorine gas forms chloric acid in the **respiratory system**, such mixtures can be noxious to operators. Then, Ar-$C1_2$ mixtures are not recommended, except in special cases where adequate safety and control are implemented.

TERNARY SHIELDING GAS MIXTURES:

Argon-Oxygen-Carbon Dioxide: Mixtures containing these three components have been termed **"universal" mixtures** due to their ability to operate using short circuiting, globular, spray, pulse and high density ty- pe transfer characteristics. Several triple-mixes are available and their application will depend on the desi-red metal transfer mechanism and optimization of the arc characteristics.

Argon-5-10% CO_2 - **1-3% O_2**: The main advantage is its versatility to **weld carbon steel, low alloy steel and stainless steel of all thicknesses**, utilizing whatever metal transfer type applicable. On carbon and low alloy steels, this mixture produces **good welding** characteristics and mechanical properties. For **thin gauge** materials, the O_2 constituent assists the arc stability at very low current levels (30 to 60 amps), permitting the arc to be kept controllable helping to minimize burn through and distortion by lowering the total heat input into the weld zone.

Argon-10-20% CO_2 - 5% O_2: This mixture produces a **hot short** circuiting transfer and fluid puddle characteristics. Spray arc transfer is good and seems to have some benefit when welding with triple deoxidized wires since a sluggish puddle is characteristic of these wires.

Argon-Carbon Dioxide-Hydrogen: Small additions of hydrogen, **1-2%,** have been shown to improve bead wetting and arc stability for pulse welding stainless steel. The **CO_2** is also kept low **(1-3%)** to minimize carbon pick-up and maintain good arc stability. This mixture is not recommended on low alloy steels in the excessive weld metal hydrogen levels could develop causing weld cracking and poor mechanical properties.

Argon-Helium-Carbon Dioxide: Helium and CO_2 addition to argon increase the heat input to the weld and improve arc stability, as well, better wetting and bead. To weld on **carbon and low alloy steels**, helium ad-ditions improve the puddle fluidity, the same way that oxygen since oxidation of the weld metal and alloy loss is not a problem.

Argon- 0-30% He-5-15% CO_2: Mixtures in this range have been developed for pulse spray arc **welding of both carbon and low alloy steel.** Good mechanical properties and puddle control are characteristic of this mixture. Pulse spray arc welding with low average currents is acceptable but mixtures with low **CO**, and/or **O**, percentages will improve arc stability.

60-70% He-20-35% Ar-4-5% CO_2: This mixture is used for short circuiting transfer welding of high strength steels, especially for out-of-position applications. The **CO_2** content is kept low, to insure good weld metal toughness. The helium provides the heat necessary for puddle fluidity.

90% He-7.5% Ar-2.5% CO_2: This mixture is widely used for short arc **welding of stainless steel** in all positions. The **CO_2** content is kept low to minimize carbon pickup and assure good corrosion resistance, especially in multipass welds. The **CO_2 + argon** addition provides good arc stability and penetration.

Argon-Helium-Oxygen: The helium addition to argon increases the arc energy, when welding **non-ferrous materials**, as well as, helium addition to **argon-oxygen** affect the arc on ferrous materials. The Ar-He-O_2 mixtures have been used for spray arc welding of **low alloy and stainless steels** to improve puddle fluidity and bead shape and reduce porosity.

QUATERNARY SHIELDING GAS MIXTURES:

Argon-Helium-Co_2-O_2: Commonly known as "quad mix", this mixture will give good mechanical properties and operability throughout a wide range of deposition rates. Its major application is welding **low alloy high tensile base materials**, but has been used also on **mild steel** for high productivity welding. Weld economics are an important consideration in using this gas for mild steel welding, in that other less expensive mixtures are available for high deposition welding.

Regardless of the type of welding that need to be done, there is a shielding gas that will best suit the requirements. The **Tables 1-4 and 1-5**, below, summarize which shielding gas is best suited for welding a variety of materials using both the short arc and spray arc process.

Table 1-4 - Short Arc Welding

METAL	ARGON	HELIUM	ARGON HELIUM MIXTURES	ARGON-CO_2 MIXTURES	ARGON-HELIUM CO_2 MIXTURES	AR-O_2-CO_2	CO_2
ALUMINUM	•	•	• (HE-75)				
CARBON STEEL				• (C-25) OR (C-50) OR (C-8) (4) (C-15)		• STARGON	•(1)
HIGH STRENGTH STEELS					• (A-415) OVER 14 GA.	• STARGON UP TO 14 GA.	
COPPER			• (HE-75)				
STAINLESS STEELS				• (C-25) (1)	• (A-1025)	• STARGON	
NICKEL ALLOY	•		• (90% HE-10% AR) OR (HE-75)		• (A-1025)		
REACTIVE METALS	•	•	(HE-75) •				

(1) – WIRE DESIGNED FOR CO_2 REQ'D.

Table 1-5 - Spray Arc & Pulse Spray Arc Welding

METAL	ARGON	HELIUM	ARGON-OXYGEN	AR-CO_2	ARGON-HELIUM GAS MIXTURES	Ar He CO_2	(2) AR-O_2-CO_2	Ar CO H_2	(3) CO_2
ALUMINUM	•	•			•(90% HE-10% AR) OR (HE-75)				
CARBON STEELS			• (O_2-2) (O_2-5)	• (C-15) (C-8) OR (C-25) (1) Pulse Blend C-5			• STARGON LINDE 5-22		•
LOW ALLOY STEELS			• (O_2-2)	(C-8)		• A415	• STARGON OVER 3/32" LINDE 5-22		
COPPER & SILICON BRONZE	•	•			• (90% HE-10% AR) OR (HE-75)				
STAINLESS STEELS			•(O_2-1) (O_2-2)					$H_2$1 CO_2-2	
NICKEL ALLOYS	•	•			• (HE-75)				
REACTIVE METALS	•	•							

(1) – SINGLE PASS WELDS (2) – HIGHER QUALITY ON HEAVY MILL SCALE PLATE WHEN USED WITH L-TEC 83 AND 87 HP WIRES. (3) – USED WITH FLUX CORED WIRE AND FOR HIGH SPEED SOLID WIRE WELDING. (4) – THIN MATERIAL

GMAW – WIRE ELECTRODES:

Electrode selection is **based primarily on the composition of the metal** being welded, considering the process variation, joint design, material surface conditions and weld mechanical properties, in combination with the **shielding gas** that determines the resulting physical and mechanical properties of the weld. All commercially electrodes contain **deoxidizing metals** as, silicon, manganese, titanium and aluminum in small percentages, to prevent oxygen porosity. Some contain **other metals** as, titanium and zirconium to avoid nitrogen porosity.

Depending on the process variation and base materials, the diameters of the electrodes typically **range from 0.7 to 2.4 mm (0.028 – 0.095 in.)** but can be as **large as 4 mm (0.16 in.)**. The **smallest** electrodes, generally up to **1.14 mm (0.045 in.)** are associated with short-circuiting metal transfer process, while the **most common** spray-transfer process electrodes are usually at least **0.9 mm (0.035 in.)**.

To achieve these goals a wide variety of electrodes exist. One of the most **important factors** to consider in GMAW welding is the correct filler wire. However, there is no industry-wide specification of wires, conform to AWS standards. There are **five** factors that influence the choice of **filler wire** for mig welding:

1. Base plate chemical composition;
2. Base plate mechanical properties;
3. Shielding gas employed;
4. Type of service or applicable specification requirements;
5. Type of weld joint design.

Ferrous Materials Wire Electrodes: For welding carbon steels, the primary function of the alloying additions in electrodes, is to control the **deoxidation** of the weld puddle and to help determine the weld mechanical properties, as in combination with oxygen results in a slag or glass formation on the surface. Then, removing oxygen from the puddle eliminates the cause of weld metal porosity.

Silicon (Si): Silicon is the most **commonly employed deoxidizing element**, containing **0.40%-1.0% Si**, depending on intended use. In this percentage range, silicon exhibits very good deoxidizing ability. Increasing amounts of Si will increase the strength of the weld, with only a small decrease in the ductility and toughness. However, above **1.0-1.2% Si**, the weld metal may become crack sensitive.

Manganese (Mn): Manganese is also a commonly used as **deoxidizer and strengthener** and constitutes **1.0%-2.0%** of mild steel wires. Increasing amounts of Mn, increases the **weld metal strength** to a greater degree from Si, and will also reduce the hot crack sensitivity of the weld metal.

Aluminum (Al), Titanium (Ti) and Zirconium (Zr): These elements are very strong deoxidizers. Very small **additions** of these elements are sometimes made, usually not more than **0.20%** combined. In this range, some increase in strength is also achieved.

Carbon (C): Carbon influences the structural and **mechanical properties** deeper than any other element, usually between **0.05% to 0.12%**, sufficient to provide the necessary weld metal strength without affecting ductility, toughness, and porosity. Increasing carbon content in both wire and plate has an effect on porosity, particularly **when welding with CO_2 shielding gas**.

When the **carbon content** of the wire electrode and the workpiece exceeds **0.12%,** the weld metal loses carbon in the form of CO. This can cause porosity, but additional deoxidizers help to overcome this.

Nickel, Chromium and Molybdenum: Are often added in small amounts, to improve mechanical and/or corrosion resistance properties in carbon steels and in larger amounts in stainless steel wires. When welding is done with **Ar-O 1% to 3%** or with mixtures of Argon containing **low CO_2** content, the chemical composition will not vary greatly from the analysis of the wire electrode.

However, when **only CO_2** is used, reductions in Si, Mn and other deoxidizing elements can be expected, but Ni, Cr, Mo and C contents will remain almost constant. Using also only CO_2, wires with very low carbon contents (0.04-0.06%) will produce higher carbon content.

CARBON STEEL ELECTRODES:

The welding current, weld puddle size, amount of rust, mill scale and oil found on the base plate surface, or **O_2 and CO_2** content of shielding gases, increases the Mn and Si of the wire electrode and provide the highest quality weld. The following is a description of the characteristics and intended use of the most common wire electrodes of each classification appearing in Table 1-6.

ER70S-2: This wire is heavily deoxidized and is designed for producing sound welds in all grades of carbon steel: killed, semi-killed and rimmed. Because of the added deoxidants (Al, Zr and Ti) in addition to Mn and Si, it is suited for **welding carbon steels** having a rusty surface. Ar-O_2, Ar-CO_2 and CO_2 shielding gases can be used.

ER70S-3: Are one of the most widely used for a variety of applications, and can be used with pure CO2, mix of Ar-O_2 or Ar-CO_2 to produce sound welds in killed and semi-killed steels. Rimmed steels should be welded with only Ar-O, or Ar-CO_2 to produce medium quality welds. In a multipass weld, the tensile strength will range between **65,000 and 85,000 psi**, depending on the base metal dilution and shielding gas. This wire has its application on automobiles, farm implements and home appliances.

ER70S-4: Contain higher levels of manganese and silicon than E70S-3 and this improves the soundness on semi-killed or rimmed steels and increases the weld metal strength. It performs well with Ar-O_2, Ar-CO_2 and CO_2 shielding gases using either the spray arc or short arc processes. Structural steels such as **A7, A36**, common ship steels, **piping and boiler and pressure vessel steels A515 Grade 55 to 70** are usually welded with this wire. Weld **beads are flatter and wider** than those made with ER70S-2 and ER70S-3, using identical shielding gases and welding conditions.

ER70S-5: Additions of silicon and manganese also contain aluminum as a deoxidizer and due the high **Al** content, can be used for welding **killed, semi-killed and rimmed steel** using CO_2 shielding gas and high welding currents. Ar-O_2 and Ar-CO_2 may also be used; however, **short-circuiting type** transfer should **be avoided** because of the excessive puddle viscosity. Welding is restricted to the **flat position** only.

ER70S-6: Contain high silicon and manganese content as deoxidizers, with good weld quality for welding **carbon steels,** using CO_2 shielding and high welding currents. May be used with **Ar-O_2** mixtures containing **5% or more O_2** for high-speed welding. **Contains no aluminum**, then, the short-arc technique with CO_2 or Ar-CO_2 can also be used. The weld puddle is fluid, similar to those with ER70S-4.

ER70S-7: This is a **high performance** wire designed for use where superior weld quality and optimum appearance are desired. With higher manganese/silicon ratios than ER70S-3 and ER70S-6 wires, provides superior edge wetting and bead shape over a wide range of welding parameters with a variety of shielding gases. The extra deoxidizing capability of this wire helps to minimize the occurrence of porosity defects when welding over mill scale or light rust.

ER8OS-D2: Contain silicon and manganese as deoxidants, as well as, molybdenum for increased strength may be used for all position welding with Ar-CO_2 and CO_2 shielding gases, as well as, Ar-O_2 for the flat position. This wire can be used for welding **low alloy steels** as **AISI 4130** and high-yield strength steels as T-1, Naxtra and SSS-100, where the ultimate in mechanical properties is not necessary.

STAINLESS STEEL ELECTRODES:

Choosing the appropriate wire for stainless steel welding, there are generally fewer factors to consider. Unlike carbon and steel wires, there are no mechanical property requirements for the resulting weld metal. Some of the most commonly used wire classifications and their intended uses are as follows:

1) Shielding gases are **limited to Ar - 1%O_2** for spray arc or A-1025 (7.5Ar-90He-2.5CO_2) for short arc.
2) Wires are for the most part chosen to match the chemistry of the base material.
3) Deoxidizer levels are not of great importance.

ER308L: Used for welding **304 stainless steel**. The chromium and nickel contents are identical. The lower carbon content reduces any possibility of carbide precipitation and the inter-granular corrosion that can occur. **Carbon** content is less than **0.04%.**

ER308LSi: Similar chemistry as **ER308L**. However, a higher silicon level improves the wetting characteristics of the weld metal, particularly when **Ar - 1% O_2** shielding gas is used. If the dilution of the base plate is extensive, high silicon content can cause greater crack sensitivity than a low silicon content. This results from the weld being fully austenitic or a low ferrite.

ER309L: Used to weld **309 stainless steel,** when severe corrosion conditions is encountered, but can also be used to weld **type 304** stainless steels, or as well, joining **carbon mild steel to type 304**.

ER316L: Used to weld type **316 stainless steel**. The addition of molybdenum makes this wire electrode applicable for high service where creep resistance is desired. **Carbon** content is less than **0.04%.**

ER316LHSi: This wire, due to its lower carbon content, will be less susceptible to intergranular corrosion caused by carbide precipitation when **used in place of ER316L**. Again, the higher silicon level (Si type) will improve the wetting, but may increase crack sensitivity if dilution of the base material is extensive.

ER347: This wire is much less subject to intergranular corrosion from carbide precipitation, as tantalum and/or columbium are added to act as stabilizers. It is used for welding base materials **with similar chemistry** and where **high temperature** strength is required.

