Gas Metal Arc Welding of Stainless Steel

TABLE OF CONTENTS

SECTION 1

1

Introduction

This training program was written to give you a better understanding of the MIG welding process. MIG is an acronym for Metal Inert Gas, which is not technically correct for stainless steels because shielding gases for these materials contain an active gas such as oxygen or carbon dioxide. The correct term according to the American Welding Society (AWS) is Gas Metal Arc Welding (GMAW). We will use the correct terminology as defined by the AWS and also explain the slang used so that you will be familiar with all the terms applicable to this process.

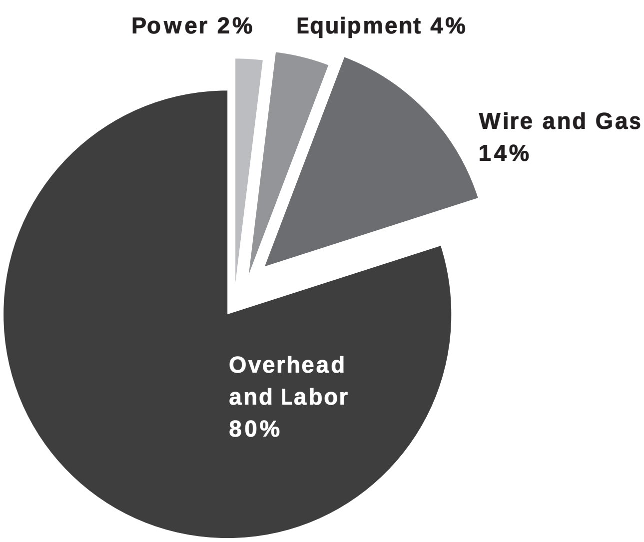


Figure 1 – Breakdown of Stainless Steel Welding Cost

As you learn more about GMAW, it will become apparent that this is a sophisticated process. Welders who have used "stick" welding (Shielded Metal Arc Welding or SMAW) are sometimes of the opinion that the GMAW process is simpler; but to deposit a high quality bead requires as much knowledge as, or more than, with the SMAW process. The reason for this is the number of variables that affect the arc and the degree of control the operator has over those variables.

The purpose of this manual is to make you a better welder by increasing your knowledge of how the GMAW process works. A more knowledgeable welder can be more productive by working smarter, not harder. *Figure 1* shows why your company is interested in educating you in welding stainless steel. Your labor and overhead account for about 80% of the cost of depositing weld metal. Any knowledge you gain from this course not only helps you, but also helps to make your company more competitive in a very tough marketplace. If you should have any questions in the future that this manual or your supervisor cannot answer, please feel free to have him contact your Praxair regional engineering staff for further assistance.

Base Metals

Stainless steels were accidentally discovered in the 1800s when cannon barrels were being cast. They noticed that the castings from a certain ore didn't rust. They had found a load of ore that was high in chromium. Steel is classified as a stainless steel when its chromium content exceeds 10.5%. At this level a thin, invisible oxide layer forms on the surface of the base metal. This adherent oxide layer effectively stops the oxidation (rusting) process. This protective film is self-healing in the presence of oxygen (20.9 %of the make-up of air is oxygen). Carbon steels, of course, form a loose, flaky oxide that we call rust. As this rust flakes off, more of the base metal is exposed to the atmosphere, which allows the corrosion process to continue. Stainless steels are defined as steel alloys where the chromium content ranges from 10.5% to 30%.

There are five distinct types of stainless steel. Each is iron-based with alloying additions designed to modify specific characteristics. The major grades are as follows:

1. Ferritic
2. Austenitic
3. Martensitic
4. Precipitation Hardening
5. Duplex

Ferritic Stainless Steel –
Ferritic stainless steel contains from 10.5 to 30% chromium, is low in carbon, with some alloys containing major amounts of molybdenum, columbium and titanium. These alloys are typically used where corrosion is not severe, such as in automobile exhaust systems, cookware, architectural applications and automotive trim. Ferritic stainless steels are magnetic at room temperatures due to their body-centered cubic crystal microstructure.

Austenitic Stainless Steel –
Austenitic stainless steels contain from 16% to 26% chromium, up to 35% nickel, and have very low carbon content. Some of these steels are also alloyed with a minor amount of molybdenum, columbium and titanium. Austenitic stainless steels are used where corrosion can be severe. They are easily weldable. All alloys of this type are non-magnetic due to their face centered cubic structure at room temperature. Austenitic grades include the 200 and 300 series of stainless steels. The 304 and 316 grades are very commonly used in welded fabrications. Over 80% of today's stainless steel welding applications are done with these types of grades.

Martensitic Stainless Steel –
Martensitic alloys contain from 12% to 17% chromium, up to 4% nickel and .1% to 1.0% carbon. Some alloys will also have minor additions of molybdenum, vanadium, columbium, aluminum and copper. These alloys are used where high mechanical strength, hardness and corrosion resistance are required. They are not easily weldable.

Precipitation Hardening Stainless Steel –
Precipitation hardening alloys contain between 11% and 18% chromium, 3% and 27% nickel and low carbon content. Some of the alloys will also have minor additions of molybdenum, vanadium, columbium, aluminum and copper and boron.

Duplex Stainless Steel –
Duplex stainless alloys have 18% to 28% chromium, 2.5% to 7.5% nickel and low carbon contents. Some of the alloys will also have additions of nitrogen, molybdenum and copper. Duplex alloys have a ferritic and austenitic make-up. They offer the high strength properties of the ferritic stainlesses combined with some of the corrosion properties of the austenitic stainlesses.

How are Stainless Steels Formulated?
In order to understand how stainless steels resist corrosion, let's look at the basic metallurgy of these materials. All metals are crystals, meaning that the atoms are arranged in an ordered matrix. An easy way to visualize a metal is to think of layers of balls with each ball in the layer touching its four neighbors *(see figure 2)*.

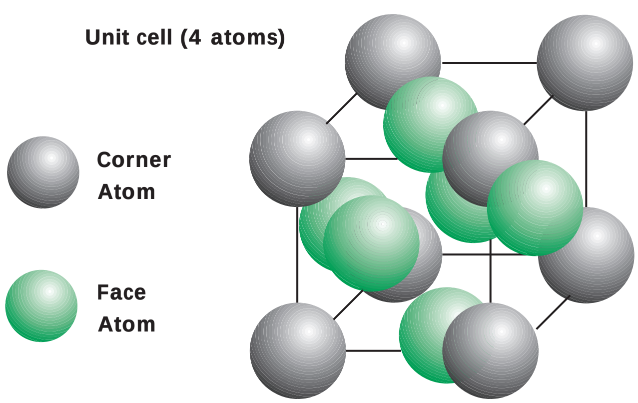


Figure 2 – Iron Face Centered Cubic Unit Cell

The balls represent the atoms of iron, chromium, nickel, molybdenum and other metallic alloying elements.

Carbon and nitrogen are much smaller than the metal atoms, and fit into the open spaces between them. These atoms are called interstitials. The layers above and below the first layer are arranged identically, except that they are shifted on a 45 degree angle to fall into the areas where the first layer of balls intersect. Now each ball in the second plane is touching four balls in its layer and four balls in the layers directly above and below it. The orderly manner in which metals are arranged in crystals is one of the reasons that they are so strong. When a metal yields, or deforms plastically, the planes of atoms slip in relation to adjacent planes. The only single crystal materials used today are for turbine blades. They are extremely strong due to the orderliness of the matrix. They are also extremely expensive to make.

The stainless steel alloys that are used in fabrication are actually made up of grains or groups of crystals. During welding, grains begin to grow into the molten puddle from the solid base metal at the edge of the weld. When two grains contact each other, they stop growing. The intersections of these grains are called grain boundaries. In the types of alloys that we use, a lot of the "slip" or shifting of atoms occurs at these grain boundaries. Because of grain boundaries, the actual strength of these steels is typically 25% to 50% of the theoretical strength of a single crystal of iron.

The following section lists some of the elements that are commonly added to stainless steels to produce alloys that give us the desired properties.

A. Alloying Elements

Carbon

Carbon strongly promotes the formation of austenite that influences material properties. Carbon can strengthen the matrix through the formation of particles such as iron carbide (Fe_3C). The larger size of the carbide compound pins the layers within the metal matrix and makes it much more difficult for the material to yield. Higher levels of carbon in austenitic stainless steel can lead to the formation of chromium carbide ($Cr_{23}C_6$) and a subsequent deterioration in corrosion resistance.

Austenitic grades are typically $\leq$ 0.20% C, ferritics are $\leq$ 0.12% C and the martensitic grades are either $\leq$ 0.15% C or from 0.6 to 1.2% C.

Chromium

Additions of chromium increase corrosion resistance, strength, wear resistance, heat resistance, and the hardness when added to stainless steels. Chromium promotes the formation of ferrite and can form carbide particles that affect the strength of the material. Chromium forms a very tight, adherent oxide layer that resists further oxidation. At elevated temperatures, this layer grows thicker and changes color. This can be seen on motorcycle exhaust pipes. First a straw color is produced (about 700 F), then a blue (about 1,000 F). If chromium levels are decreased in localized areas below about 10% due to chromium carbide precipitation at the grain boundaries, corrosion resistance is decreased.

Columbium + Titanium

Columbium (also called niobium) is added in small percentages and stabilizes austenitic grades by forming columbium carbides (CbC). Titanium, also a stabilizer, preferentially combines with carbon, before chromium, to maintain corrosion resistance in the material. If these stabilizers are not present and carbon levels are high, chromium carbides form in the heat affected zone (HAZ) of the weld, decreasing the corrosion resistance of the material just outside the weld deposit.

Copper

Copper can be used as a strengthening agent in alloys that respond to precipitation hardening. Upon cooling or the application of some other heat treatment cycle, copper forms a precipitate in the matrix, making deformation more difficult and increasing the strength of the material.