The Table 1-6, below, lists the chemical requirements and designations for all stain less steel wires covered by the American Welding Society Specification A5.9:

Table 1-6 - Stainless Steel Wire Electrodes

AWS CLASS	ESAB DESIG-NATION	CARBON	CHROM.	NICKEL	MOLYB.	COLU. + TANT.	MANGA-NESE	SILICON	PHOS.	SULF.
ER308	308	0.08	19.5-22.0	9.0-11.0			1.0-2.5	0.25-0.60	0.03	0.03
ER308L	308L	0.03	19.5-22.0	9.0-1 1.0			1.0-2.5	0.25-0.60	0.03	0.03
ER309	309	0.12	23.0-25.0	12.0-14.0			1.0-2.5	0.25-0.60	0.03	0.03
ER330	310	0.08-0.15	25.0-28.0	20.0-22.5			1.0-2.5	0.25-0.60	0.03	0.03
ER312	312	0.15	28.0-32.0	8.0-3 0.5			1.0-2.5	0.25-0.60	0.03	0.03
ER316	316	0.08	18.0-20.0	11.0-14.0	2.0-3.0		1.0-2.5	0.25-0.60	0.03	0.03
ER316L	316L	0.03	1 8.0-20.0	11.0-3 4.0	2.0-3.0		1.0-2.5	0.25-0.60	0.03	0.03
ER317		0.08	1 8.5-20.5	13.0-15.0	3.0-4.0		1.0-2.5	0.25-0.60	0.03	0.03
ER318		0.08	18.0-20.0	11.0-14.0	2.0-3.0	8XC-1.0	1.0-2.5	0.25-0.60	0.03	0.03
ER320		0.07	19.0-21.0	32.0-36.0	2.0-3.0	8XC-1.0	2.5	0.6	0.04	0.03
ER347	347	0.08	19.0-21.5	9.0-1 1.0		10XC-1.0	1.0-2.5	0.25-0.60	0.03	0.03

*AWS A5.9

NON-FERROUS WIRE ELECTRODES:

Aluminum alloy wire electrodes are **magnesium, manganese, zinc, silicon and copper** and contain additions of several alloying elements to improve weld properties, to weld any given type of aluminum. The most popular are the magnesium and the silicon. The **Table 1-7** lists the chemical requirements and designations for all aluminum wires covered by the American Welding Society Specification A5.10.

Copper & Copper Alloy Electrodes: The alloying elements generally decrease the conductivity of pure copper, necessary to increase strength, deoxidize the weld metal and match the base metal. The **Tables 1-8 and 1-9** present the various copper-base wire electrodes and the required tensile strengths. The choice **is not dependent on shielding gas**, **as only argon and helium are recommended**. The various wire electrodes are as follows:

ERCu: The low alloy content, ERCu wires are restricted to welding of **pure copper**. Deoxidized and oxygen-free copper can be soundly welded with good strength. However, **electrolytic tough pitch copper should not be welded** with an ERCu electrode, if quality is required.

ERCuSi-A: Primarily used to join **copper-silicon alloys**, as chemistry match is adequate, but can be used to weld **copper-zinc alloys**. Due the high silicon level and the resulting deoxidation, **electrolytic tough pitch copper** can be adequately welded and superior welds are made with these electrodes. Thus, **welding of galvanized steel plates,** can be successfully accomplished.

ERCuSn-A: Primarily used for **welding phosphor bronzes**, but can be used to **weld cast iron and mild steel**, and because of the deoxidizing ability of the phosphorus, can be used on electrolytic tough pitch. However, ERCuSnA wires do not yield a fluid weld puddle so, **preheating** may be necessary. **Copper-zinc** alloys **can also be welded**.

ERCuSn-C: Replaces ERCuSn-A where greater hardness, tensile strength and yield strength are required. **Post weld heat treating** is necessary and on copper-zinc alloys and a better weld is achieved.

ERCuA1-A2: Can be used to weld a variety of **copper alloys and ferrous metals**, and the higher **aluminum content and iron** additions result in a weld stronger and harder than ERCuA1-A1. Materials welded with this wire are aluminum bronzes (alloys 612, 613, and 618), as well as, yellow brasses, high-strength copper-zinc, silicon, bronze, carbon steel, copper alloys, clad steels and aluminum castings (alloys 952 and 958). This can also be used for wear and corrosion-resistant surfacing.

Table 1-7 - Aluminum Wires - Chemical Composition

AWS CLASS	ESAB DESIG-NATION	MAGN.	IRON& SILICON	IRON	SILICON	COPPER	MANG.	CHROM.	ZINC	NICK.	TITAN.
ER1100	1100 HQ(1)	--	1.0	--	--	0.05-0.20	0.05	--	0.10	--	--
ER1260	--	--	0.40	--	--	0.04	0.01	--	--	--	--
ER2319	--	0.02	--	0.30	0.20	5.8-6.8	0.20-0.40	--	0.10	--	0.10-0.20
ER4145	--	0.15	--	0.80	9.3-10.7	3.3-4.7	0.15	0.15	0.20	--	--
ER4043	4043 HQ (1)	0.05	--	0.80	4.5-6.0	0.30	0.05	--	0.10	--	0.20
ER4047	--	0.10	--	0.80	11.0-13.0	0.30	0.15	--	0.20	--	--
ER5039	--	3.3-4.3	--	0.40	0.10	0.03	0.30-0.50	0.10-0.20	2.4-3.2	--	0.10
ER5554	5554 HQ (1)	2.4--3.0	0.40	--	--	0.10	0.50-1.0	0.05-0.20	0.25	--	0.05-0.20
ER5654	5654 HQ (1)	3.1-3.9	0.45	--	--	0.05	0.01	0.15-0.35	0.20	--	0.05-0.15
ER5356	5356 HQ (1)	4.5-5.5	0.50	--	--	0.10	0.05-0.20	0.05-0.20	0.10	--	0.06-0.20
ER5556	5556 HQ (1)	4.7-5.5	0.40	--	--	0.10	0.50-1.0	0.05-0.20	0.25	--	0.05-0.20
ER5183	5183 HQ (1)	4.3-5.2	--	0.40	0.40	0.10	0.50-1.0	0.05-0.25	0.25	--	0.15
R-CN4A	--	0.03	--	1.0	1.5	4.0-5.0	0.35	--	0.35	--	0.25
R-CN42A	--	1.2-1.8	--	1.0	0.70	3.5-4.5	0.35	0.25	0.35	1.7-2.3	0.25
R-SC51A	--	0.40-0.60	--	0.80	4.5-5.5	1.0-1.5	0.5	0.25	0.35	--	0.25
R-SG70A	--	0.20-0.40	--	0.60	6.5-7.5	0.25	0.35	--	0.35	--	0.25

*AWS A5. 10-69

(1) HQ is ESAB's designation for shaved wire.

Table 1-8 - Copper & Silicon Bronze

MATERIAL	THICKNESS IN.	(mm)	JOINT DESIGN	FILLER METAL DIA. IN	(mm)	SHIELD. GAS	CURRENT	TRAVEL SPEED IPM	mm/sec.	NO. OF PASSES
COPPER	UP TO 3/16	(4.8)	SQUARE BUTT	0.045	(1.1)	ARGON	180-250	14-20	6-8	1-2
COPPER	1/4	(6.4)	75°-90° BEVEL 1/16-3/32 NOSE (1.6-2.4mm)	1/16	(1.6)	HE-75	250-325	10-18	4-8	1-2
COPPER	3/8	(9.6)	75°-90° BEVEL 1/16-3/32 NOSE (1.6-2.4mm)	1/16	(1.6)	HE-75	300-325	6-12	3-5	1-3
COPPER	1/2	(12.8)	75°-90° DB BEVEL 3/32 NOSE (2.4mm) 3/32-1/8 GAP (2.4-3.2mm)	1/16	(1.6)	HE-75	330-400	8-14	4-6	2-4
SILICON-BRONZE	1/4	(6.4)	SQUARE BUTT 1/16 (1.6mm) GAP 60° BEVEL	1/16	(1.6)	ARGON	300	15	6	1

FLUX-CORED CARBON STEEL ELECTRODES:

Selection of a Flux-Cored Wire for **welding carbon steels** is usually based on the operating characteristics and mechanical properties of the weldment. Summarized below are the operating characteristics to be fo- und in flux cored wires belonging to various AWS A5.20 classifications.

E70T-1: This wire is formulated with a **rutile base slag system** which yields a smooth arc, low spatter and a light, easy peeling slag, capable of making **flat fillet welds** with equal legs in the horizontal position. These wires contain moderate amounts of deoxidizers making it usable in multi-pass welding.

E70T-1/T-9 – DOWNHAND: Formulated for optimum performance on **heavier rust and mill scale**, contains high amounts of deoxidizers, characterized by low smoke, high deposition **efficiencies 88%**, and fluid slag. The puddle is fluid, so, this wire tends to produce convex horizontal fillets that make clean-up minimal.

E70T-2 - SINGLE PASS – Contains high amounts of deoxidizers to tolerate substantial rust and mill scale. Thus, their multiple pass strengths typically **exceed 100 ksi** and perform very well at high travel speeds, but **not recommended** for **multi-pass** use.

E71T-1M/T-9M - ALL POSITION: Formulated with a fast freezing slag to support the molten weld puddle out of position. At low **(140-200 amps)**, may exhibit good gap bridging characteristics. At high amps **(200-250 amps)**, may exhibit deep root penetration, higher deposition rates and low fume generation.

E81T1-Ni2 - HIGH TOUGHNESS – ALL POSITION: These wires contain 2.0-3.0% nickel, operate essentially the same as the E71T-1 all position wires. This addition yields good toughness of at 30-50 ft.lbs, depending on shielding gas and cooling rates, minimum 70 ksi UTS after stress relief, useful **for pressure vessels** fabrication. This wire also meets **AWS D.1.1 E8018-C1** chemical requirements for welding **A242 and A588** weathering steels.

WELDING PARAMETERS AND TECHNIQUES:

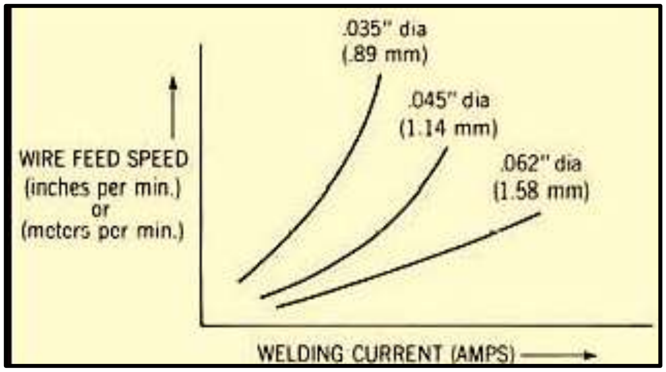
After selecting the wire and gas, operating conditions must also be chosen. The four important parameters are the **welding current, wire electrode extension, welding voltage and arc travel speed**. Because these factors can be varied over large range, are considered the primary adjustments in any welding operation and values should be recorded for every different type of weld to permit reproducibility.

Welding Current: is the electrical amperage in the power system as the weld is being made, usually read from the power source meter, but a separate ammeter is often used. In the GMAW process, the welding current is directly related to **wire-feed speed** (if the wire extension beyond the guide tip is constant). In other words, an increase (or decrease) in the wire-feed speed will cause an increase (or decrease) of the current. This relationship is commonly called the "**burn-off'** characteristic.

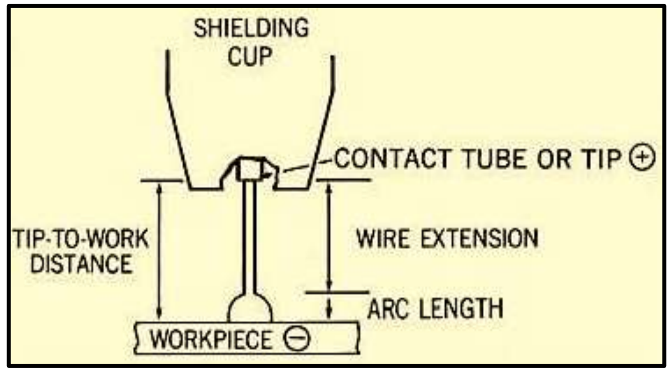
Each type of wire (steel, aluminum, etc.) has a different burn-off characteristic. In other words, for every addition to the current, there is a proportional (and constant) increase in the melt off. However, at higher welding currents, particularly with small diameter wires, the burn-off curve becomes non-linear, due to resistance heating of the wire extension beyond the guide tube. This resistance heating is known at **PR**

heat where **I** = welding current and **R** =resistance. The greater is the welding current, the greater the PR heating.

Wire Electrode Extension: Or “stick-out” is the **distance** between the last point of electrical contact (usually the end of the contact tip), and the end of the wire electrode. It is in this area that **PR heating** effect occurs. The contact tip-to-work distance, because of its effect on the wire extension, affects the welding current required to melt the wire at a given feed speed. Basically, as the tip-to-work distance is increased, the amount of **I^2R heating** increases and the welding current required to melt the wire is decreased.



Burn-Off Characteristics



Tip-to-Work Distance

The control of **tip-to-work distance** is very important, as the tip-to-work distance increases, the arc becomes less stable. Long extensions result in excess of weld metal being deposited. Using a low arc heat, causes poor bead shape and low penetration. For **solid wires** and short arc welding, the **tip-to-work distance** recommended is **3/8 in**. **(10 mm)**. For **flux-cored wires** (0.045 in. or 1.2 mm), the recommended tip-to-work is **3/4" to 1” (19-25 mm).** Using larger diameter cored wires, the recommended tip-to-work is **1" - 1 1/4" (25-32 mm)**.

It is recommended, not to use too long tip-to-work or to extend the arc beyond the point of complete gas coverage, because this could result in **weld porosity** and in an **unstable arc**. It is very important that the wire extension be kept as constant as possible during the welding operation. In view of the substantial effect on the welding operation, it is always wise to record not only current and voltage, but also the wire-feed speed.

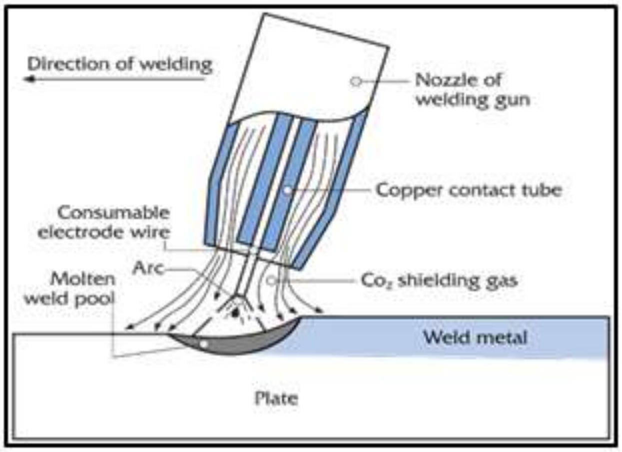
Arc Travel Speed: Is the linear rate that the arc moves along the workpiece. This parameter is usually expressed as inches or meters per minute. The main considerations for GMAW arc travel speed are:

1) As the material thickness increases, the travel speed must be lowered.
2) For a given material and joint design, as the welding current is increased, so is the arc travel speed.
3) Higher welding speeds are attainable by using the forehand welding technique.

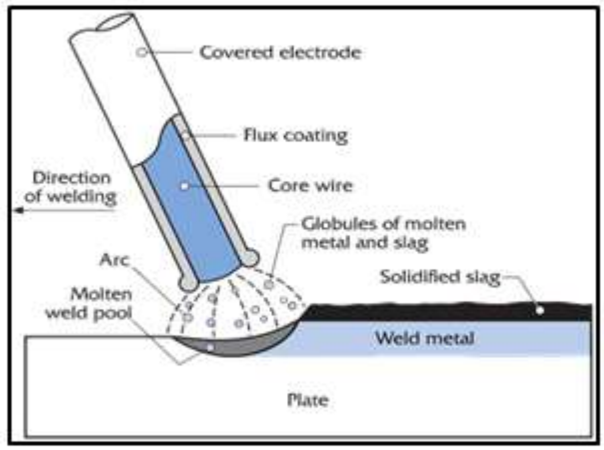
The basic technique for GMAW is quite simple, since the electrode is fed automatically through the torch (head of tip). By contrast, in Gas Tungsten Arc Welding (TIG), the welder must handle a welding torch in one hand and a separate filler wire in the other, and in Shielded Metal Arc Welding (SMAW), the operator must frequently chip off slag and change the welding electrodes. GMAW requires only that the operator guide the welding gun with proper position and orientation along the area being welded.

Keeping a consistent contact tip-to-work distance (the *stick out* distance) is important, because a long stick out distance can cause the electrode to overheat and also wastes shielding gas. Stick out distance varies for different GMAW weld processes and applications. The orientation of the gun is also important - it should be held so as to bisect the angle between the workpieces; that is, at **45°** for a **fillet weld** and **90°** for welding a **flat surface**.

The travel angle, or lead angle, is the angle of the torch with respect to the direction of travel, and it should generally remain approximately vertical. However, the **desirable angle changes** somewhat depending on the type of shielding gas used—with pure inert gases; the bottom of the torch is often slightly in front of the upper section, while the opposite is true when the welding atmosphere is carbon dioxide.



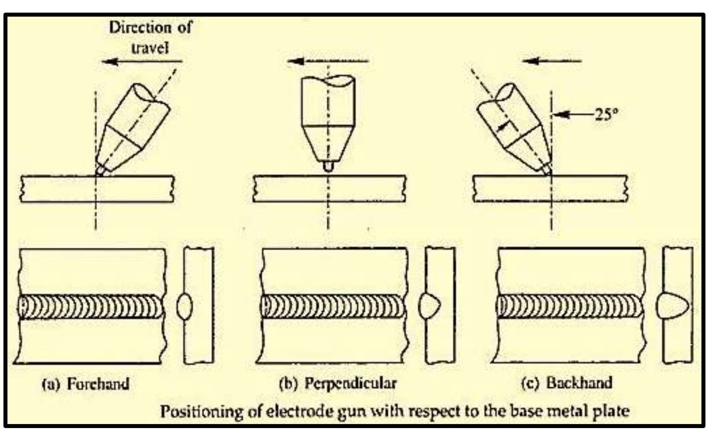
GMAW Wire Electrode



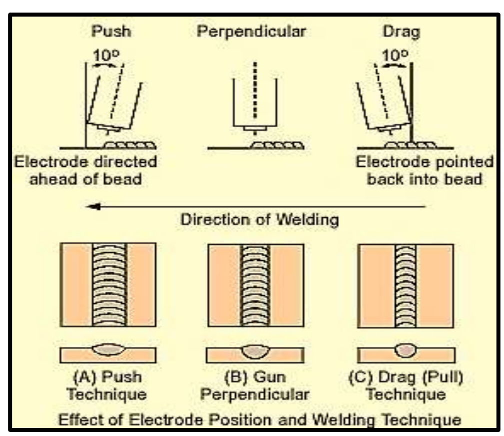
SMAW Covered Electrode

Backhand Method: Means the torch is positioned so that the wire is feeding **opposite to the direction of arc** travel and the filler metal is being fed into the weld metal previously deposited. The angle relative to the plate for the **fillet weld** is usually 45°. However, for a **beveled butt joint**, this angle may only be a few degrees from the **vertical** to allow for proper wetting of the weld metal to the side wall.

Forehand Method: Means the torch is angled so that the electrode wire is fed in the same direction as arc travel. Now the filler metal is being deposited, for the most part, directly on the workpiece. It should be noted that a change in welding direction is not required to facilitate forehand or backhand welding, only a reversal in the longitudinal torch positioning. Generally, the backhand technique yields a more stable arc and fewer spatters on the workpiece.



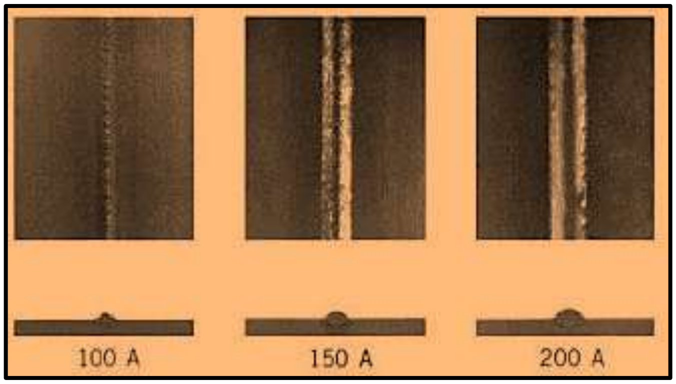
Positioning of electrode gun with respect to the base metal plate



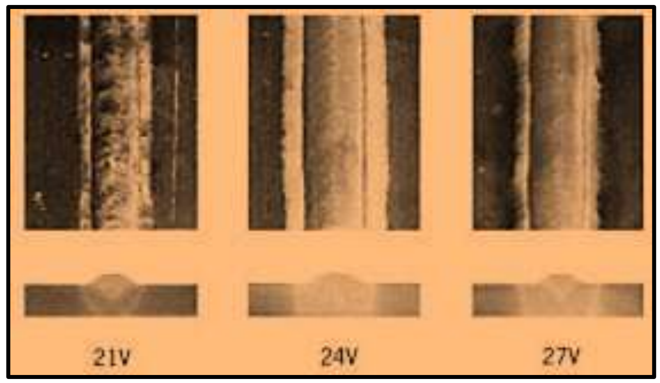
Effect of Electrode Position and Welding Technique

Weld Bead Characteristics: Weld penetration is the distance that the fusion line extends below the surface of the material being welded. Welding **current** is of primary importance to penetration. An increase or decrease in the current will increase or decrease the weld penetration respectively. Effects of arc travel speeds are similar to the welding voltage. With lower speeds, too much metal is deposited, and the molten weld tends to roll in front of the arc and "cushions" the base plate. This prevents further penetration.

The **forehand** welding technique causes **shallower** penetration than the backhand technique. Better weld penetration is achieved with a torch **angle of 25°** in the **backhand** welding technique. However, beyond this degree of torch angle, arc instability and spatter may increase. For very **thin** materials or where low penetration is required, a **forehand** technique is generally used.



Effect of Welding Current on Weld Penetration



Carbon Steel-Short Arc C-25 Shielding

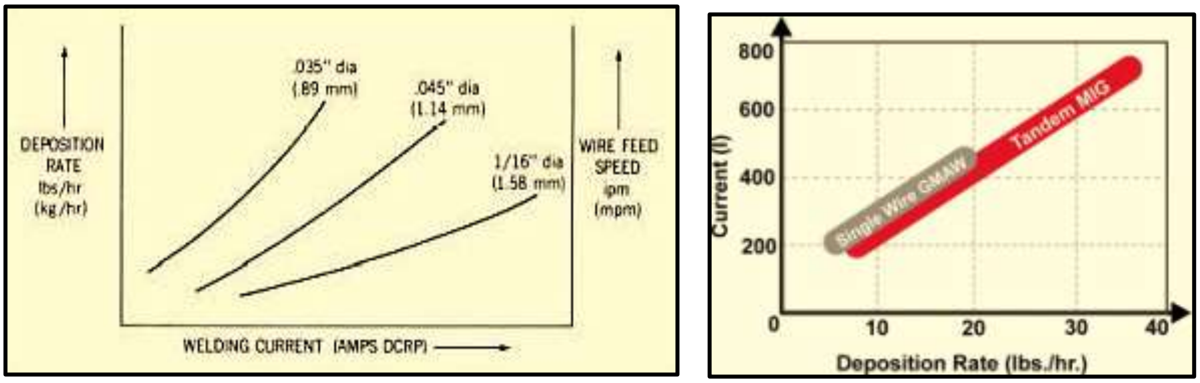
Deposition Rate: The deposition rate describes **how much** usable weld metal will be **deposited in one hour of actual arc**, on time. Because the GMAW process is very efficient, only a very small amount of weld metal is lost as spatter. The deposition rate for any wire is calculated by the equations:

$$\textbf{Deposition rate} = \frac{\text{wire feed speed (in./min.) x 60 min./hr}}{\text{inches of wire per lb.}} \quad \textbf{(lb/h)}$$

$$\textbf{Deposition rate} = \frac{\text{wire feed speed (m./min.) x 60 min./hr}}{\text{meters of wire per kg.}} \quad \textbf{(kg/h)}$$

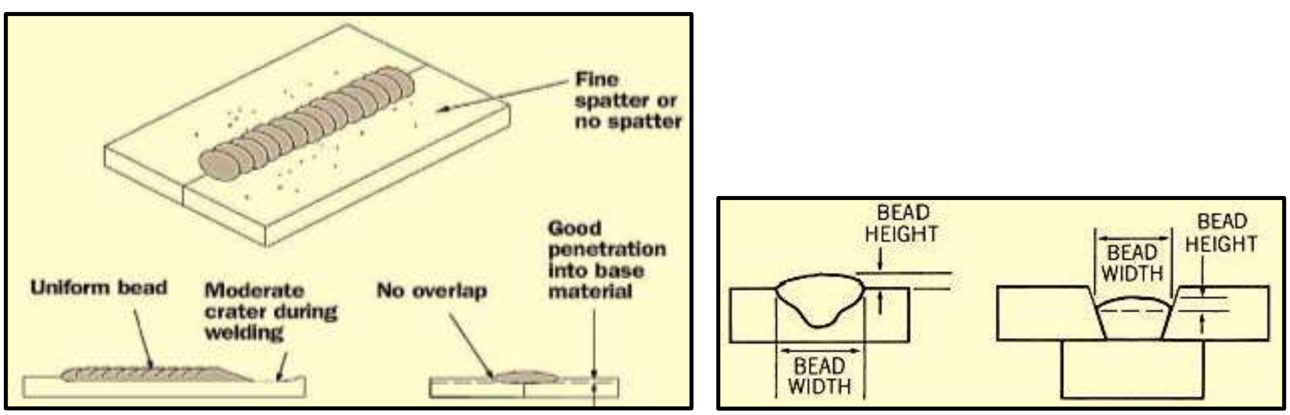
MATERIAL \ WIRE DIAMETER	.030 IN (.76 mm)	.035 IN (.89mm)	.045 IN (1.14 mm)	3/64 IN (1.18 mm)	1/16IN (1.58 mm)	3/32 IN (2.38 mm)
MILD STEEL	4956 IN (276.9)	3648 IN (203.9)	2196 IN (122.7)	–	1152 IN (64.4)	516 IN (28.8)
STA I N LESS STE EL (3XX SERIES)	4872 (272.2)	3588 (200.5)	2160 (120.7)	–	1140 (63.7)	504 (28.2)
ALUMINUM	14412 (805.3)	10596 (592.1)	–	6408 (358.1)	3372 (188.4)	1500 (83.8)
COPP ER	4356 (243.4)	3192 (1 78.4)	1932 (108.0)	– –	1020 (57.0)	432 (24.1)
SI L I CON BRONZE	4596 (256.8)	3372 (188.4)	2040 (114.0)	– –	1068 (59.7)	480 (26.8)

The graphs below gives the deposition rates in **lb/h (m/kg)** for various wire electrodes in a variety of sizes. The current can also be varied by changing the tip-to-work distance. Usually the forehand welding technique is employed. Increasing the deposition rate in this manner will also have an effect on weld penetration. When more metal is being deposited at a given welding current, the penetration will be reduced, resulting a “cushioning” of the arc force by the extra weld metal deposited.



Deposition Rate vs. Welding Current

Weld Bead Appearance: Two characteristics of the weld bead are the **bead height and width**, as shown below. These characteristics are important to assure that the weld joint is properly filled, with a minimum of defects, particularly in multi-pass weldments. When the bead height is too great, it becomes very difficult to make subsequent weld passes that will have good fusion. In order to change weld bead size, the lbs. (kg) of weld metal deposited per linear foot (m) of the weldment must be changed. Welding current and travel speed are the welding parameters primarily used to control weld bead size.



Weld Bead Characteristics

Thus, as the arc voltage (arc length) increases, the bead height decreases and bead width increases. Increasing the bead width, the bead height becomes **flatter** and the weld metal is said to be **“wet”,** that is, the base material is welded more efficiently. Wire extension and the welding technique employed (backhand or forehand welding) also affects these characteristics. When long extensions are used to increase deposition rates, bead height will increase to a greater extent than bead width.

Although larger, the **weld bead** becomes more peaked, as shown above, the backhand welding technique also produces a high, narrow weld bead. Decreasing the lagging torch angle also decreases the bead height and increases the width. Then, the forehand technique yields the flattest, widest weld bead.

Welding Wire/Method Recommendations

Wire Type	Considerations
Solid Carbon-Steel ER70S-6	May be used with CO2 or 75% Argon/25% CO2 (C-25), SteelMIX®, SteelMIX® 3 or SteelMIX® Extra
	CO2 gas provides deeper penetration
	75% Argon/25% CO2 has less spatter than CO2. SteelMIX(s) have less than either
	Indoor use with no wind
	For auto body, manufacturing, fabrication
	Welds thinner materials (22 gauge) than flux cored wires
Flux Cored/ Carbon-Steel E71T-GS	No shielding gas required
	Excellent for outdoor windy conditions
	For dirty, rusty, painted materials
	Hotter than solid wires, welds to 18 gauge materials and thicker
Solid Aluminum ER-4043 ER-5356	Must be used with Argon, AluMIX™, or other Argon/ Helium mixes
	Recommended to be used with spool guns for best results
	5356 is harder for stronger welds and easier feeding
Solid Stainless Steel ER308/308L	Use with StainMIX™ 3 or Helium/Argon/CO2 mixtures
	For 301, 302, 304, 305 and 308 stainless base metals

WFS Range Relationships For Short Circuit Transfer on Steel

Wire Size	Amperage Range	Wire Feed Speed Range
.023"	30-90	100-400
.030"	40-145	90-340
.035"	50-180	80-380
.045"	75-250	70-270

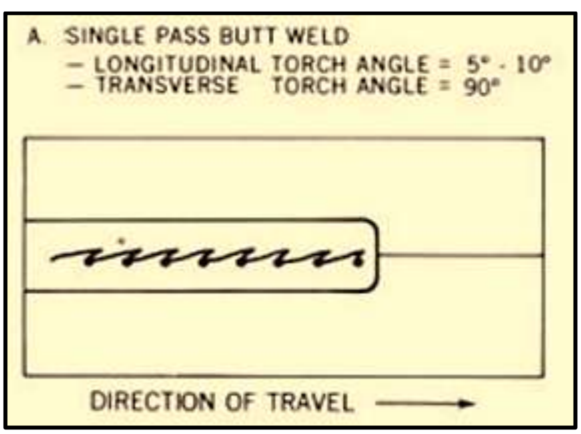
Rule of Thumb Metal Thickness - Amperage Needed

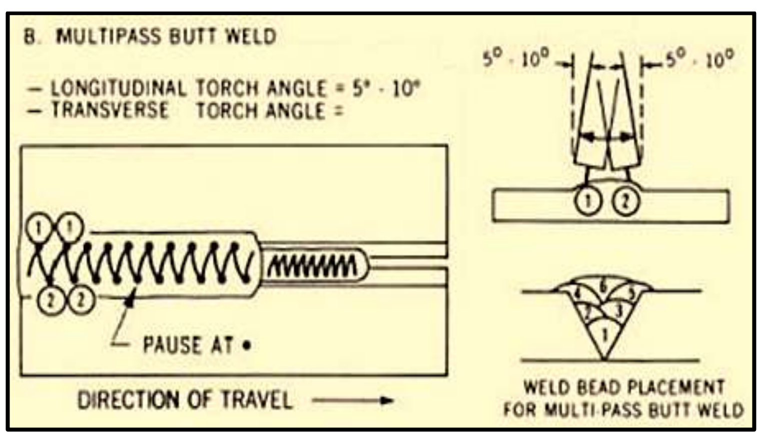
Gauge Number	Nearest Fraction Of An Inch	Rule Of Thumb Amperage
18	3/64" = .047	47
16	1/16" = .062	62
14	5/64" = .078	78
12	1/10" = .100	100
10	1/8" = .125	125
8	5/32" = .156	156
6	3/16" = .187	187

WELDING POSITIONS:

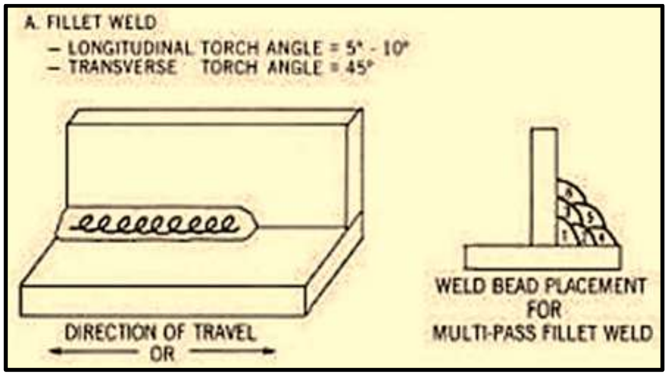
No discussion of welding techniques would be complete without some reference to the methods of torch manipulation. The best practices only serve as a guide to be used during welder training. As individual wel-ders become more proficient with the GMAW process, they will adapt their torch manipulations to best suit the job at hand.