Manganese

Manganese is added in small amounts as a deoxidizer, desulfurizer and strengthener. Manganese additions to austenitic stainless grades of steel also reduce the crack sensitivity of the weld metal. Manganese reacts with some of the available free oxygen to form manganese oxide (MnO). It will also combine with any free sulfur to form manganese sulfide (MnS). Sulfur is detrimental because it solidifies at low temperatures and can locate at grain boundaries where it dramatically reduces the strength of the weld metal. After combining with oxygen and sulfur, manganese, a weak carbide former, will form manganese carbide (Mn_3C) which helps to strengthen the matrix.

Molybdenum

Molybdenum, another strong carbide forming element, is used in alloy steels from .5% to 1.5%. Molybdenum improves yield strength and resistance to high temperature deformation (creep). Molybdenum in stainless steels can reduce pitting (highly localized corrosion) in corrosive environments. Molybdenum is a strong ferrite former in a stainless steel weld deposit.

Nickel

While nickel does not form any carbide in a steel matrix, hardenability, ductility and toughness are all improved by the microstructural changes which occur as nickel is added. Nickel is added to austenitic stainless steels (300 series) in concentrations of 7 to 35%. Nickel additions in the 9% range encourage a fully austenitic microstructure. This non-magnetic crystalline structure maintains its strength and ductility to very cold temperatures (-300 F).

Silicon

Silicon is added mainly as a deoxidizer. It combines with oxygen to form SiO_2 ("glass") which floats on the surface of the weld puddle along with manganese oxide (brown, brittle slag islands). Silicon improves the fluidity of the puddle and makes it wet the base metal more effectively. Silicon also promotes the formation of ferrite in a stainless steel weld deposit.

Nitrogen

Nitrogen is a very strong austenite former. It is added in controlled amounts in addition to strong nitride forming elements to produce grain refinement and microstructural modifications in duplex stainless steel. Nitrogen is 30 times more effective than nickel in stabilizing the austenite phase in duplex stainless steel.

Phosphorus

Phosphorus is generally considered an impurity in stainless steels, and is usually listed as a maximum allowable percentage. Phosphorus tends to segregate and push the carbon into the surrounding matrix, causing the material to become brittle.

Sulfur

Sulfur is also considered an impurity. Like phosphorus, it usually is specified with a maximum allowable concentration. Because of its low melting temperature, sulfur in the puddle moves to the grain boundaries of the solidifying weld metal. This segregation at the grain boundaries reduces the strength of the material. Manganese is added to prevent this as it combines with the sulfur (Mn + S = MnS) before it can react with iron. Certain steels called free machining steels, contain up to .3% sulfur; these alloys are difficult to weld and have poor strength when compared to other stainless alloys.

Now that you have more of an understanding of the alloys that are added to stainless steels, let's look at some of the available alloys.

B. Stainless Steel Alloys

The stainless steel designation system is based on a three-digit system for most alloys that specifies the chemistry. The precipitation hardening alloys are an exception to this rule. The “L” designation indicates a low carbon form of that particular alloy.

Table 1 – Stainless Steel Alloys

	% Addition							
SAE/AISI	**Cr**	**Ni**	**Mn**	**Mo**	**C(mx)**	**Si(Mx)**	**Other**	**Tensile**
Ferritic								
405	11.5 - 14.5	–	1.0	–	.08	1.0	.1 - .3 Al	60 ksi
409	10.5 - 11.7	–	1.0	–	.08	1.0	.48 - .75 Ti	55 ksi
430	16.0 - 18.0	–	1.25	–	.12	1.0	.6 Mo	60 ksi
Austenitic								
304	18 - 20	8 - 12	2	–	.08	1		85 ksi
304L	18 - 20	8 - 12	2	–	.03	1		80 ksi
316	16 - 18	10 - 14	2	2 - 3	.08	1		85 ksi
316L	16 - 18	10 - 14	2	2 - 3	.03	1		78 ksi
321	17 - 19	9 - 12	2	2	.08	1	.4Ti min	87 ksi
Martensitic								
410	11.5 - 13.5	–	1.0	–	.15	1.0		100 ksi
420	12.0 - 14.0	–	1.0	–	.15	1.0		250 ksi
440C	16.0 - 18.0	–	1.0	.75	.95 - 1.2	1.0		280 ksi
Precipitation Hardening								
15-5 PH	14.0 - 15.5	3.5 - 5.5	1.0	–	.07	1.0	Cu & Nb	190 ksi
1 7-7 PH	16.0 – 18.0	6.5 - 7.5	1.0	–	.09	1.0	.7 - 1.5Al	210ksi
Duplex								
329	23.0 - 28.0	2.5 - 5	1.0	1 - 2	.20	.75		90 ksi

Electrical Characteristics

A. Constant Voltage Power Supply Basics

The GMAW power supply (or welding machine) connected to the torch is basically a big transformer/rectifier. Its purpose is to take high voltage (575v or 220v) and low current (20-50 amps/leg) AC power and transform it to low voltage (16-40v), high current (80-500 amp) DC power. To change AC to DC, a device called a rectifier is used. Direct current is utilized as it provides a much more stable arc. Most GMAW power supplies are set-up using a reverse polarity connection. Reverse polarity is designated as DCEP, which means Direct Current, Electrode Positive. An easy way to remember this is:

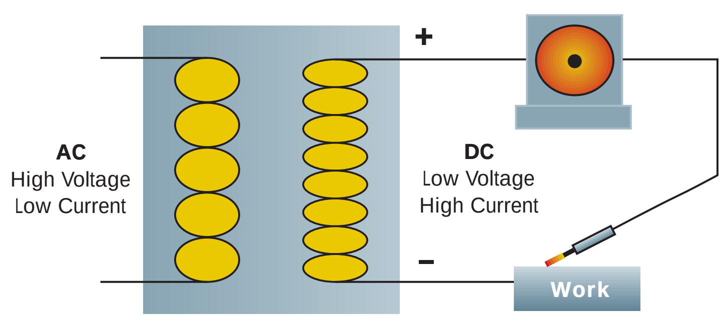
Congress is made of:

SENators And **REP**resentatives

Straight **E**lectrode **N**egative

Reverse **E**lectrode **P**ositive

Almost all GMAW power supplies are constant voltage machines, while Stick Electrode (SMAW) and TIG (GTAW) machines are a constant current design.



Reverse Polarity - DCEP (DC - Electrode Positive)
Straight Polarity - DCEN (DC - Electrode Negative)

Figure 3 – Typical GMAW Power Supply

B. Constant Voltage Power Supply Controls

All constant voltage (CV) power supplies have at least two operator-adjustable settings: current and voltage. Current is set by adjusting the wire feed rate; voltage is set with a voltage adjustment on the power supply or on the remote control. Increasing wire feed speed increases current proportionally so that enough current is available to melt the wire and deposit it in the weld pool. Voltage adjusts the length of the arc.

Some power supplies also provide the options of adjustable slope and inductance. The purpose of these controls will be discussed in the section on power supply characteristics. *Figure 4* shows a power supply with the standard voltage (arc length) and wire feed speed (current) adjustments. This power supply also allows the operator to change the inductance and slope.

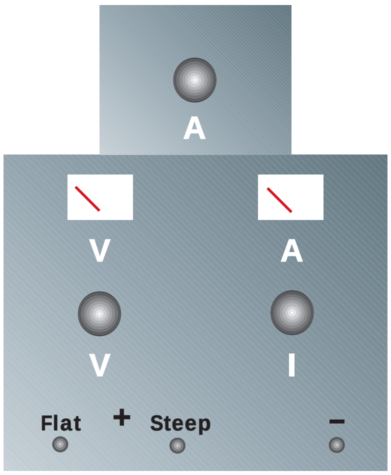


Figure 4 – Power Supply Adjustments

C. Electrical Stick-Out

Electrical stick-out (ESO) is the distance measured from the contact tip in the torch to the workpiece, as *figure 5* shows. ESO is very important, and does affect the following:

1. Preheats the electrode
2. Burns off drawing lubricants
3. Determines current level

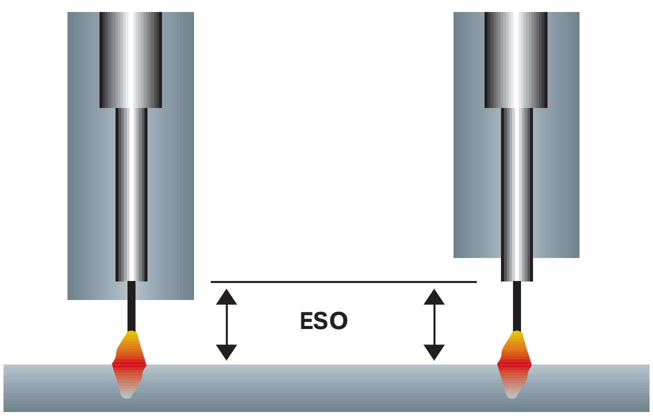


Figure 5 – Measuring Electrical Stick-Out

The wire in the GMAW process is called an electrode because it conducts electricity. The current is transferred to the wire at the contact tip. The energy resulting from the welding current is distributed to two different places in the welding circuit; **(1)** resistance heating of the electrode, and **(2)** penetration into the base metal, as *figure 6* shows. The electrode acts like the elements in a home toaster. As current passes through it, resistance heating occurs and its temperature rises. The increased temperature burns off drawing lubricants used in the manufacturing of the wire. The temperature rise also helps make it easier to melt the electrode. This is the reason that deposition rate increases as ESO increases. As ESO increases, current is decreased. This also helps to keep the contact tip cooler at higher deposition rates. This is a big help in controlling penetration, because as current increases, so does the depth of penetration. By using a slightly longer stick-out, more weld metal can be deposited without burning through thinner parts. This is a useful trick when welding light gauge stainless steel, as base metal distortion is reduced with an increase in the ESO. Increasing ESO makes the arc harder to start because less current is available at the arc due to resistance heating. As more resistance is put into the welding circuit (increased ESO), the effective slope of the system is also increased. This reduces the short-circuit current available to start the arc.