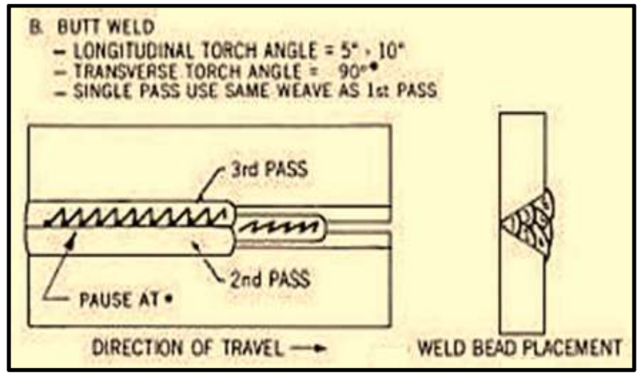
Flat Position: For the single-pass, butted joint, a slight back-stepping motion is used. Gapped root pass-es are made with a small, back-and-forth weave pattern. For fill and cover passes, the same weave, with an adjustment for the desired width, is used, with care taken to pause at the sidewalls to obtain adequate fill in these areas.



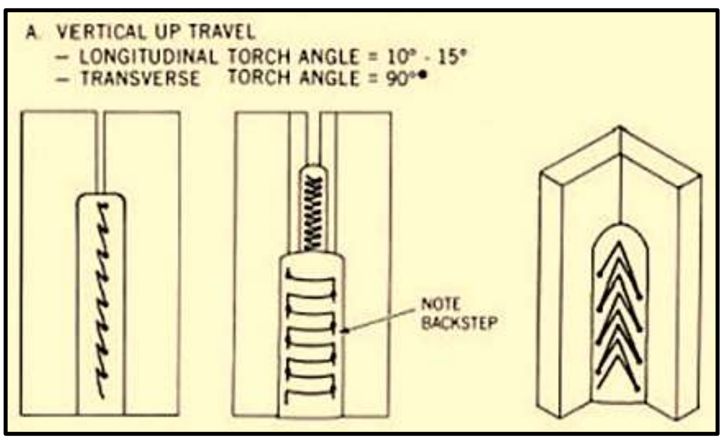


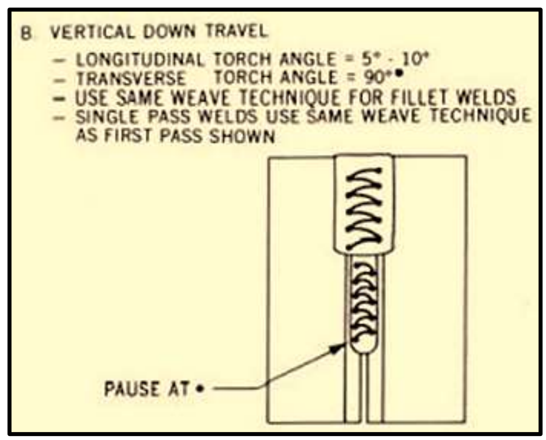
Horizontal Position: Recommended weaving patterns, torch positions and bead sequences are shown in Figure 7-16. For fillet welds, a circular motion is recommended. For butt weld root passes and fill passes, an in-line, back-and-forth motion is used with width adjustments as required. A slight pause is used at the tie-in to the previous bead.



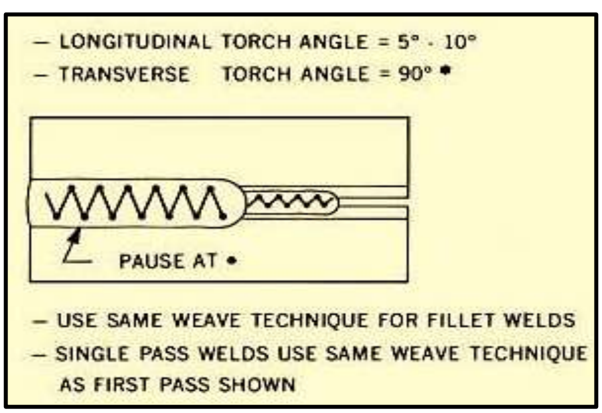


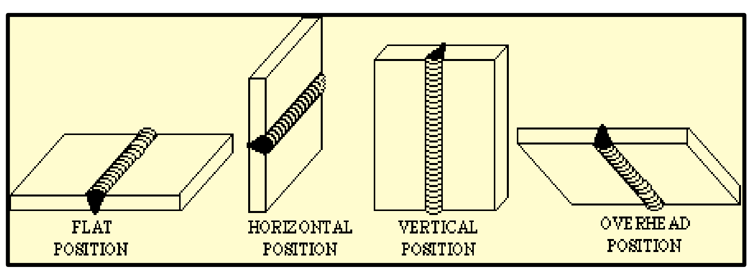
Vertical Position: For **vertical up**, for a square edge preparation an in-line, back-and-forth weave is used. For a beveled, multipass joint a "U" pattern is used for the root. The fill and cover passes are made using a side-to-side weave with a back step at the walls. For a vertical up fillet a "Christmas Tree" pattern is used with pauses at the side walls. For **vertical down** an inverted "U" pattern is used, pausing at the side walls for the root, fill, and overpasses keeping the arc on the leading edge of the puddle, to improve welding soundness.





Overhead Position: Again, a back-and-forth weave is used with pauses at the plate sidewalls. This applies to root, fill, and cover passes. Below is also shown the main welding positions.





GMAW - BEST PRACTICES:

This section covers more specifically welding of **low-carbon steels**, **stainless steels**, **aluminum** alloys and **copper** alloys. To obtain the optimum welding conditions which best satisfy the particular requirements of a new application and a good stable welding, should be used all recommended methods reported before. When changes to welding conditions are required, should be carefully made. Then, there are several important points:

1. The arc voltage is read between the last point of electrical contact in the torch (usually the guide tube) and the workpiece. It is not the voltage shown on the power source meter, which is generally 1.5 to 2.5 volts or higher depending on the size and length of power cable.
2. The weld size equals the material thickness in the case of fillet welds.
3. The tables below are based on a tip-to-work distance of 3/8 in. (9.4mm) for short arc welding and 3/4 in. (19.2mm) for spray arc welding.
4. Vertical welding conditions are designed for vertical up travel.
5. If the shielding gases in tables are different, slight adjustments of these conditions will be necessary, then, a burn-off chart for each wire should be presented. Using these graphs, the wire-feed speed for any given current value may be approximated.

Weld Quality Assurance: Two of the most prevalent quality problems in GMAW are dross and porosity. Dross is a common problem in aluminum welds, normally coming from particles of aluminum oxide or aluminum nitride, present in the electrode or base materials. To reduce dross and porosity, electrodes and workpieces **must be brushed** with a wire brush or chemically treated to **remove oxides** on the surface.

In GMAW the **primary cause** of porosity is gas entrapment in the weld pool, which occurs when the metal solidifies before the gas escapes. The gas can come from **impurities** in the shielding gas, as well as, from an excessively long or violent arc. Oxygen in contact with the weld pool, either from the atmosphere or the shielding gas, causes dross, as well. As a result, sufficient flow of inert shielding gases is necessary, and welding in wind should be avoided.

Due higher thermal conductivity, **aluminum welds** are especially susceptible to greater cooling rates and thus, porosity. The welding speed and the current must be high enough to provide sufficient heat and stable metal transfer, but low enough to arc remains steady. Preheating can also help reduce the cooling rate, by reducing the temperature gradient between the weld area and the base material. Thus, a few basic precautions must be taken, to avoid porosity and lack-of-fusion defects:

1. The material to be welded should be as clean as possible. All grease, oil, lubricants, all scale, rust and other oxides should be either mechanically or chemically removed. This is of extreme importance when welding aluminum.
2. When welding carbon steel plate, use only the shielding gas-wire combinations recommended for the specific variety of steel in use, killed, semi-killed, or rimmed.
3. Avoid welding conditions which result in the weld bead solidifying very rapidly, as very high travel speeds and trapped gases, which can cause porosity.
4. Maintain an adequate shielding gas flow and protect the welding area from wind and drafts.
5. Keep the welding wire centered in the shielding gas pattern, since wire twisting is usually responsible for the wire being off center, by using a wire straightening device on the wire feeder.

6. When welding both sides of a plate, where there has been no penetration of the first weld entirely, be sure that the second pass deeply penetrates the first.
7. When the first pass has entirely penetrated, or where a root gap is used, it is a good practice to grind the back side to sound weld metal before the second weld is made. This is mandatory when welding aluminum and copper and where x-ray quality welds are required in carbon and stainless steel.
8. Avoid welding conditions which allow the molten weld metal to roll out in front of the arc. This is the main cause for lack-of-fusion defects, in particular, downhill welding.
9. In multipass welding, grind to a flat surface all weld beads which appear to be peaked and exhibit poor wetting.
10. Remove the small patches of oxide slag found on the weld bead with a file or screwdriver, if another weld is to be made over it.

Joint Design: Plates **3/16 in., (4.8 mm)** thick or less may be butt welded with **square edges** using the short arc process or allow current spray arc (aluminum), with a root gap of **0 to 1/32 in. (0.8 mm)**. Plates **3/16 in., (4.8 mm) and 1/4 in. (6.4 mm**) thick may be **square butt welded** with the spray arc process with a 1/32 to 3/32 in. (0.8-2.4mm) root gap. In all cases, a single pass can be used if a permanent or temporary backup bar is used.

For the overhead position, it is usual practice to always butt weld using a **backup bar**. However, if a backup is not used for 1/8 in. (3.2 mm) thick plate and above, **two passes** are usually necessary, one from each side. A bead overlaps greater than the original root gap is desired to prevent centerline porosity and poor fusion.

Plates **1/4 in. (6.4 mm) thick and thicker**, generally require **single or double "V" grooves** with 45° to 70° included angles (depending on base material and thickness) to produce quality welds. A **1/16 in. (1.6 mm**) root face with a **1/32 in. (0.8 mm)** root opening is used. In single "V" grooves where no backup is used, a sealing pass from the back side will generally be required.

Low Carbon Mild Steel: Short arc welding should be used for welding **thin materials** in the flat position, bridging large gaps and all welding out-of-position. Either **CO_2 or Ar-CO_2** mixtures may be used. The conditions shown in Table 1-8 were developed using a **C-25 (75% Ar - 25% CO_2)** mixture. From the standpoint of arc stability, weld bead shape, minimal spatter and resulting mechanical properties of the weld, C-25 yields the best results for general short arc welding.

For **spray arc welding**, Ar-O_2 and Ar-CO_2 mixtures may be used. For the same reasons given above, the best mixture for this type of welding is 95% Ar - 5% O_2 (0-5) or C-8 since CO_2 will not produce a spray transfer, 95% Ar - 5% O_2 was used to develop the conditions found in Table 1-8 spray arc welding should be used in the flat position for single or multi-pass welding of thicker material.

When low currents are used, vertical welds can be made using a downhill arc travel. Either the **backhand or forehand** welding technique may be interchangeably used for welding in the flat position with no adjustments. The travel speeds associated with vertical down welding are much higher than vertical up.

Vertical down is usually preferred for welding thinner material **(up to 1/4 in. (6.4 mm)** thick, where speed is important and root passes in multi-pass welding. Vertical up welding is recommended for welding thicker materials, where quality and strength are required because of fewer tendencies to "cold lap.

Table 1-8 - Welding Conditions - Short Arc E70S-3

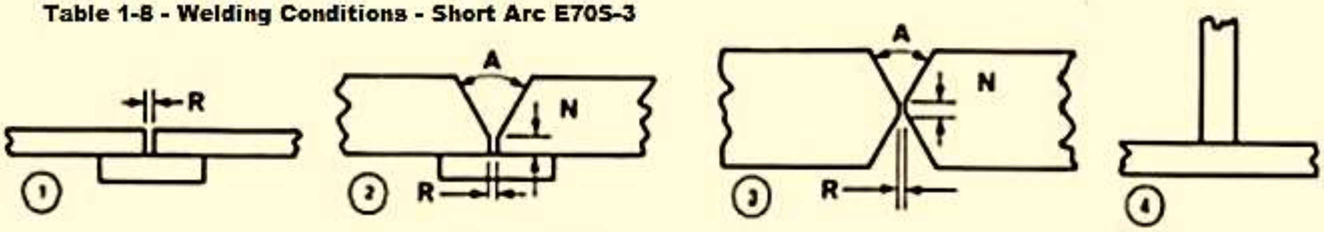


PLATE THICK. IN.	mm	WELD POSITION	JOINT DE-SIGN	(R) ROOT OPENING IN.	mm	(N) NOSE THICK. IN.	mm	FILLER METAL DIA. IN	mm	WIRE FEED SPEED IPM	mm/sec.	(4) VOLTAGE	AMPS DCRP	TRAVEL SPEED IPM	mm/sec	NO. OF PASSES
.025	.64	F,H,V^3,O	1 & 4	0				.030	(.76)	110-120	47-51	13-14	45-50	20-25	8-11	1
.037	.94	F,H,V^3,O	1 & 4	0				.030	(.76)	125-135	53-57	13-14	55-60	20-25	8-11	1
		F,H,V^3,O	1 & 4	0				.035	(.89)	110-120	47-51	15-16	70-75	30-35	13-15	1
		F	1	1/32	(.79)			.035	(.89)	180-190	76-80	16-17	110-115	25-30	11-13	1
		H	1	1/32	(.79)			.035	(.89)	170-180	72-76	16-17	105-110	25-30	11-13	1
.0625	1.6		4					.035	(.89)	180-190	76-80	16-17	110-115	23-28	10-12	1
		V^3,O	1	1/32	(.79)			.035	(.89)	140-150	59-63	15-16	85-90	13-18	5-8	1
			4					.035	(.89)	145-155	61-66	15-16	90-95	23-28	10-12	1
		F	1	1/32	(.79)			.035	(.89)	265-275	112-116	18-20	150-155	14-19	6-8	1
			1	1/32	(.79)			.045	(1.1)	150-160	63-68	18-19	160-165	15-20	6-8	1
		H	1	1/32	(.79)			.035	(.89)	220-230	93-97	17-18	120-125	13-18	5-8	1
.125	3.2		4					.035	(.89)	270-280	114-118	18-20	155-160	23-28	10-12	1
			4					.045	(1.1)	175-185	74-78	18-20	175-185	25-30	11-13	1
		V^3,O	1	1/32	(.79)			.035	(.89)	220-230	93-97	17-18	130-135	13-18	5-8	1
			4					.035	(.89)	220-230	93-97	17-19	130-135	18-23	8-10	1
		F	1	3/16	(4.8)			.045	(1.1)	220-230	93-97	19-20	210-215	15-20	6-10	1
			2	3/32	(2.4)	1/16	(1.6)	.045	(1.1)	220-230	93-97	19-20	210-215	13-18	5-10	1
		H	4					.045	(1.1)	210-225	89-95	19-21	210-215	15-20	6-8	1
.1875	4.8		1	3/16	(4.8)			.045	(1.1)	180-190	76-80	18-20	175-185	12-17	5-7	2
			2	3/32	(2.4)	1/16	(1.6)	.045	(1.1)	180-190	76-80	18-20	175-185	15-20	6-8	1
		V^3,O	2	3/32	(2.4)	1/16	(1.6)	.035	(.89)	200-210	85-89	17-18	120-125	10-15	4-6	2
			4					.035	(.89)	240-250	102-106	17-19	140-145	13-18	5-8	1

Stainless Steel: Short arc welding should be used for **welding thin materials** in the flat position, bridging large gaps and all welding out of position. The best shielding gas to use for short arc welding of stainless steel is **A-1025 (90% Helium, 7.5% Argon and 2.5% CO_2)**. This mixture provides good penetration, arc stability, and weld properties (particularly corrosion resistance) in single or multi-pass weldments. C-25 (75% Ar-25% CO_2 can be used, but only for single pass welds where corrosion resistance of the weld metal is not essential to the end use.

CO_2 shielding gas can **never be used** for stainless steel. **Spray arc** should be used in the flat position for single or multi- pass welding of thicker material. For spray arc welding, an **Ar-1% O_2** gas mixture will reach the best results, particularly from the standpoint of bead appearance. If, for a certain application, wetting of the weld bead has proven difficult, Ar-2% O_2 shielding gas mixtures will help. However, the chrome oxide build-up will cause the weld bead to be slightly discolored.

As for the welding techniques that can be used, the same considerations are true with stainless steel as for low carbon mild steel. However, the forehand technique is sometimes preferred, as a flatter weld can be made, although the surface will be more oxidized. Welding conditions for stainless steel are shown in **Table 1-9** (below).

Table 1-9 - Short Arc & Spray Arc - Stainless Steel

Material Thickness 1 Fraction	Decimal	Electrode Dia. 2	Welding Current Am s-DCRP	Arc Voltage	Wire Feed IPM	Shielding Gas Flow CFH (3)	Travel Speed IPM	No. of Passes
		.030			150-190			
1/16	.063	.035	60-100	15-18	90-190	25-30	15-30	1
3/32	.093	.035	125-150	17-21	230-280	25-30	20-30	1
1/8	.125	.035	130-160	18-24	250-290	25-30	20-25	1
5/32	.156	.045	190-250	22-26	200-290	25-30	25-30	1
		.045			260-370			
1/4	.250	1/16	225-300	22-30	110-150	30-45	25-30	1
3/8	.375	1/16	275-325	22-30	225-250	30-45	15-20	2
1/2	.500	3/32	300-350	22-30	75-85	30-45	5	3-4
3/4	.750	3/32	350-375	22-30	85-95	30-45	4	5-6
1	1.000	3/32	350-375	22-30	85-95	30-45	2	7-8

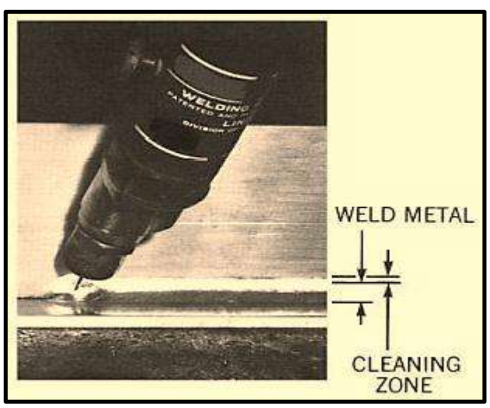
Note—Data is for flat position. Reduce current 10-20% for other positions.
Short arc should be used for vertical and overhead welds with .030-.045" electrode diameters.

1. For groove and fillet welds. Material thickness also indicates fillet weld size.
2. HiSil electrode wire are more fluid, producing flatter welds.
3. Gas Selection – Argon oxygen (1 to 5% oxygen) — flat position and horizontal fillet only.
   Argon-CO_2 (75% Argon-25% CO_2) – All position, some carbon pickup.
   Stargon — All position. Some Carbon pickup
   *Helium, Argon, CO_2 (A1025) – For all position welding.
   Carbon Dioxide (CO_2) – Where carbon pickup can be tolerated.

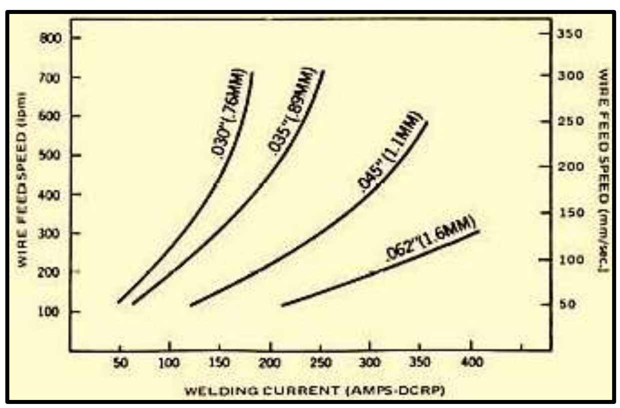
*Shielding gas flow rate should be increased 50-100% for A1025. For Helium mixes, voltage increases of 6 to 7 volts are to be anticipated.

Aluminum: The most common and preferred transfer method for welding aluminum is with the **spray arc process**, regardless of the material thickness or position of welding. The high heat conductivity of aluminum is such that even with the high heat input produced with a spray arc, the solidification rate of the weld puddle is rapid enough to allow welding out of position. Pure **argon shielding gas** is most commonly used for semi-automatic (manual) welding as the weld puddle is very controllable and the resulting weld exhibits good bead shape and soundness.

However, if a hotter puddle is desired, for thick plates or automatic welding for example, **argon-helium mixtures** may be used. The short arc process may be used for welding extremely thin aluminum, and spray arc should be used whenever possible. If care is not taken to provide a clean welding surface, the fast freezing puddle produced by the short arc process is very likely to yield porosity. Only the **forehand and vertical-up welding technique** can be used for **welding aluminum**, unlike the welding of steel. Wide weaves should be avoided, as the weld bead may become excessively oxidized.



Aluminum Welding Technique

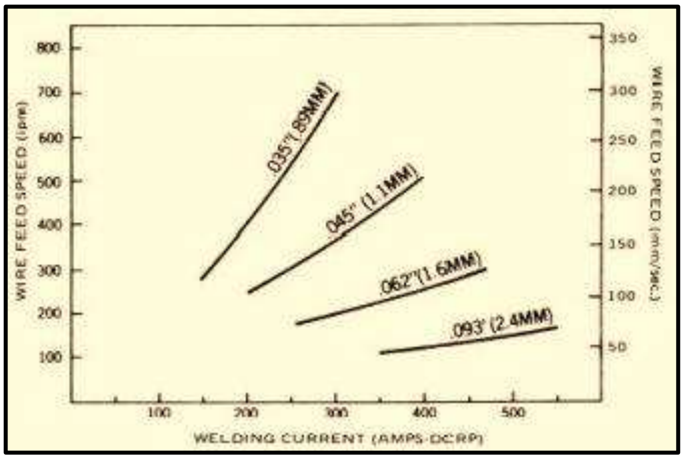


Stainless Welding Conditions

Copper: Copper, like aluminum, is also a material having extremely high heat conductivity. Therefore, the spray arc process should be used for **all position** welding. To help overcome the sluggish weld puddle of copper wires (E Cu), **helium-argon (75% He-25% Ar)** should be used on the thicker materials. Although pu-re argon shielding will provide better arc stability, its use should be restricted to thinner materials **(1/4 in. (6.4 mm and below)**. However, argon may be used; the alloy content improves puddle fluidity:

1. Copper-nickel alloys (E Cu Ni wire electrodes).
2. Silicon-bronze (E Cu Si wire electrodes).

Another practice used to increase the weld puddle fluidity is initially **preheating** the plate before welding and maintaining a high interpass temperature while multi-pass welding. The forehand welding technique should be used to produce a well-shaped weld bead. Because the arc is on the leading edge of the puddle, some preheating of the plate will take place, thus permitting better wetting. The backhand will yield a bead that is more convex and heavily oxidized.



Burn-Off Characteristics – Deoxidized Copper Wire

Welding Conditions for GMAW of Copper-Spray Transfer

Electrode	Diameter		Minimum Welding Current	Arc Voltage	Filler Wire Feed		Minimum Current Density	
Type	in	mm	A	V	in/min	mm/s	kA/in^2	kA/mm^2
ERCu	0.035	0.9	180	26	345	146	191	0.30
Deox	0.045	1.1	210	25	250	106	134	0.21
Copper	0.062	1.6	310	26	150	63	101	0.16

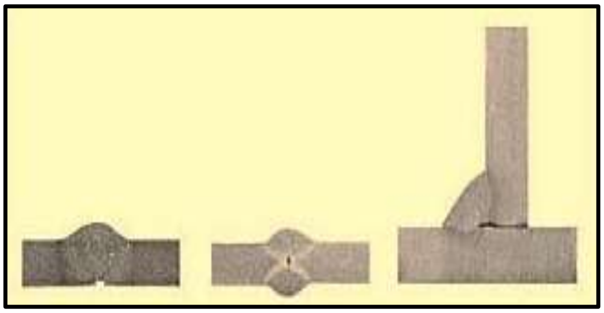
Vertical-up welding is also the recommended method for copper. The weld should be deposited as straight stringers or with a small weaving technique. Wide weaving patterns should be avoided. The vertical-down technique may be used for **thin materials** (under 1/4 in. (6.4 mm) thick) but lack of fusion defects are very likely to occur. Unlike all the other materials mentioned, welding in the overhead position is extremely difficult, although possible. When it is accomplished, the bead shape and wetting are very poor. This type of welding should be avoided if at all possible.

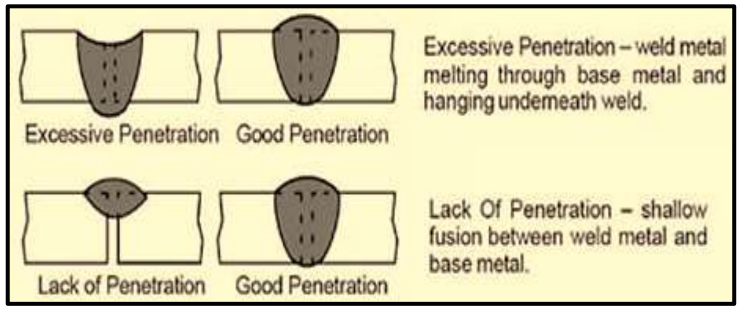
WELD DEFECTS AND CORRECTIONS:

With the correct welding conditions, techniques and material quality standards, the GMAW process will yield a very high quality weld deposit. **Most defects** encountered in welding are due to an improper welding procedure. Once the causes are determined, the operator can easily correct the problem. Defects usually encountered include incomplete penetration, incomplete fusion, undercutting, porosity, and longitudinal cracking. This section deals with the corrective action that should be taken.

Incomplete Penetration: Welding current has a great effect on penetration. Incomplete penetration is usually caused by the use of **too low welding currents** and can be eliminated by simply increasing the amperage. Other causes can be the use of **too slow travel speeds** and an **incorrect torch angle**. Both will allow the molten weld metal to roll in front of the arc, acting as a cushion to prevent penetration. The arc must be kept on the leading edge of the weld puddle. This type of defect is found in any of three ways:

1) When the weld bead does not penetrate the entire thickness of the base plate.
2) When two opposing weld beads do not interpenetrate.
3) When the weld bead does not penetrate the toe of a fillet weld but only bridges across it.



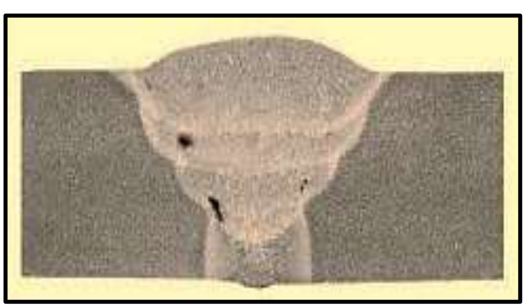


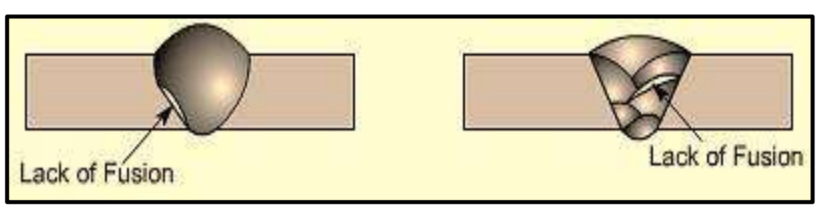
Examples of Lack of Penetration

Lack of Fusion: Also called **cold lapping or cold shuts**, occurs when there is no fusion between the weld metal and the surfaces of the base plate. The most common cause of lack of fusion is a poor welding technique. Either the weld puddle is too large (travel speed too slow) and/or the weld metal has been permitted to roll in front of the arc. Again, the arc must be kept on the leading edge of the puddle. When this is done, the weld puddle will not get too large and cannot cushion the arc.

Another cause is the use of a **very wide weld joint**. If the arc is directed down the center of the joint, the molten weld metal will only flow and cast against the side walls of the base plate without melting them. The heat of the arc must be used to melt the base plate. This is accomplished by making the joint narrower or by directing the arc towards the side wall of the base plate. When multipass welding thick material, a split bead technique should be used whenever possible after the root passes. Large weld beads bridging the entire gap must be avoided.

Lack of fusion can also occur in the form of a **rolled over bead crown**, generally caused by a very low travel speed and too large a weld in a single pass. However, it is also very often caused by **too low** welding voltage. As a result, the **wetting** of the bead will be poor, due the presence of aluminum oxide. This oxide is a refractory with a melting point of approximately **3500°F (1927°C)**, also insoluble in molten aluminum. If this oxide is present on the surfaces to be welded, fusion with the weld metal will be hampered. The best safeguard against this is to remove all oxide as soon before welding as possible. Although iron oxide (rust, mill scale) can be welded over in mild steel, an excessive amount can cause lack of fusion.



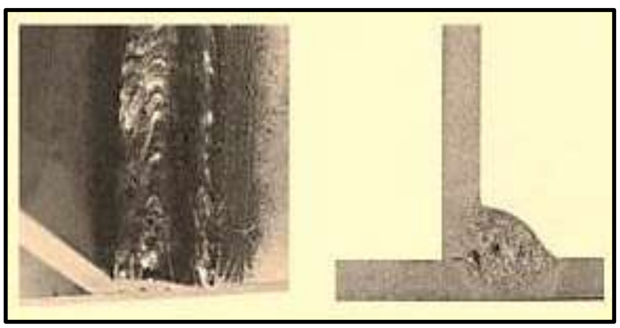


Undercutting: Is a defect that appears as a groove in the parent metal directly along the edges of the weld. It is most common in **lap fillet welds**, but can also be encountered in **fillet and butt joints**, caused by improper welding parameters, as travel speed and arc voltage. When travel speed is too high, the weld bead will be very peaked because of its extremely fast solidification and surface tension draws the molten metal along the edges of the bead, piling it up along the center. The undercut groove is drawn into the weld not allowing the wet back properly due the rapid solidification.