ESO also affects shielding gas coverage. As the distance increases from the contact tip to the work (also called TWD – tip to work distance), you reach a point where the shielding gas cannot effectively blanket the molten weld puddle. This will be covered in more detail in the shielding gas section.

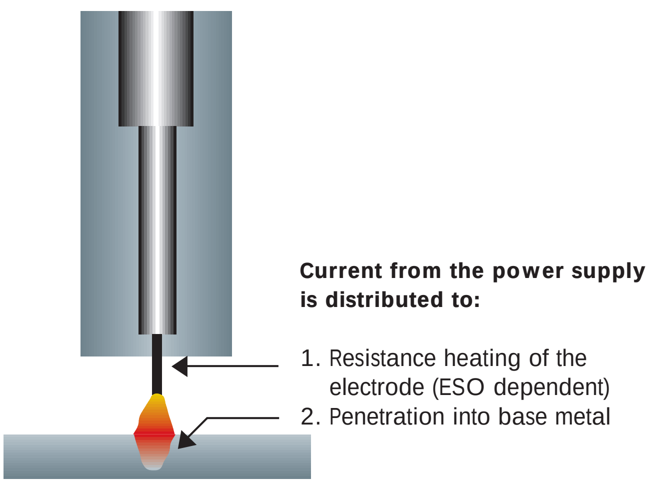


Figure 6 – Current Distribution

D. Constant Voltage Power Supply Characteristics

1. Slope

The characteristics of a power supply are determined by the components used in its design. The performance of a typical machine is described by a graph such as *figure 7*. Most constant voltage power supplies without slope adjustment are factory preset at about 2 volts/100 amps (flat slope).

Figure 7 – Power Supply Characteristic Curves

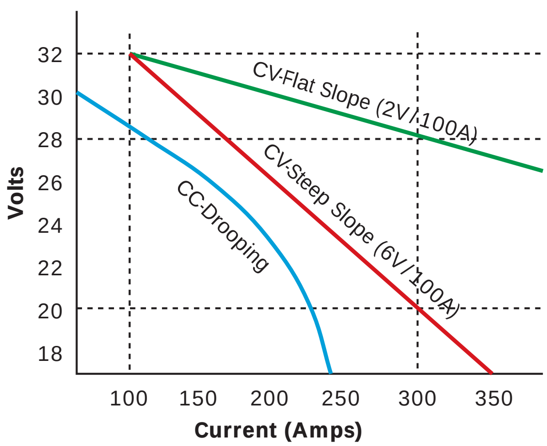
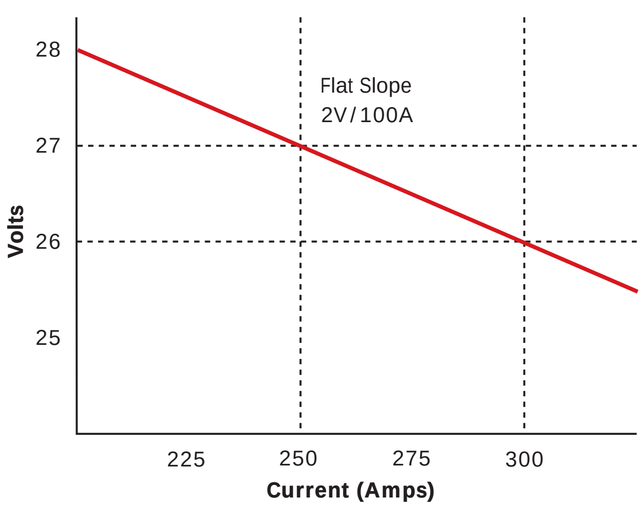


Figure 8 – The Effect of Slope on Current and Voltage



This means that for each increase of 100 amps, the power supply will produce 2 volts less without a change on the voltage control. The lower slope line is 6 volts/100 amps, and is about the maximum slope seen in a constant voltage power supply (steep slope). A few machines are still available with continuously adjustable slope; others have external or internal taps to switch between slopes. Increasing the slope of a power supply to control short-arc welding at low currents is necessary because the short-circuit current is limited. This reduces the tendency to burn-through on thinner materials and decreases spatter on arc starts. This will be explained further in the section on metal transfer. Again, this is a very good feature to have when welding stainless steel as it helps to lower weld spatter when working in the short-arc range (14-22 volts).

Figure 8 shows a typical 2 volt/100 amp slope power supply characteristic curve. A review of this graph helps to explain why the arc changes during welding. As an example, select a welding condition of 27 volts and 250 amps. As welding continues, if the stick-out (ESO) is reduced the welding conditions change. As that change is made, the spatter level begins to increase. As ESO is decreased, less current goes into preheating the wire and more goes into the arc. Suppose the current increases 50 amps, which is easily done with a torch movement of about 1/4". This moves the operating point to the second point in *figure 8;* here the voltage decreases to 26v while the current increases to 300 amps. This voltage is at the minimum for spray transfer; this would account for the slight increase in spatter that is observed. This will be explained in more detail in Section 6.

Measuring Actual Welding Voltage

Measuring actual welding voltage is a useful way to be certain that the condition is within the range specified by the welding procedure. Hard starts can result from bad connections in the welding circuit. The voltage drop due to bad connections increases the slope of the system, and reduces the available short-circuit current. Comparing the voltage at the power supply terminals and between the feeder and the work *(figure 9)* will give the voltage drop due to resistance.

Figure 9 – Measuring Actual Welding Voltage

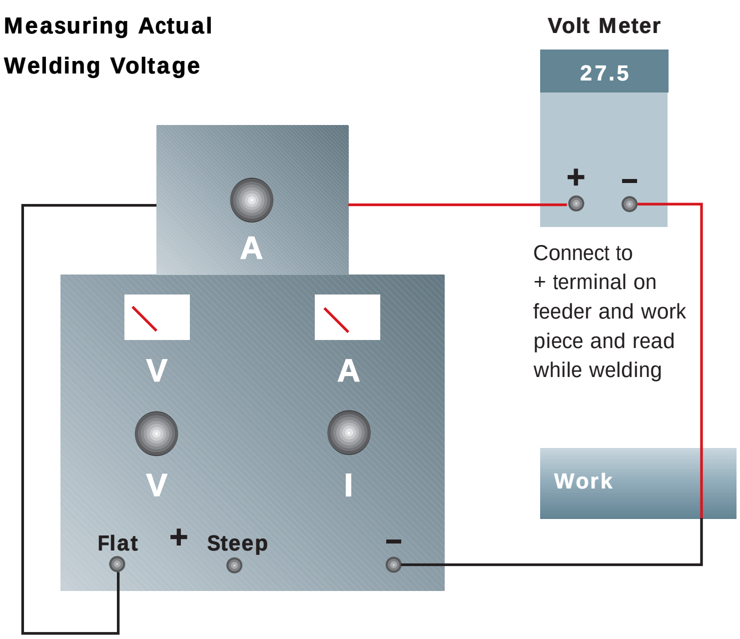
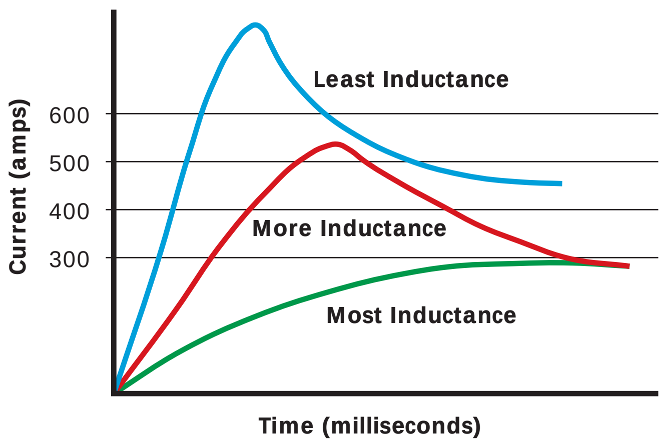


Figure 10 – The Effect of Increasing Inductance



It can measure as high as 5 volts which makes starting the arc difficult and generates more weld spatter.

2. Inductance

Inductance is an adjustment that is provided more frequently than slope on CV power supplies. Inductance is another method for controlling the arc. This is done by controlling the rate at which the welding current reaches the setting selected. *Figure 10* shows a plot of inductance vs. time. The top curve shows what happens with no additional inductance and the current rises as quickly as the power supply will allow it to rise. This can result in very hot starts or even in the wire exploding at these very high current levels. Inductance should be kept low for spray transfer. This produces better arc starting and more stable arc at high currents. High inductance settings can make it hard to initiate the arc because it limits the maximum short-circuit current available for this purpose.

Referring again to *figure 7*, as the electrode first touches the work to strike an arc, the voltage falls to 0 arc volts. At 0 volts (no arc length or a dead short), the power supply produces the maximum short-circuit current. For a machine rated at 450 amps (at 100% duty cycle) this might be 550-600 amps. This can be enough current to explode the wire and make the arc difficult to start. If the arc start is too hot, either the slope can be increased or inductance added to reduce the current at arc initiation. Inductance can also be beneficial when welding with low current short-arc, as it makes the puddle more fluid and allows it to better wet the base material.

3. Heat Input

A useful formula often used by welding engineers is the heat input equation. If you have been welding high strength or corrosion resistant alloys, you may already be familiar with this formula. It allows you to calculate the amount of heat delivered to the workpiece.
The formula is:

$$\text{Heat Input} = \frac{\text{Amps x Volts x 60}}{\text{Travel Speed (in/min)}}$$

Heat input is measured in units of energy/unit of length (joules/inch). A joule is a unit of energy equal to 1 watt of energy into the workpiece per second. While a joule is not a familiar unit of measurement, there are a lot of uses for the heat input formula itself.