Decreasing the arc travel speed will gradually **reduce** the size of the **undercut** and eventually eliminate it. When small or intermittent undercuts are present, raising the arc voltage or using a leading torch angle is also corrective actions. In both cases, the weld bead will become flatter and wetting will improve. When the arc voltage is **raised** to excessive levels, undercutting may again **appear**, mainly in spray arc welding. The heat transfer of a long arc is relatively poor, so actually the arc is supplying no more total heat to the weld zone. The outermost areas are very quickly cooled and again proper wetting is prevented.

The arc length should be **kept short**, not only to avoid undercutting but to increase penetration and weld soundness. Excessive current can also cause undercutting. The arc force, arc heat and penetration are so great that the base plate under the arc is actually "blown" away. Again, the outermost areas of the base material are melted but solidify quickly. Puddle turbulence and surface tension prevent the puddle from wetting properly. It is always advisable to remain within the current ranges specified for each wire size.

Porosity: Porosity is gas pores found in the solidified weld bead. However, it is possible that porosity can only be found at the weld center. Pores can occur either under or on the weld surface. The most common causes of porosity are **atmosphere contamination**, excessively oxidized work piece surfaces, inadequate deoxidizing alloys in the wire and the presence of foreign matter.




Examples of Porosity

The atmospheric gases that are primarily responsible for porosity in steel are nitrogen and excessive oxygen. Atmospheric contamination can be caused by:

1) Inadequate shielding gas flow.
2) Excessive shielding gas flow. This can cause aspiration of air into the gas stream.
3) Severely clogged gas nozzle or damaged gas supply system (leaking hoses, fittings, etc.)
4) An excessive wind in the welding area. This can blow away the gas shield.

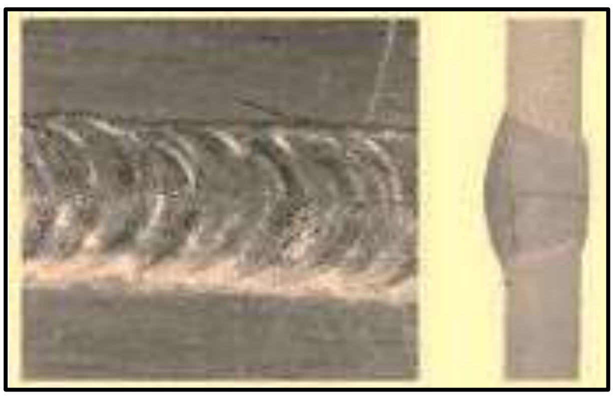
However, considerable oxygen can be tolerated without porosity in the absence of nitrogen, but oxygen in atmosphere can cause severe problems with aluminum because of its rapid oxide formation. The gas supply should be inspected at regular intervals to insure freedom from leakage. In addition, excessive moisture in the atmosphere can cause porosity in steel and particularly aluminum.

Care should be taken in humid climates. For example, a continuous coolant flow in water cooled torches can cause condensation during periods of high humidity and consequent **contamination** of the **shielding gas**. Excessive oxidation of the work pieces is an obvious source of oxygen as well as entrapped moisture. Again, this is particularly true for aluminum where a hydrated oxide may exist. Anodized coatings on aluminum must be removed prior to welding because they contain water as well as being an insulator.

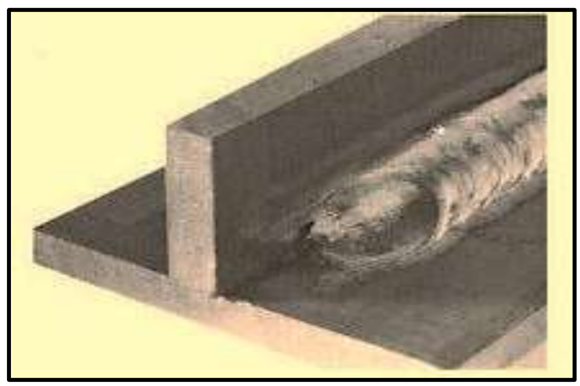
Porosity can be caused by **inadequate wire deoxidation** when welding semi-killed or rimmed steels. The oxygen in the steel can cause CO porosity if the proper deoxidizing elements are not present. An example is excessive lubricant on the welding wire. These hydrocarbons are sources of hydrogen which is particularly harmful for aluminum.

When solidification rates are extremely rapid, any gas that would normally escape is trapped. Extremely **high travel speeds** and **low welding current** levels should be avoided. Erratic arc characteristics can be caused by poor welding conditions (voltage too low or high, poor metal transfer) and fluctuation in the wire feed speed. All these occurrences cause severe weld puddle turbulence. This turbulence will tend to break up the shielding gas envelope and cause the molten weld metal to be contaminated by the atmosphere.

Longitudinal Cracking: Longitudinal cracking of weld beads are not often found in Mig welding. However, can be one of two types: **hot cracks and cold cracks**. Hot cracks occur while the weld bead is between the liquidus (melting) and solidus (solidifying) temperatures, and usually result from the use of an incorrect wire electrode (aluminum and stainless steel alloys), as well as, the chemistry of the base plate. Joint design and welding techniques that results in a weld bead excessively concave can promote cracking.



Example of Crater Cracking



Example of Longitudinal Cracking

This **defect** may often be encountered particularly with any **5000 series aluminum**, called a **crater crack**, which appears at the end of the weld where the arc has been broken. The reason for this defect is the incorrect technique for ending the weld. To properly end a weld, the crater should be filled, simply done by reversing the arc travel direction before breaking the arc. When the welding control is designed to supply gas for a short time after the arc is broken, the crater should be shielded until it is completely solidified. The Table 1-10 below, shows ten types of defects, cause and corrective actions.

Table 1-10 - Weld Troubleshooting

FAULT OR DEFECT	CAUSE AND/OR CORRECTIVE ACTION
1) POROSITY	A. OIL, HEAVY RUST, SCALE, ETC. ON PLATE B. WIRE – MAY NEED WIRE HIGHER IN Mn AND Si C. SHIELDING PROBLEM; WIND, CLOGGED OR SMALL NOZZLE, DAMAGED GAS HOSE, EXCESSIVE GASFLOW, ETC. D. FAILURE TO REMOVE GLASS BETWEEN WELD PASSES E. WELDING OVER SLAG FROM COVERED ELECTRODE
2) LACK OF PENETRATION	A. WELD JOINT TOO NARROW B. WELDING CURRENT TOO LOW; TOO MUCH C. ELECTRODE STICKOUT WELD PUDDLE ROLLING IN FRONT OF THE ARC
3) LACK OF FUSION	A. WELDING VOLTAGE AND/OR CURRENT TOO LOW B. WRONG POLARITY, SHOULD BE DCRP C. TRAVEL SPEED TOO LOW D. WELDING OVER CONVEX BEAD E. TORCH OSCILLATION TOO WIDE OR TOO NARROW F. EXCESSIVE OXIDE ON PLATE
4) UNDERCUTTING	A. TRAVEL SPEED TOO HIGH B. WELDING VOLTAGE TOO HIGH C. EXCESSIVE WELDING CURRENTS
5) CRACKING	A. INCORRECT WIRE CHEMISTRY B. WELD BEAD TOO SMALL C. POOR QUALITY OF MATER IAL BEING WELDED
6) UNSTABLE ARC	A. CHECK GAS SHIELDING B. CHECK WIRE FEED SYSTEM
7) POOR WELD STARTS OR WIRE STUBBING	A. WELDING VOLTAGE TOO LOW B. INDUCTANCE OR SLOPE TOO HIGH C. WIRE EXTENSION TOO LONG D. CLEAN GLASS OR OXIDE FROM PLATE
8) EXCESSIVE SPATTER	A. USE $Ar-CO_2$ OR $Ar-O_2$ INSTEAD OF CO_2 B. DECREASE PERCENTAGE OF He C. ARC VOLTAGE TOO LOW D. RAISE INDUCTANCE AND/OR SLOPE
9) BURNTHROUGH	A. WELDING CURRENT TOO HIGH B. TRAVEL SPEED TOO LOW C. DECREASE WIDTH OF ROOT OPENING D. USE $Ar-CO_2$ OR $Ar-O_2$ INSTEAD OF CO_2
10) CONVEX BEAD	A. WELDING VOLTAGE AND/OR CURRENT TOO LOW B. EXCESSIVE ELECTRODE EXTENSION C. INCREASE INDUCTANCE D. WRONG POLARITY, SHOULD BE DCRP E. WELD JOINT TOO NARROW

SETTING GMAW PARAMETERS:

Good **equipment** makes Gas Metal Arc Welding easier. Material thickness and wire diameter, allow you to focus on proper technique while achieving smooth, spatter-free starts, a common problem area for occasional welders; however, not all welding machines have this capability. To determine which welding machine and technology suit you the best, find a local welding supply distributor that has an on-site welding lab or will allow you to test-drive a machine before buying one.

1. **Material thickness determines amperage:** As a guideline, each **0.001 inch** of material thickness requires 1 Ampere, then a plate 0.125 in. thickness = 125 A.

2. **Select proper wire size, according to amperage:** Since you don't want to change wires, select one of the most **commonly used**, for example: 0.023 in. = 30-130 A; 0.030 in. = 40-145 A; 0.035 in. = 50-180 A; 0.045 in. = 75-250 A.

3. **Set the voltage:** Voltage determines height and width of bead. If no chart, manual or specifications are available for setting the correct voltage, you can **try this**: while one person welds on scrap metal, an assistant turns down the voltage until the arc starts stubbing into the work piece. Then, start welding again and have an assistant increase the voltage until the arc becomes unstable and sloppy.

A voltage midway between these two points provides a good starting point. There is a **relationship** between arc voltage and arc length. A short arc decreases voltage and yields a narrow, "ropey" bead. A longer arc (more voltage) produces a flatter, wider bead. Too much arc length produces a very flat bead and a possibility of an undercut.

4. **Set the wire feed speed:** Wire speed controls amperage, as well as the amount of weld penetration. A **speed** that's **too high** can lead to burn-through. If a manual or weld specification sheet is not available, use the multipliers in the following chart to find a good starting point for wire feed speed. For example, for 0.030-in. wire, multiply by 2 in. per amp to find the wire feed speed in inches per minute (IPM).

For Wire Size	Multiply by	Ex. Using 1/8 in. (125 amps)
0.023 in.	3.5 in. per amp	3.5 x 125 = 437.5 IPM
0.030 in.	2 in. per amp	2 x 125 = 250 IPM
0.035 in	1.6 in. per amp	1.6 x 125 = 200 IPM
0.045 in.	1 in. per amp	1 x 125 = 125 IPM

Examine the Beads: Check all parameters by examining the **weld bead** deposited. Its appearance indicates what process needs to be adjusted.

Good Weld (Figure 1): Check the good penetration into the **base material**, flat bead profile, appropriate bead width, and good tie-in at the toes of the weld (edges where the weld metal meets the base metal).

Voltage Too High (Figure 2): Too much voltage is marked by **poor arc control**, inconsistent penetration, and a turbulent weld pool that fails to consistently penetrate the base material.

Voltage Too Low (Figure 3): Too little voltage results in poor arc starts, control and penetration. It also causes **excessive spatter**, a convex bead profile, and poor tie-in at the toes of the weld.

Figure 1

Figure 2

Figure 3

Travel Speed Too Fast (Figure 4): A narrow, convex bead with inadequate tie-in at the toes of the weld, **insufficient penetration**, and an inconsistent weld bead are caused by traveling too fast.

Travel Speed Too Slow (Figure 5): Traveling too slow introduces too much heat into the weld, resulting in an excessively **wide weld** bead and poor penetration. On thinner material it may also cause burn through.

Figure 4

Figure 5

Wire Feed Speed/Amperage Too High (Figure 6): Setting the wire feed speed or amperage too high (depending on what type of machine you're using) can cause **poor arc** starts, lead to an excessively wide weld bead, burn-through, excessive spatter, and poor penetration.

Wire Feed Speed/Amperage Too Low (Figure 7): A narrow, oftentimes convex bead with **poor tie-in** at the toes of the weld marks insufficient amperage.

No Shielding Gas (Figure 8): A lack of or inadequate shielding gas is easily identified by the porosity and pinholes in the face and interior of the weld.

Figure 6

Figure 7

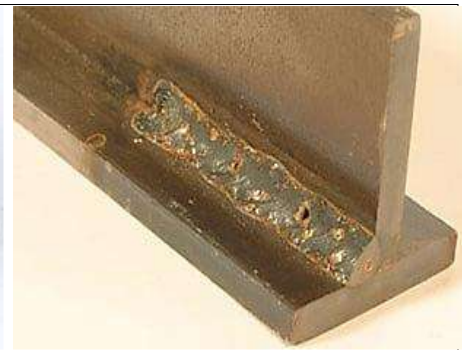


Figure 8

Compare welding to photos to determine proper adjustments.

Good Weld	Travel Too Fast	Travel Too Slow	Voltage Too Low	Voltage Too High	Amperage Too Low	Amperage Too High	Less Stickout No gas

IMPORTANT CORRECT PARAMETERS:

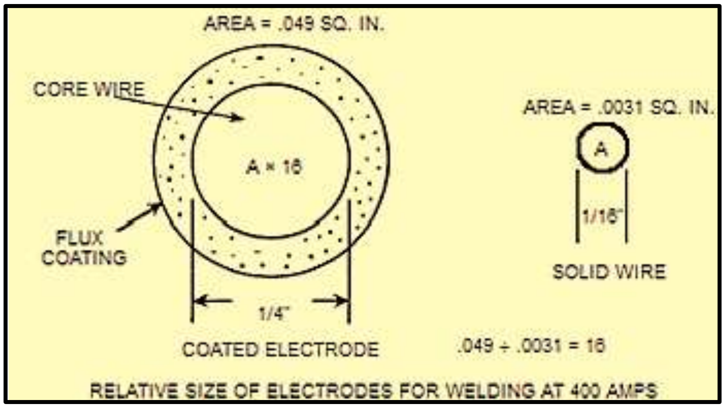
Regardless of parameters choices, to read the **owner's manual** is very important. It contains important information about proper operation and safety guidelines. Most companies offer their manuals online. Beyond workpiece material, joint design and positions, other factors also affect results and settings. When good results are achieved in some GMAW welding, one of the best practices is to record the parameters.

Power Source - A **direct current** and **constant voltage** power source are recommended for Gas Metal Arc Welding, which may be a **transformer-rectifier** or a rotary type unit. The lower open circuit voltage and self-correcting arc length feature, makes it most suitable. Constant voltage power sources used for spray transfer and **flux cored electrode** welding are the same. However, if the unit is to be used for short-circuiting arc welding, it must have a **"slope"** or slope control.

Current Density: It is necessary that the term "**current density**" be understood. The figure below, shows a **1/4" coated electrode** and a **1/16" solid wire**, both capable of carrying 400 amperes. Since the area of the 1/16" wire is only 1/16 of the coated electrode, thus, the **current density** of this wire is 16 times greater than the current density of the 1/4" wire using equal welding currents.