For example, suppose that welding is done at the second condition used as an example in *figure 8*. That condition was 300 amps and 26 volts. For this example, say the travel speed is 10 in/min. This works out to a heat input of 46,800 joules/in. If we know that the welding involves bridging a gap, ESO can be increased to reduce current and increase voltage while reaching the first condition indicated. That was 250 amps and 27 volts, still at 10 in/min. The heat input is now 40,500 joules/in. By increasing ESO (stick-out), heat input has been reduced by almost 15%.

The heat input formula is also used when welding high alloy materials, but it also helps in understanding the uses of the power supply characteristic curve.

The heat input formula can assist in preparing welding procedures where similar material thicknesses and joint configurations are welded. After determining the range of heat inputs that produce an acceptable weld, the range of heat inputs can be calculated. This is really helpful in increasing speeds for robotic welding. The required travel speed can be calculated as wire feed speed (current) and voltage are increased. The formula is also helpful in controlling distortion. Conditions that put less energy into the metal can be calculated, which reduces distortion.

SECTION 4

4

Shielding Gases

At high temperature, all metals commonly used for fabrication will oxidize in the presence of the atmosphere. Every welding process provides shielding from the atmosphere by some method. When welding steels we want to exclude oxygen, nitrogen, and moisture from the area above the molten puddle.

In the **Oxy-fuel process,** the weld pool is shielded from the atmosphere by the combustion by-products of carbon monoxide (CO) and carbon dioxide (CO_2). In stick welding (SMAW), CO and CO_2 are also the shielding gases. The 60XX type of electrode uses a cellulosic coating, which has very high moisture content. The moisture produces oxygen and hydrogen in the arc environment.

Submerged-arc welding shields the puddle by a different method. As the puddle progresses, the intense heat melts the flux in the joint area; this forms a slag that covers the weld and excludes the atmosphere.

GMAW (MIG) and **GTAW (TIG)** are both gas shielded processes in which the shielding gas is provided from an outside source. No fluxing agents are included in the filler metal of solid wires.

A. Shielding Gas Functions

For the purpose of this discussion the GMAW process will be emphasized because it constitutes the greatest portion of welding done in industry. A good portion of this information is applicable to GTAW too.

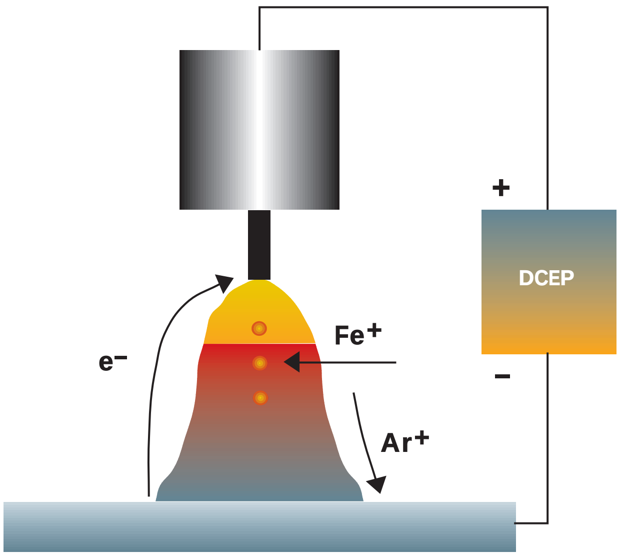
The major functions of a shielding gas are to:

1. Protect the puddle from the atmosphere
2. Support the arc plasma
3. Provide oxygen for wetting (ferrous alloys)
4. Control type of metal transfer
5. Affect arc stability
6. Control welding costs.
7. Impact the penetration properties of the weld deposit.
8. Impact welding fume levels.

As was mentioned earlier, the atmosphere must be displaced while the puddle is cooling or oxidation will occur rapidly. This appears as a gray surface on the weld bead. One cause of porosity is the result of poor shielding when atmospheric oxygen combines with carbon in the puddle. As the weld metal cools, porosity occurs as this carbon monoxide escapes from the center of the bead. If air is aspirated into the shielding gas line through a leak, nitrogen and moisture will also contaminate the shielding gas. Nitrogen, while very soluble in the puddle at high temperatures, will cause porosity as it escapes during cooling of the weld bead.

The shielding gas also provides a portion of the arc plasma, which transfers the welding current across the gap between the electrode and the work as *figure 11* shows. This is accomplished by "ionizing" the gas, which frees electrons to transfer the current from the work to the electrode. Metallic and argon ions (atoms stripped of an electron) transfer the positive charge across the arc. This explains in part why the arc becomes very unstable when a MIG torch is hooked up using straight polarity (DCEN) rather than reverse polarity (DCEP). In DCEN, the positive current is trying to remove metal atoms from the plate, which are much harder to melt than a small diameter electrode.

Figure 11 – Transfer of Current across the Arc Plasma



In steels (carbon and stainless), oxygen stabilizes the arc and reduces the surface tension of the weld metal. Oxygen is obtained from direct additions of oxygen or carbon dioxide to the shielding gas. Surface tension, the force that causes water to bead up on a waxed car surface, is not desirable when depositing a weld bead. In GMAW, if pure argon is used instead of a mixed gas, the bead does not wet out and appears as though it is sitting on top of the part surface (convex bead).

Figure 12 shows the basic gases used in shielding GMAW. The ionization potential is the amount of energy (in electron volts) required to establish an arc. The use of a helium rich gas such as Praxair's HeliStar™ A-1025 blend ($He/Ar/CO_2$) for short-and pulse-arc welding of stainless steel requires 3-5 volts more than an Ar/CO_2 mixture at the same current. The shielding gas used also has a pronounced effect on the type of metal transfer obtained.

Gas	Characteristic	Ionization Potential (eV)
Ar	Totally Inert (Cool)	15.759
He	Totally Inert (Hot)	24.587
O_2	Highly Oxidizing	13.618
CO_2	Oxidizing (Dissociates)	13.769
H_2	Highly Reducing	13.598

Figure 12 – Gases Used for Shielding

There is a "best gas" for almost every application, but there may be 2 or 3 gases that will do a very reasonable job over a large variety of applications. Gases are selected on the basis of performance, availability, cost and many other variables. Further discussion of gases and metal transfer is found in *section 6*.

Stability of the arc plasma is another factor influenced by the shielding gas. Pure argon provides a stable arc, and is used when welding reactive metals such as aluminum. Argon/oxygen mixtures are also very stable, and are used in steel welding applications. Pure carbon dioxide provides a less stable arc plasma, but its addition to argon can be very beneficial where depth and width of penetration need to be controlled. Some shielding gases use additions of oxygen and carbon dioxide in one mixture. Blends for stainless steels may also use additions of helium and hydrogen with a carbon dioxide component.

B. Flow Rates

Once the shielding gas is selected, it is critical to make sure that the flow rate is within certain limits. For low current short-arc applications, 25-35 scfh (standard cubic feet per hour) is adequate if ESO is held from 3/8" to 1/2". For high current short-arc and the spray transfer mode, flow rates need to be increased to the 35-45 scfh range. *Figure 13* shows the best way to measure the flow rate using a torch flowmeter.

Regulator-flowmeters can vary the inlet pressure to the flowmeter. As inlet pressure falls when a cylinder gets low, the flow rate is actually skewed to a higher reading. For example, a regulator-flowmeter, installed in a low pressure line (20 psig), showed a flow reading of 70+ scfh, but the actual flow rate was 15 scfh. The regulator had reduced the pressure in the flowmeter to about 5 psig instead of the correct design pressure of 50 psig. Flow rates must be kept in a controlled range so that the shielding gas column does not become unstable and mixes with air at both low and high flow rates or when forced to flow past an obstruction in the nozzle such as spatter. This type of flow is called turbulent (non-axial flow).

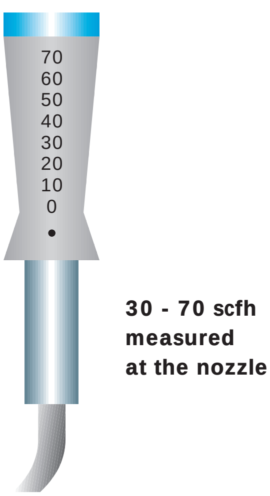
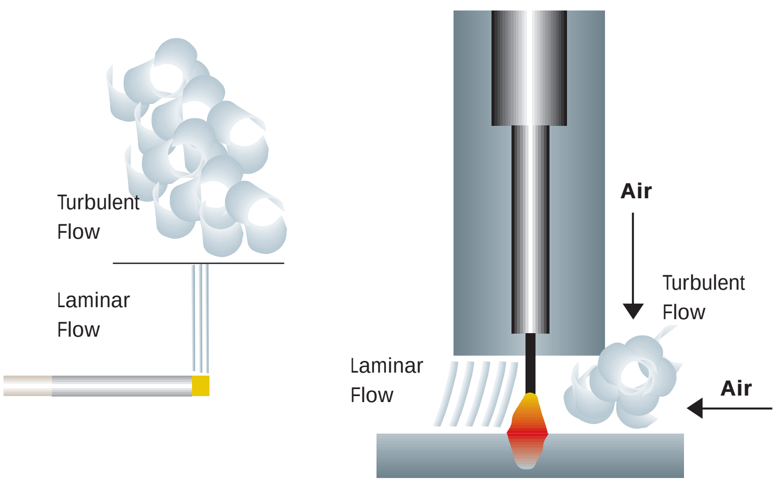


Figure 13 – Measuring Actual Flow Rate

Testing has shown that the shielding gas flow remains laminar from 30 scfh up to about 70 scfh with a 400 amp gun (using a 5/8" diameter nozzle). Above 70 scfh, the flow becomes turbulent and mixes with air. A cigarette in an ashtray can illustrate the difference between laminar and turbulent flow. The smoke initially leaves the tip, in a tight, orderly laminar flow. A few inches above, the flow becomes turbulent and the smoke mixes with the air rapidly as shown in *figure 14*. This same thing happens with a column of shielding gas. The erratic quality of the shielding can provide a weld that looks satisfactory, but can contain subsurface (honeycomb) porosity. As deposition rates increase, a 35-45 scfh flow rate is still satisfactory unless there are breezes or drafts. Fans and drafts will displace a shielding gas, and may require increasing flow rates to 50-70 scfh. Reducing cup-to-work distance can also improve shielding.

Figure 14 – Laminar and Turbulent Flow



C. Gas Losses

Loss of shielding can cause problems in GMAW. Inadequate gas coverage can result in an oxidized surface or porosity. The first step in troubleshooting what you think may be a gas loss is the use of a torch flowmeter. This flowmeter fits over the nozzle on a torch and measures the actual flow rate of your shielding gas *(figure 13)*. Compare the actual reading with that of the station flowmeter (if used). The two readings should be very close to each other. If not, there may be some potential problem areas.

Threaded Connections are notorious for leaking if not properly sealed. A pipeline with shielding gas at 50 psi can leak a lot of expensive gas. **It will also allow air to diffuse in,** as *figure 15* shows.

If the leak is large enough, no amount of flow can give a good quality weld. A pressure test of your distribution system can quantify the leak rate. Use a liquid leak detector to pinpoint any leaks.

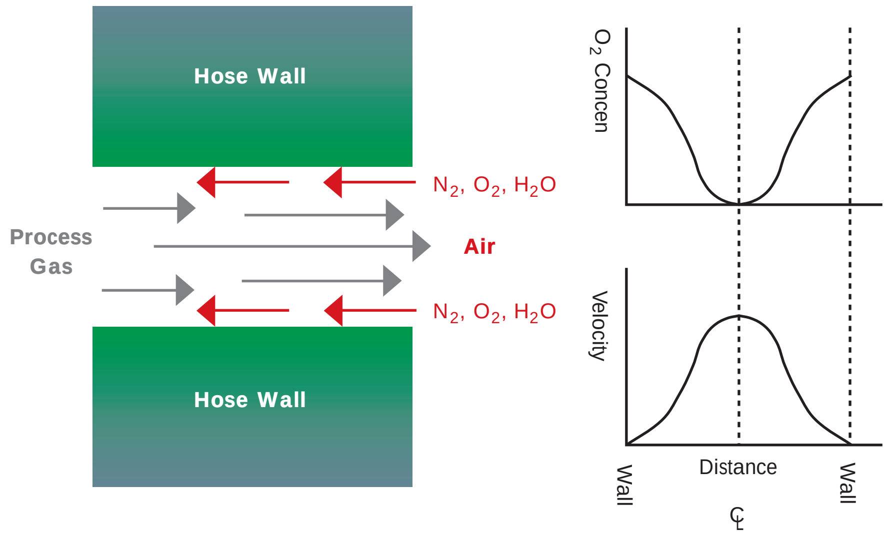
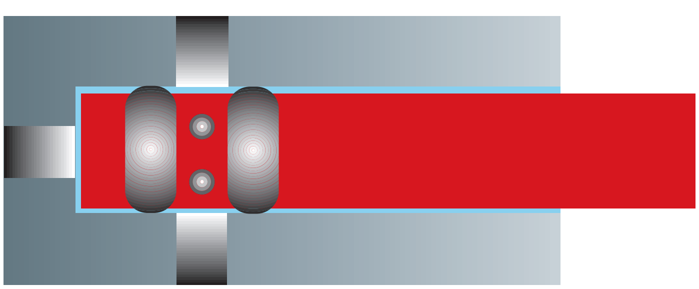


Figure 15 – Back Diffusion Allows Air to Leak into a Pressurized Line

A few shops use **quick disconnects** for their shielding gases. They are also prime suspects when investigating leaks. For this reason, they are not recommended for use with shielding gases. Use a liquid leak detector solution to check them. If the flow measurement at the torch indicates a much lower flow than the station flowmeter, find the source of the problem by disconnecting the supply hose at the wire feeder. Use the torch flow meter to check the flow out of the hose. If the flow meter is correct, check if a **leaking fitting or if the o-rings in the back of the liner** have been damaged *(figure 16)*. These can be easily replaced, and should be lightly coated with silicone grease to avoid damaging them during reinstallation.

Figure 16 – O-Rings Seal the Gas Ports at the Feeder

Lube O-Ring with silicone grease before installing



Another place where **shielding gas flow can be disrupted is in the diffuser.** The gas diffuser is found at the point where the contact tip is mounted. Its purpose is to distribute the gas evenly to produce laminar flow out of the gas nozzle. If spatter builds up on the diffuser, it can clog it and reduce the gas flow enough to provide poor shielding. If the diffuser is only partially blocked, the entire gas flow may try to exit the holes still open and create unbalanced turbulent flow. This in itself will aspirate air into the shielding gas column and may once again cause porosity.

Figure 17 –
Air Aspirated by the *Venturi* Effect can Contaminate the Shielding Gas

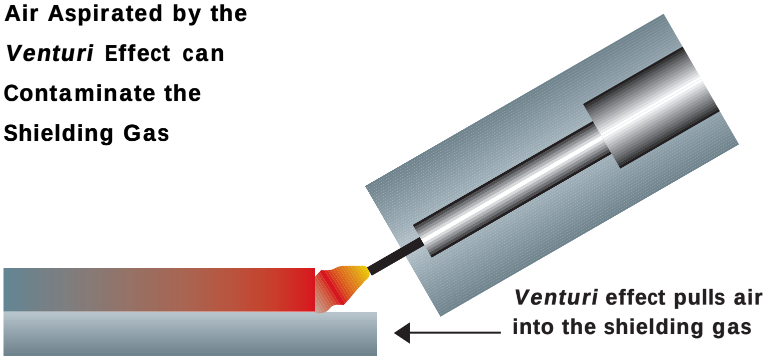


Figure 18 –
Pressure Correction Formula for Flowmeters

Example: A flowmeter calibrated at 20 psig on a 50 psig line indicating 40 scfh

$$\text{Actual Flow Rate} = \text{Indicated Flow Rate} \times \sqrt{\frac{\text{Actual Pressure (psia)}}{\text{Calibration Pressure (psia)}}}$$

$$\text{Actual Flow Rate} = 40 \text{ scfh} \times \sqrt{\frac{50 + 14.7}{20 + 14.7}}$$

$$= 40 \times 1.37 = 54.6 \text{ scfh}$$

Holding the torch at too small an angle can also create a *venturi* effect between the plate and the nozzle. This will contaminate the shielding gas stream with air and cause porosity *(figure 17)*.

Some welders clean spatter from nozzles by tapping the gas cup against the work to knock the spatter out. This can create a problem by eventually causing the cable to gooseneck and the gas connection to loosen, or by distorting the gas nozzle. If either happens, it is possible to lose your gas coverage in the torch handle and aspirate air into the shielding gas stream.

One final thing to check is **incorrect inlet pressure to the flowmeter.** All flowmeters are calibrated for one specific inlet pressure, and the actual flow reading will be incorrect if the inlet pressure does not match the calibration pressure. *Figure 18* shows what happens when a 20 psig calibrated flowmeter is attached to a 50 psig line. The actual flow is 26% higher than indicated on the flowmeter. The easiest way to check this is by using a torch flowmeter, because it is calibrated for atmospheric pressure at the outlet.

Although a welder doesn't often get the chance to select the filler material, this section is included for your information. Knowing how and why wires are alloyed can sometimes be helpful when a problem arises.

A. Filler Metal Alloying Additions

This listing found in *figure 19* shows the main alloying elements used in stainless steels and the reasons for their addition. These are the same constituents that are used in filler metals, although the proportions may be different.

Chromium – Chromium is added to improve corrosion resistance of the deposited weld metal. The chromium level in the filler metal is usually selected to match or exceed the amount found in the base material.

Nickel – Nickel, also added for corrosion resistance, improves low temperature mechanical properties of the deposited weld metal. Nickel promotes the formation of austenite in the weld structure.

Stainless steel is iron that is alloyed with	
Chromium	Corrosion Resistance
Nickel	Corrosion Resistance
Silicon	Deoxidation
Manganese	Deoxidation & Strength
Molybdenum	Increased Pitting Resistance
Niobium	Combines with Carbon

Figure 19 – Stainless Steel Alloying Additions

Silicon – Silicon acts to deoxidize the weld puddle. Silicon reacts with oxygen in the weld puddle before metallic elements such as iron and chromium. This deoxidation cleans the puddle, and silicon dioxide impurities float to the surface of the puddle. They then freeze (along with manganese dioxide) to form slag islands. Silicon is also added in higher concentrations to some filler materials to improve the fluidity of the puddle. When silicon reacts with oxygen, heat is released (exothermic reaction) which makes the puddle more fluid. High silicon wires can create more slag islands that may cause more grinding in multi-pass weldments. High silicon wires are not recommended for joints under extreme restraint as the crack resistance of the standard filler metals is superior.

Manganese – This element is added for three reasons: **(1)** Deoxidation. Manganese combines with oxygen in the weld metal before the carbon does so there is little or no oxidation of carbon in the weld puddle (which produces carbon monoxide and causes porosity.) **(2)** Desulfurization. Manganese combines with sulfur to form manganese sulfides before the sulfur can segregate to the grain boundaries and form low melting point iron sulfides. Iron sulfides can cause hot cracking in steels.

(3) Mechanical properties. Manganese can be used in place of nickel to stabilize the austenite phase and increase resistance to weld metal cracking.

Figure 20 – Deoxidation Reactions

Liquids

$Si + 2O \rightarrow SiO_2$

$Mn + O \rightarrow MnO$

Gases

$C + O \rightarrow CO$

$C + 2O \rightarrow CO_2$

Molybdenum – Molybdenum reduces the occurrence of pitting (high localized corrosion) in corrosive environments. In stainless steels it is also a strong ferrite former. Stainless steel wires that are high in molybdenum are easily identified as they usually have a suffix of Mol (ex. 317L Mol).

Columbium (Niobium) and Titanium – These act to stabilize the structure and properties of the weldment by preferentially combining with carbon to form columbium and titanium carbides. This prevents a loss of chromium that can result in sensitization (loss of corrosion resistance).