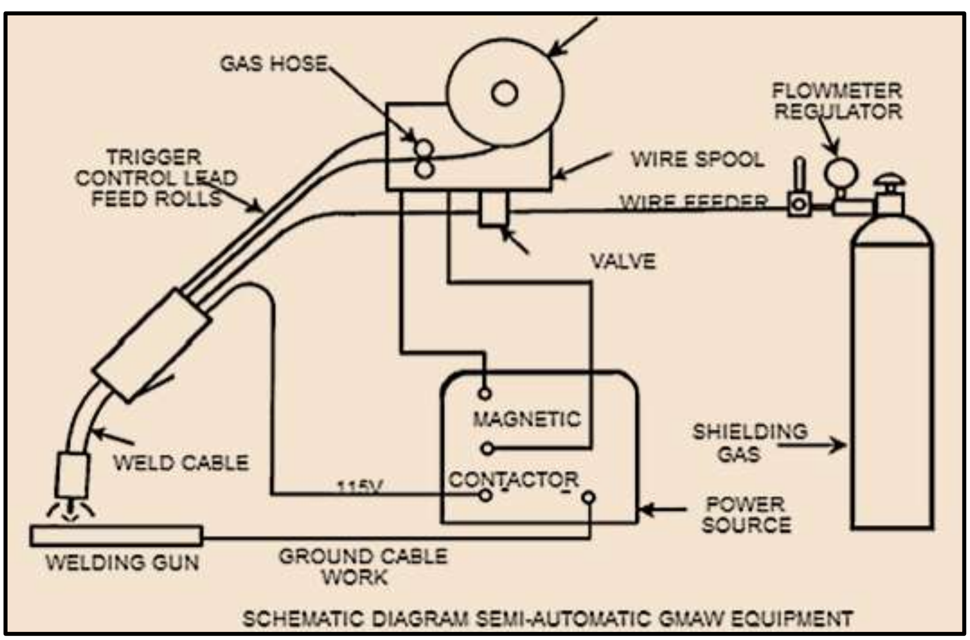
If we were to increase the current through the **1/4" coated electrode**, the resistance heating through the **1/4" electrode** length would be excessive. The rod would become so hot that the **coating** could **crack**, rendering it useless. The **1/16" solid wire** carries a high current at a distance of less than 3/4", the approximate distance from the end of the contact tip to the arc.

Electrodes: Solid electrodes used in GMAW are of high purity and chemistry must be closely controlled, as some types, purposely contain **high levels of deoxidizers** for use with CO_2 shielding. Most steel electrodes are **copper plated**, for protecting the surface. The copper inhibits rusting, provides smooth feeding, and helps electrical conductivity. The electrode manufacturer draws down the electrode to a very small finished diameter, and the most common are from **diameters 0.030" thru 1/16"**.



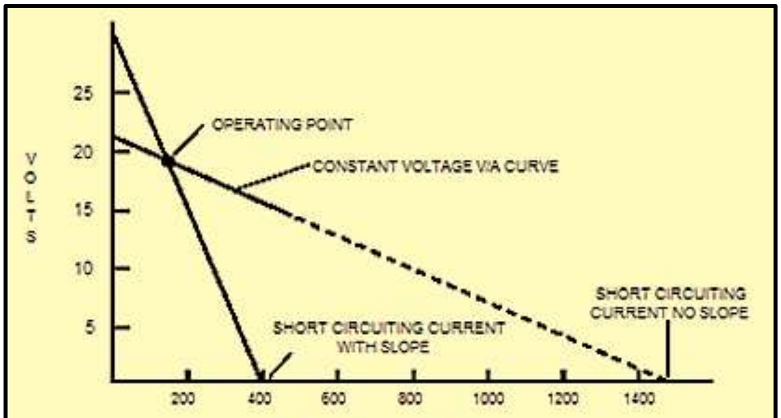
Equipment and Operation: The equipment used for gas metal arc welding is more complicated than that required for Shielded Metal Arc Welding. Initial cost is relatively high, but the **cost** is rapidly **amortized** due to the savings in labor and overhead achieved by the rapid weld metal deposition. The equipment necessary for Gas Metal Arc Welding (GMAW) is listed below:

1) Power source
2) Wire feeder
3) Welding gun
4) Shielding gas supply
5) Solid electrode wire
6) Protective equipment



Slope Control: Is a means of limiting the high short-circuit current, which is a characteristic of this type of welding. The effect of slope on the short-circuiting current is approximately **150 amperes and 18 volts**, has no slope components in the power source. When the current at short-circuit is **over 1400 amperes**, this high current may cause too much spatter and the arc would be erratic.

With the slope components in the circuit, the **short-circuiting current is approximately 400 amperes**, and the molten bead is pinched off the end of the wire, more gently. The slope may be adjustable for varying wire diameters or it may be fixed, giving a **good average value** for **0.035" and 0.045"** diameter wires, the two most popular sizes. If we were to plot the current rise on a graph, we would see that the current rise if very rapid, as shown by the broken line.



EFFECT OF SLOPE ON SHORT CIRCUITING CURRENT

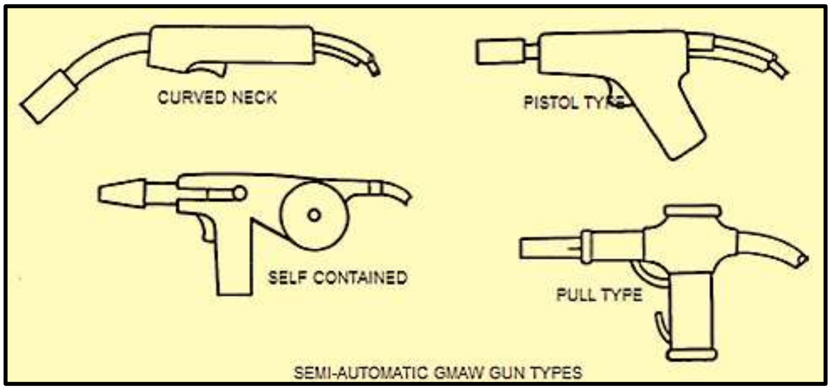
This rapid current rise can be controlled by using a device called output circuit of the welder (sometimes called a stabilizer, which acts like a flywheel or damper by retarding the rate of rise by the solid line. By preventing the rapid current rise, the arc becomes smoother, the spatter is reduced, and bead shape and appearance are improved. Some GMAW power sources have a selector that can switch in several different inductance values to finely tune the arc, also have a receptacle to receive the electrical power required, which turns on the **welding power** to the **welding gun** when the gun trigger is actuated.

Wire Feeders: Controlling of the main contactor in the power source is for safety reasons. This assures that the welding wire will only be energized when the switch on the welding gun is always depressed. The flow of shielding **gas is controlled** by a solenoid valve (magnetic valve) in the wire feeder, to turn the shielding gas on and off, when the gun switch is actuated.

Most feeders utilize a dynamic **breaking circuit** to quickly stop the motor at the end of a weld, to prevent a long length of wire protruding from the gun when the weld is terminated, or, have a burn-back circuit that allows the welding current to stay on for a short period of time after wire feeding has stopped, to allow the wire to burn back exactly the right amount for the next arc initiation.

Welding Guns: Guns for GMAW have several characteristics in common. All have a **copper alloy shielding** gas nozzle that delivers the gas to the arc area in a no turbulent, angular pattern to prevent aspiration of air. The nozzle may be **water cooled** for semi-automatic welding at high amperage, and for automatic welding where the arc time is of long duration.

Welding current is transferred to the welding wire as the wire travels through the contact tip or contact tube located inside the gas nozzle. The hole in the contact tip through which the wire passes is only a few thousandths of an inch larger than the wire diameter. A worn contact tip will result in an erratic arc due to poor current transfer. Figure below shows different semi-automatic gun configurations, commonly used.



- ✓ **The curved neck or "goose neck" type**: Is probably the most commonly used. It allows the best access to a variety of weld joints. The wire is pushed to this type of gun by the feed rolls in the wire feeder through a feed cable or conduit that usually is 10 or 12 feet in length. The shielding gas hose, welding current cable, and trigger switch leads are supplied with the welding gun.

- ✓ **The pistol type gun:** Is similar to the curved neck type, but is less adaptable for difficult to reach joints. The pistol type is also a "push" type gun and is more suitable for gas metal arc spot welding applications.

- ✓ **The self-contained type**: Has an electric motor in the handle and feed rolls that pulls the wire from 1 or 2 pound on a spool. The need for a long wire power cable is eliminated, and the wire feed speed may be controlled by the gun. Guns of this type are often used for **aluminum wires** up to **0.045" diameter**, although they may also be used for feeding steel or other hard wires.

- ✓ **The pull type gun**: Has either an electric motor or an air motor mounted in the handle coupled to a feeding mechanism. The **wire spool** is located in the control cabinet, located at **fifty feet** from the gun. When feeding long distances, a set of "push" rolls assist in feeding the wire, known as a "push-pull" feed system especially useful in feeding softer wires such as aluminum.

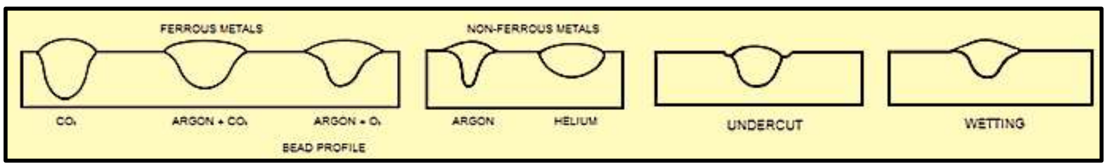
Shielding Gases: In gas metal arc welding, there are a variety of shielding gases that can be used, either alone or in combinations of varying degrees. The choice is dependent on the **type of metal transfer** employed, the type and thickness of metal, the bead profile penetration, and speed of welding.

Straight Carbon Dioxide (CO_2): Is often used for **short-circuiting** arc welding because of its low cost. The deep penetration usually associated with CO_2 is minimized because of the low amperage and voltage settings used with this process. Compared to other gas mixes, CO_2 will produce a harsher arc and therefore, greater spatter levels.

Using CO_2 the temperature reached in welding causes carbon dioxide and decomposes into carbon monoxide and oxygen. To reduce the possibility of porosity caused by entrapped oxygen in the weld metal, it is wise to use electrodes that contain deoxidizing elements, such as silicon and manganese. If the current is increased above the short circuiting range, the use of carbon dioxide tends to produce a globular transfer.

Mixing argon: In proportions of **50-75%** with carbon dioxide will produce a smoother arc and reduce spatter levels. It will also widen the bead profile, reduce penetration, and encourage "**wetting**". Wetting is a uniform fusion, along with joining edges of the base metal and the weld metal, and minimizes the weld imperfection, known as undercutting.

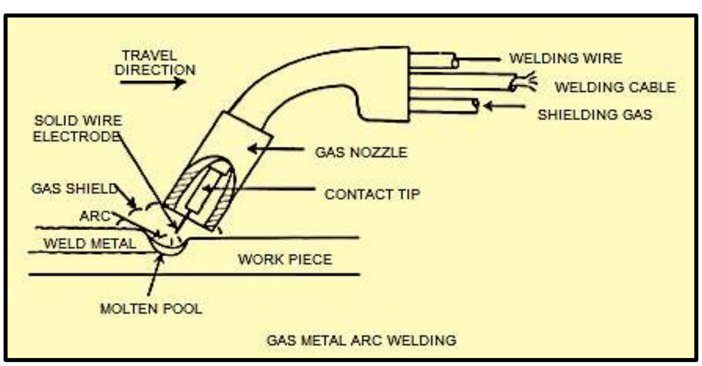
75% Argon/25 CO_2 mixture: Is often chosen for short circuit **welding of thin** sections, however, the **50%-50%** works well on **thicker** sections, but shielding gases can affect the metallurgy of the weld metal. As an example, a mixture of **Ar- CO_2** may be used for **stainless-steels**, but excessive carbon may be transferred into the weld metal, then, the corrosion resistance of the stainless steel is reduced, as the carbon content increases. A less reactive **mixture of 90% He-7.1/2% Ar-2.1/2% CO_2** is sometimes chosen. This combination, known as a "**trimix**", provides good arc stability and wetting.



Pure argon: Produces the **spray arc transfer** and performs well on **nonferrous** metals but may be also used on ferrous metals. To make argon suitable for spray transfer on ferrous metals, small additions of **1.0 to 5.0% oxygen** have proven to provide remarkable improvements. The arc stabilizes, becomes less spatter, and the weld metal wets out nicely. If the percentage of argon falls below 80%, it is impossible to achieve true spray transfer.

Pure helium: Or combinations of **helium and argon** are used for welding **nonferrous** metals. The bead profile will broaden as the concentration of helium increases. For **pulse spray transfer**, the selection of shielding gas must be adequate enough to support a spray transfer. Material type, thickness, and welding positions are all essential variables in selecting a particular shielding gas. The following is a list of recommended gases for the following materials:

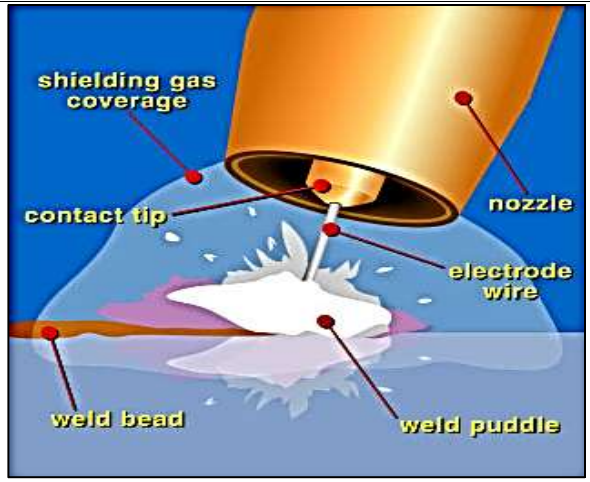
Carbon Steel: Argon/CO_2/O_2/He (Helium less than 50%)
Alloy Steel: Argon/CO_2/O_2/He (Helium less than 50%)
Stainless: Argon/O_2/CO_2 (CO_2 max. 2%)
Copper, Nickel, & Cu-Ni Alloys: Argon/Helium
Aluminum: Argon/Helium



SUMMARY FOR GMAW BEST PRACTICES:

GMAW basic concepts:

- An electrical arc is created between a continuous, consumable wire electrode and the work piece.
- The consumable wire functions as the electrode in the weld circuit and, also, as the source of filler metal.



The GMAW process:

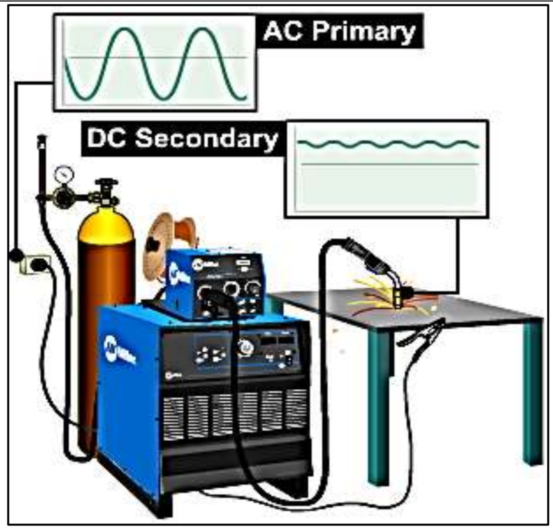
- Can weld most commercial metals and alloys including:
  - Steel;
  - Aluminum;
  - Stainless steel.
- Allows the operator to concentrate on arc control.
- Makes MIG a simpler process to learn.

A basic GMAW welding system requires:

- A power source;
- A wire feeding mechanism;
- A shielding gas cylinder;
- A regulator / flow meter;
- A MIG gun;
- And a work clamp.

The GMAW welding power source converts:

- Primary power from an outside electrical source.
- Secondary or usable power at the proper current and voltage to maintain a welding arc.

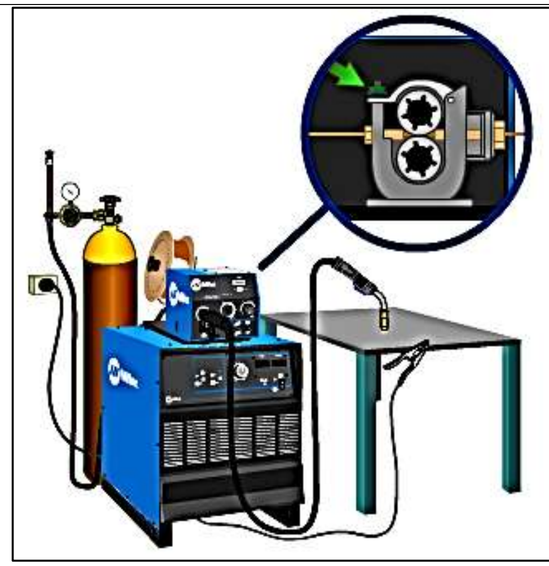


The wire feeder's drive motor turns drive rollers that:

- Grasp the wire;
- Pull it from a spool or reel;
- Feed it at a controlled speed through a guide in the gun.

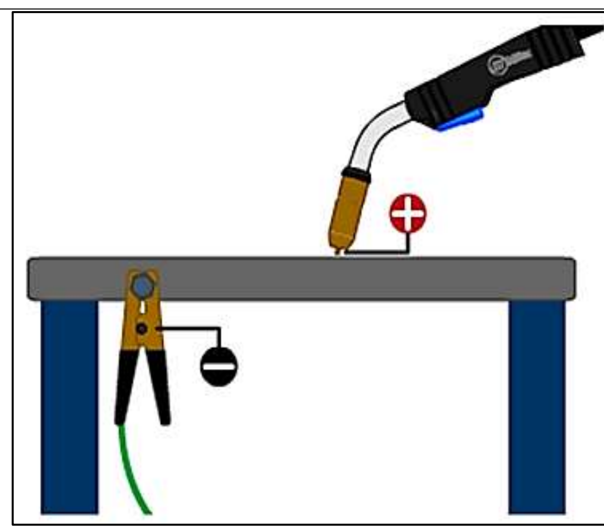
A separate control:

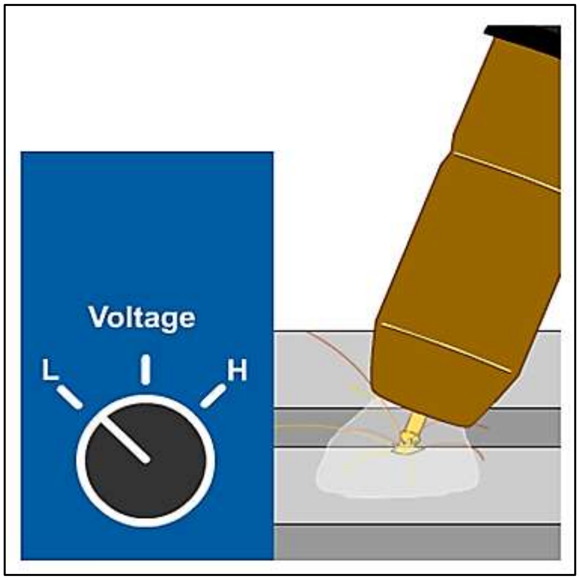
- Allows the operator to adjust the tension on the wire

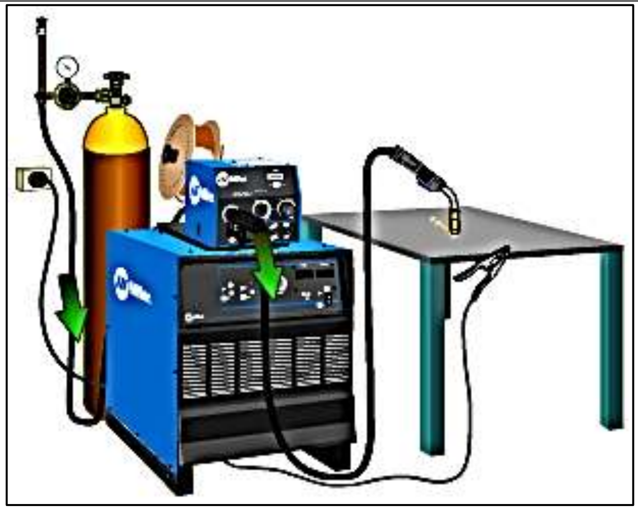
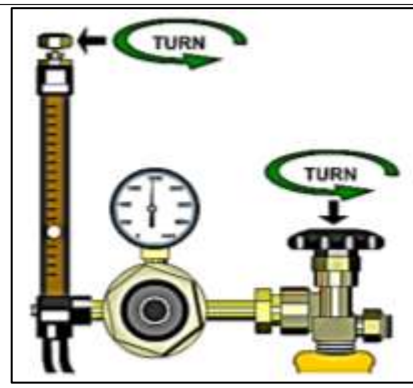


Most MIG welding uses:

- Direct current, constant voltage power;
- A reverse polarity weld circuit;
- Thus, the electrode is positive.
- Electricity flows from the negative work piece to the positive electrode in the GMAW gun.



Many types of wire feeders: • Used for different MIG welding applications. • Some are incorporated into GMAW welding power sources. • Others are separate units.	
Amperage is determined by: • Wire feed speed; • Measured in inches per minute, or IPM (or MPM, meters per minute) The Wire Feed Speed Control: • Adjusts wire feed speed; • Controls the amperage in the weld circuit; • The wire feeder may be separate from the power source.	
Inert shielding gas is used: • To protect the electrode and weld pool from contamination. • To enhance the welding capabilities of the electrical arc. • May be originally Argon or Helium. • Today reactive elements such as oxygen and carbon dioxide are usually mixed with the inert gas to improve welding performance.	

The gas cylinder: • Contains gas stored under pressure; • Should be handled very carefully; During welding, inert shielding gas is dispensed from the cylinder to: • Enhancing arc performance; • Shielding the weld area from contaminants.	
The gas regulator is important, since: • Controls the flow of gas; • The valves vary the amount of gas needed.	
The trigger on the MIG gun activates: • The wire feeding system; • Gas delivery; • Weld power.	
Power controls: The power controls on a MIG welder adjust the voltage an amperes, though the voltage will also increase the amperes. It's worth knowing that the wire speed also controls the amperes.	

Power controls:

Example: Miller Dimension 400: Machine for Mig, Tig and Stick welding, commonly used for student training.

1. **On**: Black Push Button: This is a push button that when depressed starts the machine.

2. **Off**: Red Push Button: This push button stops the machine.

3. **Current Selector**: This lever selects CV (constant voltage) for Mig welding and CC (constant current) for Tig and Stick welding. Make sure the lever is pushed up for CV for Mig Welding.

4. **Arc Control**: This setting is not used for Mig welding and is disabled when in the CV mode for Mig Welding.

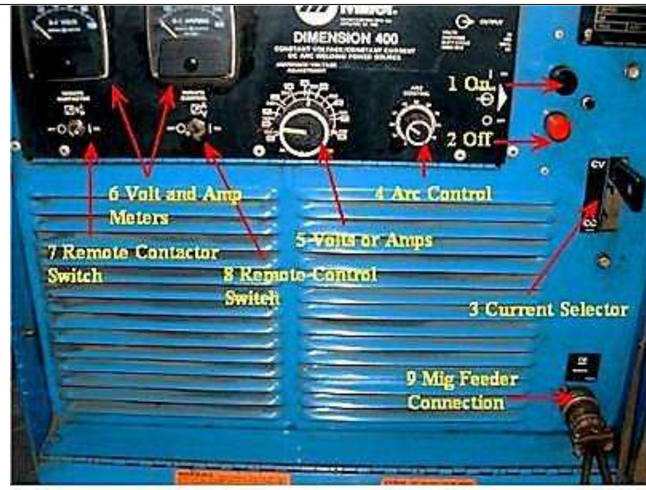
5. **Volts or Amperes Dial**: Show amperage intervals and voltage settings in the white squares. For example: 150 Amps or approximately 18 - 20 Volts.

6. **Volt and Amp Meters**: Show the amperage and voltage during welding.

7. **Remote Contactor Switch**: Should be set to **ON** to enable the **Mig Gun** trigger as the remote contactor.

8. **Remote Control Switch**: Used for Tig welding with a foot pedal, and should be in the **OFF** position for **Mig welding**.

9. **Mig Feeder Connection**: To be connected to the Mig welding machine receptacle.

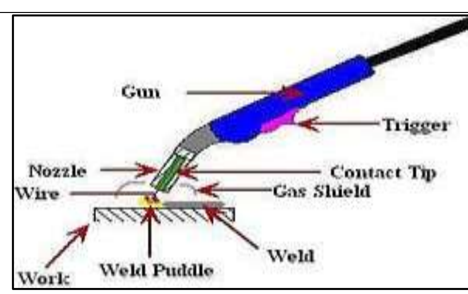


MILLER DIMENSION 400 COMBINATION MACHINE IN MIG MODE

WELDING MACHINE WITH SEPARATE WIRE FEED UNIT

MILLERMATIC MIG WELDING MACHINE

GMAW Torch: Voltage, wire speed and gas flow are set by the welder according to recommended ranges before welding. After positioning the gun, the welder pulls the trigger to start the gas flow and the arc, controlling the nozzle distance, the angle, and rate of travel speed across the joint.



Preparing the wire:

The wire reel mounting normally includes a spring tensioner, and should be initially tightened to the point where the reel of wire doesn't unravel under its own spring tension. The first 3 inches of wire should be as straight as possible to reduce the chance of damage. Sharp wire cutters can be used for trimming.

Feeding the wire to the torch:

The wire is inserted through the guide tube and over the roller and normally have two grooves, secured either by a grub screw in the side of the roller, or a knurled plastic cap. The groves are commonly matched to 0.6mm and 0.8mm.

Setting the roller tensioner:

The wire is driven by friction between the wire feed drive roller and the wire. The wire should ideally start to slip inside the rollers before the motor starts.

Setting the reel tensioner:

Finally check the tension on the wire reel. The tensioner on the reel is there to prevent the wire becoming loose, but the tension should be as light as possible.

Preparing the welding torch:

In some welding torches, it is possible to remove the contact tip from the end of the torch before feeding the wire through. If the wire snags in the torch it is possible to withdraw a little wire onto the reel, and use a rotating motion to get the wire pass the snagging point.

OBS: The filler wire **AWS ER-70S-6** designation, according to American Welding Society, is as follows:

E: Designates Electric Welding
R: Designates Filler Rod
70: Designates the Tensile Strength. (This example, the Tensile Strength is 70,000 psi.)
S: Designates Solid Wire. For Flux Core Wire the letter may be a T for Tubular Wire.
6: Designate the usability and characteristics of the wire.

Preparing the metal:

Metal needs to be completely clean of rust or paint before welding.
Light use of an angle grinder or flap wheel will quickly remove surface rust and paint, and for more inaccessible areas an air grinder can be effective.

Holding the torch:

MIG can be used one handed, but it may be much easier when you can use both hands to steady the torch.
Welding control will be further improved if you can rest an arm against something solid.

Positioning the tip:

Some welders tend to angle the torch at 20° from vertical. The contact tip should be about 6mm to 10mm from the metal to be welded, so the wire touches the plate in a good way.

Welding movement:

There are a variety of torch movements used. Generally some form of zig-zag or weaving motion is used to ensure the arc acts against both plates.

Welding direction:

Pushing the torch rather than pulling is a good habit to get into as it improves coverage of shielding gas.

For thin mild steel welded horizontally the direction of welding doesn't make a great deal of difference to the weld, so if visibility is better with the pull technique then that can be used.

Practice laying welds until the welds start looking neat. It should only take a couple of hours practice to get a feel for MIG welding.

Mig Welding Calculator: For practical methods, always try to use a Welding Calculator, such as the example below, using a Miller Calculator. When a **Mig welding test** is given using wire short circuit, the test is often done using a **3/8"- A36 structural plate**. A 37.5° bevel is used for an included angle of 75°. A 1/8" root opening with a 0-1/16" land is also common (the land is a flat area filed or ground on the sharp point of the beveled test plate).

Example: MIG (Solid Core) Welding Calculator.

All suggested settings are approximate. Welds should be tested to comply with your specifications.

1 **What material are you welding?** Steel

2 **How thick is the material?** 1/2" & Up (12.7 mm)

Short Circuit Transfer *(generally used for thinner metals and out of position welding)*	**Spray Arc Transfer** *(generally used for thicker metals in the flat or slightly horizontal position)*
Wire Size & Wire Feed Speed: Not Recommended	**Wire Size & Wire Feed Speed:** 0.045" (1.1 mm) at 390 ipm
Shielding Gas & Voltage Range: Not Recommended	**Shielding Gas & Voltage Range:** 98% Argon/2% O_2: 29-30 Volts
CO_2 gas is economical and has deeper penetration on steel, but may be too hot for thin metal. 75% Argon / 25% CO_2 is better on thin steels, has less spatter and better bead appearance.	**Amperage Range:** 315
Amperage Range: Not Recommended	

Solid Welding Wires: For steel, there are two common wire types. Use an AWS classification **ER70S-3** for all purpose, economical welding. Use **ER70S-**6 wire when more deoxidizers are needed for welding on dirty or rusty steel.

- Must be used with CO_2 or 75% Argon/25% (C-25) shielding gas.
- Indoor use with no wind.
- For maintenance, manufacturing, fabrication.
- Welds thinner materials (22 gauge) than flux cored wires.

WELDING SAFETY:

Gas Metal Arc Welding can also be dangerous if proper precautions are not taken. Since GMAW employs an electric arc, welders wear protective clothing, including heavy leather gloves and protective long sleeve jackets, to avoid exposure to extreme heat and flames. In addition, the brightness of the electric arc is a source of the condition known as arc eye, an inflammation of the cornea caused by ultraviolet light and, in prolonged exposure, possible burning of the retina in the eye.

Conventional welding helmets contain dark face plates to prevent this exposure. Newer helmet designs feature a liquid crystal-type face plate that self-darken upon exposure to high amounts of UV light. Transparent welding curtains, made of a polyvinyl chloride plastic film, are often used to shield nearby workers and bystanders from exposure to the UV light from the electric arc.

Welders are also often exposed to dangerous gases and particulate matter. Additionally, carbon dioxide and ozone gases can prove dangerous if ventilation is inadequate. Furthermore, because the use of compressed gases in GMAW pose an explosion and fire risk, some common precautions include limiting the amount of oxygen in the air and keeping combustible materials away from the workplace.

BASIC GLOSSARY:

Arc Blow: Deviation of the direction of the welding arc caused by magnetic fields in the work piece when welding with direct current.

Straight Polarity: Welding condition when the electrode is connected to the negative terminal and the work is connected to the positive terminal of the welding power source.

Reverse Polarity: Welding condition when the electrode is connected to the positive terminal and the work is connected to the negative terminal of the welding power source.

Slag: The brittle mass that forms over the weld bead on welds made with coated electrodes, flux cored electrodes, submerged arc welding and other slag producing welding processes. Welds made with MIG and the TIG processes are slag free.

Manual Arc Welding: Welding with a coated electrode where the operator's hand controls travel speed and the rate the electrode is fed into the arc.

Semi-Automatic Welding: Welding with a continuous solid wire or flux cored electrode where the wire feed speed, shielding gas flow rate, and voltage are preset on the equipment, and the operator guides the hand held welding gun along the joint to be welded.

REFERENCES & LINKS:

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