B. Wire Designations and Chemistries

The stainless steel wire designations used in the United States and Canada are specified by the American Welding Society (AWS). The classification system is based on the chemical composition of the filler wire for solid wires and on the deposited weld metal for tubular or composite electrodes. Designation nomenclature is shown in *figures 21 and 22*.

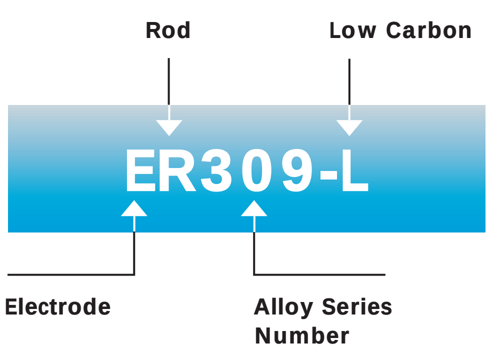


Figure 21 – AWS Solid Wire Designation

For solid wires:

E – Indicates that this wire is suitable for use as an electrode, and it can carry welding current.

R – Means that this electrode is available either as a continuous wire or as a distinct length rod. Rods are used as filler in the GTAW (TIG) process.

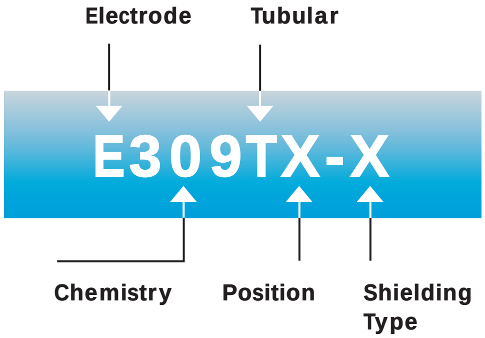
309 – The alloy designation indicates a particular chemistry range met by this consumable.

L – This indicates a lower maximum carbon level for the standard electrode of this composition (usually 0.03%).

Si – When added, this designation indicates a higher level of silicon designed to improve fluidity of the weld puddle.

Mol – When added, this designation indicates that a higher level of Molybdenum is added to the filler metal to improve corrosion resistance (when pitting corrosion is a problem.)

Figure 22 – AWS Tubular Wire Designation



For Tubular Wire:

E – Designates an electrode which carries current. No R is used because cut lengths of tubular wires are not available. The alloy designation here indicates the chemical composition of the weld metal deposited with this wire, not the composition of the wire itself.

T – This indicates the filler metal is a tubular, or fabricated wire.

X – The indication of "0" (flat and horizontal) or "1" (all position) immediately after the "T" indicates the normal welding position for this product.

X – The indication after the "dash" describes the type of shielding to be used. "1" is CO_2, "3" is none, "4" is Ar/CO_2, and "5" is 100% argon.

Figure 23 shows the chemistries of some of the more common filler metals.

Figure 23 – Common Filler Metal Chemistry

Wire	Cr	Ni	Si	Mn	Mo
308	18-21	9-11	.3-.65	1-2.5	.75
309	23-25	12-14	.3-.65	1-2.5	.75
309L	23-25	12-14	.3-.65	1-2.5	.75
316	18-20	11-14	.3-.65	1-2.5	2-3
316L	18-20	11-14	.3-.65	1-2.5	2-3
321	18.5-20.5	9-10.5	.3-.65	1-2.5	.75

C. Solidification of the Weld Puddle

Figure 24 shows how a weld puddle cools and solidifies. At the weld puddle to base metal interface, crystals begin to grow into the molten weld pool. This is very similar to the growth of ice crystals on a window seen in time-lapse photography. The crystals are called grains, and where they meet and stop growing is called the grain boundary. As the metal solidifies, the solubility of gases decreases greatly. If there is just slightly more oxygen in the puddle than manganese and silicon available for deoxidization (and also possibly nitrogen), these gases will be pushed to the centerline as the puddle freezes. This causes porosity along the solidification line and is known as centerline porosity. Larger amounts of contamination can cause gross porosity in the weld and lead to the condition shown in the bottom illustration in *figure 24*.

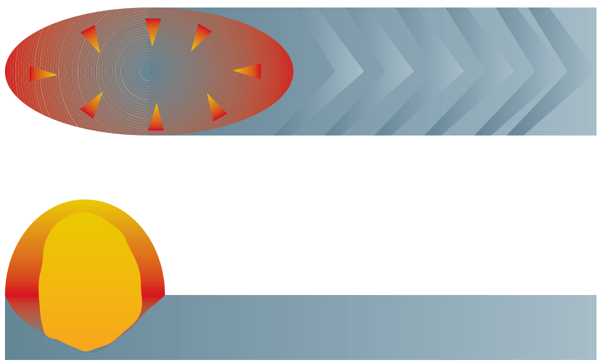


Figure 24 – Solidification of a Weld

As the weld is finished, the cooling rate at the crater increases because the weld is losing heat in all directions. This rapid cooling rate leaves less time for the gases to leave the puddle, and a hollow gas cavity can form at the crater.

Calculation of Deposition Rates

A very useful piece of information needed when calculating the cost of welding is the deposition rate. The deposition rate is usually stated in pounds of wire per hour of weld time. *Figure 25* shows the multipliers that can be used to determine deposition rate for different diameters of solid wires. The multiplier is a factor that takes into account the cubic inches of wire per hour consumed and the density of steel, to arrive at the rate in pounds per hour. To calculate the deposition rate of an .045" diameter wire at 500 ipm wire feed speed, multiply the 500 ipm times the .027 multiplier, and determine a rate of 13.5 lbs/hr of arc-on time. To determine the actual amount of metal deposited, multiply this weight by the duty cycle (% of an hour that the arc is actually on) and the deposition efficiency of the process.

Wire Diameter	Multiplier
.030	.012
.035	.0163
.045	.027
.052	.0361
.0625	.0521

Example: an .045 wire at 500 ipm

500 ipm x .027 = 13.5 lbs/hour

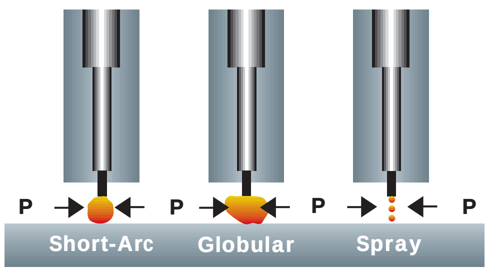
Figure 25 – Calculating Deposition Rates for Solid Electrodes

Metal Transfer

An understanding of metal transfer is very helpful when trying to solve a welding problem such as "why is there so much spatter?" or "how can more penetration be obtained?" In this section, electrical characteristics, wires and shielding gases all come together. There are four major types of metal transfer that will be discussed. They are:

1. Short-Arc
2. Globular Transfer
3. Spray Transfer
4. Pulsed Spray Transfer

Figure 26 – The Pinch Effect Tries to Pinch off the End of the Electrode



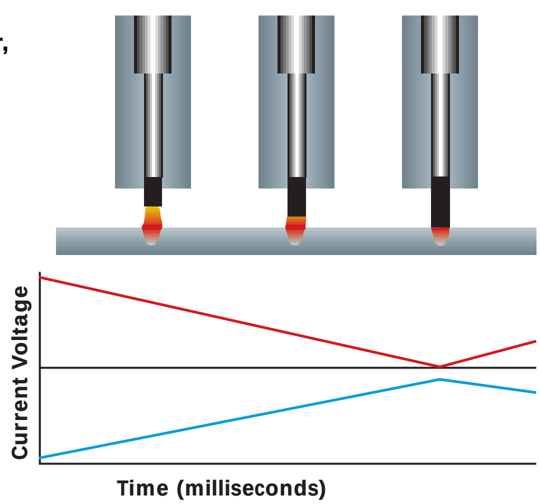
The pinch effect is a function of current

Figure 26 shows the pinch effect. The pinch effect is a function of current, and tries to pinch off the molten tip of the electrode. Higher currents and smaller areas increase the pinch effect and give cleaner metal transfer with less spatter.

A. Short-Arc

Short-arc or short-circuit transfer is basically a low heat input, low penetration process. Currents range from 40 to 50 amps (.023" wire) up to 250-275 amps (0.052" diameter wire). Voltage ranges from 14 to 21v. This process is a good choice on thin material and sheet metal and has been used extensively for out-of-position MIG welding. Short-arc is also a good choice where bridging gaps is a problem.

Figure 27 – In Short-Arc Transfer, the Electrode Shorts 60-120 Times Per Second



This form of metal transfer is called short-arc because the wire does electrically short to the workpiece. When the wire touches the base material, the arc goes out, and the current flowing through the wire begins to rapidly raise the temperature of the wire. As seen in the power supply characteristic curve, at 0 volts the power supply tries to produce a maximum current output. When the wire reaches its melting point, it flows into the puddle and the arc reignites. This shorting takes place very rapidly, from 60 to 120 times per second. *Figure 27* shows the droplet of molten weld metal pinching off just before the arc reignites in the third illustration.

After adjusting the wire feed to do the job, the voltage can be fine-tuned to where the sound from the arc becomes smooth and very regular (similar to the sound of bacon frying). Electrical stick-out must be closely controlled as it has a great impact on current levels. At the low-end condition of 40-50 amps and 14-15 volts with a .023" electrode, stick-out should be about 1/4". With a .035" electrode at 80-90 amps and 15-16 volts, ESO should be about 3/8". Also, the contact tip should extend out of the gas nozzle from 1/8" to 3/16" to increase current and arc stability at low currents. At the high end of short-arc transfer with a .045" electrode, current will be at 225-235 amps and 20-22 volts. Because of the high current levels, we increase the ESO to preheat the electrode and reduce the current. The ESO with these conditions would be in the 5/8"-3/4" range. This method gives a very controllable arc. If the arc is unstable, the usual cause is that the ESO is too long or voltage is too high. There should be very little spatter with this process, regardless of shielding gas. Argon mixtures, however, provide smaller droplets with better gap bridging and arc stability as a result.

To adjust the power supply for short-arc transfer, two variables can help, if they are available. The slope on some machines is adjustable, either externally or with internal taps. *Figure 7* shows that the steeper curve will limit the maximum current that the power supply can deliver, which is a real benefit when short-arc welding at low currents on thin materials. If the majority of your work is in the short-arc range, it is probably worthwhile to change an internal tap if the machine has one.

A power supply that has an inductance control is easier to use for short-arc transfer. As shown in *figure 10,* adding inductance slows the rate of current rise. With this available, after wire feed and voltage are adjusted, inductance should be increased to the point where the metal begins to transfer smoothly. By increasing the inductance, the current rises at a slower rate, and is at a lower level when the cycle begins again than it would be without the inductance in the circuit. Limiting short-circuit current reduces explosive, harsh metal transfer. Most short-arc welding is done with .023", .035" or .045" electrodes. Larger wires require too much current for most applications.

Gas blends for welding stainless steel that work well in short-arc transfer are He/Ar/CO_2 mixtures (Praxair's HeliStar™ A1025 and SS), Ar/CO_2 mixtures with less than 5% CO_2 (Praxair's StarGold™ C-2 and C-5), Ar/O_2 mixtures with less than 3% O_2 (Praxair's StarGold™ O-1 and O-2) and hydrogen-enhanced mixtures (Praxair's HydroStar™ gas blends). As wire feed (current) increases, it is advantageous to reduce the amount of carbon dioxide used to make the weld puddle less fluid and easier to control. Burn-through is also reduced. On thinner materials, gases lower in carbon dioxide minimize burn-through thus permitting higher currents and travel speeds. Helium is also added to the shielding gas in some stainless steel welding applications. It adds energy to the arc, allowing better wetting characteristics at lower welding current levels.

B. Globular Transfer

Globular transfer is usually not the recommended way to deposit weld metal because of the inefficiency of the process. This type of transfer produces the most spatter. Depending on the current range, shielding gas and power supply settings, globular transfer can waste 10-15% of the weld metal as spatter. Because of the inefficiency of the process, slower travel speeds or smaller bead sizes result at wire feeds comparable to spray or short-arc transfer.

When the tip of the wire begins to melt in globular transfer, as shown in *figure 28*, it only shorts to the workpiece occasionally, due to higher voltages. The inconsistent cracks and pops you hear are the breaking of the short circuits. Unlike short-circuit transfer, an arc is present most of the time, and the metal begins to form a ball on the end of the wire. This ball is held by the surface tension and the force of the arc. The arc is continuously moving to the place where the glob of metal is closest to the work, where the minimum voltage is required to sustain the arc. This creates the instability that you see and hear in the arc when the surface tension and the force of the arc are finally overcome by gravity the glob transfers. As the glob of metal hits the work, it tends to splash, throwing spatter out of the puddle onto the work.

Globular transfer occurs when voltages and currents exceed that of the short-arc range but fall short of the minimum voltage and current required to get into spray transfer. If you are using He/Ar/CO_2 mixtures (Praxair's HeliStar™ gas blends), Ar/1-2%O_2 mixtures (Praxair's StarGold™ O-1 and O-2 gas blends) or a Ar/2%CO_2 mixture (Praxair's StarGold™ C-2 gas blend), globular transfer can be avoided by setting the welding parameters correctly to obtain spray transfer.

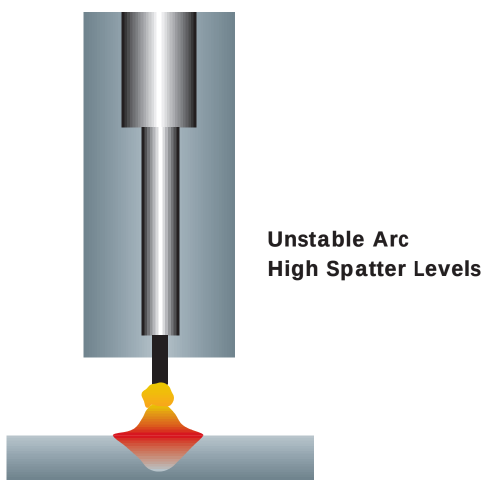


Figure 28 – Globular Transfer Produces High Levels of Spatter

C. Spray Transfer

Spray transfer is a very clean, high efficiency process. All wire diameters can be used. For most applications in the 175 amp to 400 amp range, .035" to 1/16" wires work well. When the welding equipment is set up properly, there is almost no spatter and 97-98% of the filler weld is deposited in the weld puddle (deposition efficiency).

In spray transfer, the tip of the electrode becomes pointed, as *figure 29* shows. Because the tip is so small, the current density (amps/square inch) and the pinch force are very high. This pinches off metal droplets that are smaller than the diameter of the wire. The droplets are accelerated by the magnetic field around the arc instead of transferring by gravity as in globular transfer. The small droplets are absorbed into the weld pool rather than splashing.

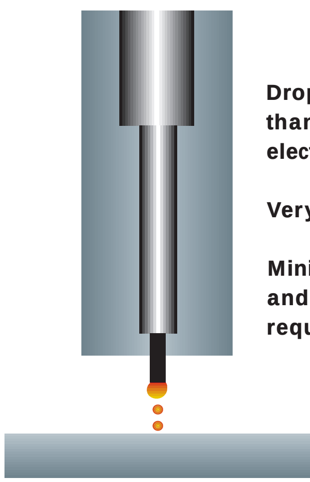


Figure 29 – Spray Transfer is a Very High Efficiency Process

Spray transfer can be used on materials as thin as 14 and 16 gauge metals with the right wire diameter (.023"). Thicker section welding is where spray really gains an advantage, especially in the flat and horizontal positions. This type of metal transfer can be used out of position but wire diameter should be smaller and the operating conditions less than in the flat position. All steels (carbon and stainless), and most other materials, can be GMAW welded in spray transfer.

The gas mixtures used for spray transfer contain lower levels of active gases (CO_2 and O_2) than blends for short-arc and globular transfer. Most contain from 85 to 90% argon, and some blends contain both carbon dioxide and oxygen. Some recently developed mixtures also contain small additions of helium (Praxair's HeliStar™ gas blends) to increase the energy in the arc.

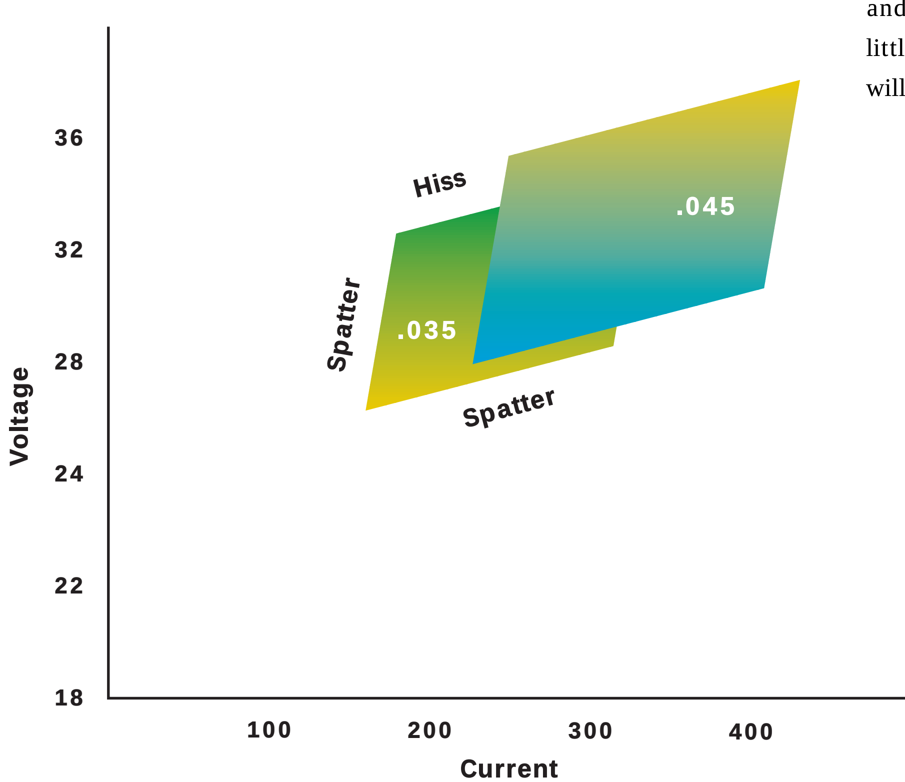
For welding austenitic (300 series) stainless steels, blends of argon with 2-5% carbon dioxide or 1% oxygen are common. Mixtures containing helium (Praxair's HeliStar™ SS gas blend) or small additions of hydrogen (Praxair's HydroStar™ hydrogen-enhanced gas blends) are used to produce high quality weld beads.

For ferritic grades, Ar/O_2, Ar/CO_2 (with up to 8% carbon dioxide), and $Ar/He/CO_2$ blends are used. Hydrogen-containing blends **cannot** be used because of the increased potential for weld metal cracking.

Figure 30 – Transition Currents with Various Shielding Gases

Wire	O-1	O-2	Helistar	PulseBlend
.035	150	155	185	145
.045	200	205	235	185
.052	235	240	270	210
.0625	290	295	325	255

Figure 31 – Spray Transfer Ranges for 98% Ar/2% O_2 .035" and .045" Electrodes



* Voltage should be measured between the positive (+) terminal on the wire feed and the workpiece (–). Voltage drops due to resistance in welding cables can be up to 6-7 volts. Use this method to help reduce spatter.

Transition Currents

To set a welding system for spray, there are minimum voltages and currents required. Voltages range from 24 to 25 v (small diameter with Ar/O_2) to 30+volts (hi-deposition with helium mixtures). A good place to start is around 26-27 volts. Using *figure 30* as a guide, make sure that your current is set slightly above the transition current shown. Then reducing the spatter is usually just a matter of increasing the voltage until the electrode begins to neck down and small metal droplets leave the wire tip cleanly.

Figure 31 shows the spray transfer ranges for .035" and .045" electrodes when using 98% Ar/2% O_2 as a shielding gas. Notice the minimum voltage and current required to get the .035" into spray are about 150 amps and 26 volts. When using the .045" electrode, the minimums are 200 amps and 27 volts. If the settings used are a little below either of these levels, spatter will result.

D. Pulsed Spray Transfer

Pulsed spray transfer is a process that combines the lower heat inputs associated with short-arc with the spatter free metal transfer and good penetration associated with spray transfer. A graph of current vs. time *(figure 32)* shows the shape to be a square wave. The current at the top of the square wave is called the peak current, and the current at the bottom of the square wave is called the background current. The background current keeps the arc established, but at very low currents – typically 20-40 amp. When the current rises to the peak current, the wire is melted into a singular droplet and is transferred across the arc in pulsed spray transfer. Because of the small size of the droplet, spatter is minimized and penetration is easily controlled due to the lower average currents when compared to spray transfer.

Due to its low heat input and fast freeze puddle, pulsed spray is beneficial for out-of-position work and for filling gaps. Since it can produce high peak currents, a larger wire can usually be used over a wider operating range. A larger wire (.045 instead of .035) will usually reduce wire costs and reduce wire feeding problems, especially for soft materials such as aluminum or copper alloys.

Recent research has shown that inverter pulsed power supplies with very rapid current rise can reduce the fume associated with higher current GMAW welding. The fuming is caused by superheating the molten tip of the wire and causing the metal to boil. The very rapid current rise reduces the superheating, leading to the reduced fume generation rates.

Any gas blend recommended for conventional spray transfer will generally work acceptably well with pulsed spray transfer. High helium blends may require special power supply programming to obtain optimum performance.

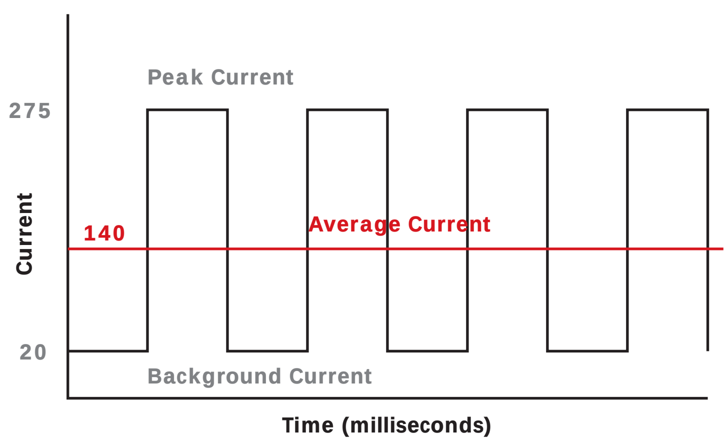


Figure 32 – Pulsed Spray Transfer Produces Low Heat Inputs With Very Clean Transfer

Welding Stainless Steel

There are a number of variables to remember when welding stainless steel. A few of the most important are:

1. **Make sure the base metal and filler metal are clean**
2. **Minimize the heat input whenever possible**
3. **Use the correct filler metal**
4. **Fill the crater upon weld completion**
5. **Avoid sensitization (overheating the base material)**

1. Make sure the base metal and filler metal are clean

Surface contamination can create problems when welding stainless steels. The base materials should be clean and degreased to remove any contamination. Dirt, grease, grinding dust, paint, markers, bending lubricants and moisture all contain compounds that will be dissociated by the heat of the arc. Carbon and hydrogen can be released in this way and absorbed by the puddle.

Wire brushes should have stainless bristles, and only grinding wheels (aluminum oxide) reserved for stainless steel should be used on any weld or base metal. Using a grinder first on carbon steel and then on stainless can contaminate the stainless with carbon-containing particles. This can cause a decrease in corrosion resistance, cracking or porosity.

Use an appropriate solvent to remove any grease and oil from the base metal. The surface should be wiped until there are no traces of dirt on a clean rag. Wire should not be left unprotected on a wire feeder for extended periods of time. Dirt, grease and oil in the shop atmosphere can settle on the wire and cause possible contamination of the weld. Use a wire pad to remove surface contamination.

When making multi-pass welds, the residual oxidation and slag islands from the last pass should be removed, before any additional passes are completed. Use a grinding wheel that is new or has been used only on stainless. If you are using a pneumatic grinder, make sure the exhaust stream is free from lubricating oil. Solvent cleans between passes.

Filler wire should not have dirt or drawing lubricants on its surface as these contaminants, too, are introduced into the puddle. These materials can also affect the stability of the arc by interfering with current transfer in the contact tip. This can cause instability in the arc and possible defects in the deposited weld metal.

2. Minimize the heat input whenever possible

When welding stainless steel, it is critical to control the heat input. High heat inputs can cause cracking, distortion, loss of strength and loss of corrosion resistance. Because of the high alloy content of stainless steel, the thermal conductivity of the material is about 20-30% less than carbon steels and the expansion rate when heated is three to four times greater than mild steel. Because of this, frequent tacking is recommended in order to provide sufficient joint constraint. This means that less heat is dissipated into the surrounding plate, so the weld zone stays hotter longer.

When welding stainless steel, it is good practice to use a low heat input process, such as short-arc, pulsed spray, or low current spray transfer, depending on the material thickness. Short-arc and pulsed-spray reduce the voltage and current in comparison to spray transfer and are recommended for thinner material. Reduced heat inputs also reduce the dilution of the weld metal with base metal and minimize the chances for carbide precipitation.

Shielding gases can also affect the heat input of the process. For low current short-arc transfer, gas blends with high helium content are sometimes used. Helium is added to increase the arc energy by increasing the operating voltage required. This ensures that there is adequate energy to provide good fusion. High helium blends are not usually used in spray transfer because of the considerably higher voltages and currents required to obtain it. The high heat input could lead to greater distortion and possible sensitization.

3. Use the correct filler metal

Selection of the correct filler metal is critical to the successful long-term performance of a stainless steel weldment. Fillers are selected based on chemistry of the materials to be joined, the corrosive media to which they will be exposed, and the microstructure required in the final deposit.

For ferritic, martensitic, and duplex stainless steels, the consumables selected generally have a composition nearly identical to that of the base material. The selection for austenitic alloys is not as simple.

The microstructure of austenitic stainless steel weld metal varies depending upon the alloys involved. To assure a strong, tough weld metal, a balance between the predominant austenitic material and the ferritic microstructural constituent must be maintained; so, selection of the proper filler metal alloy is important. To minimize microfissuring and cracking which can occur when low melting point constituents in the stainless steel segregate to grain boundaries, ferrite is used to “absorb” these impurities. The amount of ferrite is controlled by the composition of the weld metal. By selecting a consumable with more ferrite than austenite stabilizers, a proper balance between the two microstructures is obtained.

A special “selection diagram” for austenitic filler materials has been developed and modified by several researchers. First developed as the “Schaeffler Diagram” and then modified to become the “Delong Constitution Diagram” and the “WRC Ferrite Number Selection Guide,” these tools can be used to select the appropriate filler material, depending upon the type of base material to be joined and the expected amount of mixing (or dilution) between the base and filler metals.

Copies of these diagrams can be found in documents published by the American Welding Society and a number of the filler metal manufacturers.

Some applications can also benefit from the use of low carbon and stabilized filler materials that help control sensitization. High silicon wires are specified to improve metal transfer and make the puddle more fluid for improved bead shape.

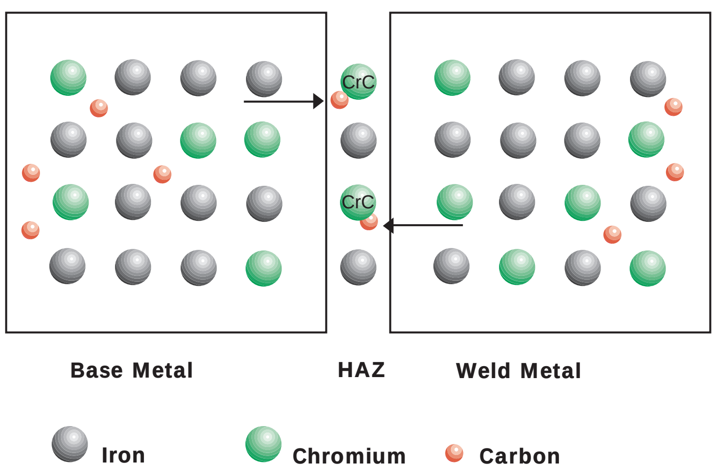


Figure 33 – Sensitization of a Stainless Steel

4. Fill the crater upon weld completion

A very good welding practice is to spend an extra fraction of a second at the weld crater to ensure that it fills properly. The shrinkage stresses that occur as the weld metal solidifies can produce strains great enough to pull the metal in the crater apart as it is freezes. These cracks are sometimes not visible to the naked eye. Filling the crater provides enough metal to resist these strains, while the increased heat also helps to slow the weld cooling rate to reduce any strain produced.

5. Avoid sensitization (overheating the base material)

Sensitization is the formation of chromium carbides in the heat-affected zone (HAZ), the area directly adjacent to the weld. The heat-affected zone has been heated to just below its melting temperature followed by rapid cooling. As *figure 33* shows, the metal atoms occupy the regular sites in the matrix. These metals are the iron, chromium, nickel, molybdenum and manganese atoms. The carbon atoms occupy the small spaces between the metal atoms called interstitial spaces. In the temperature range of 800 F - 1500 F, the carbon atoms actually move through the metal matrix and combine with the chromium atoms to form chromium carbide ($Cr_{23}C_6$).

Stainless steels begin to lose corrosion resistance when the free chromium in the matrix falls below about 10.5%. When carbide precipitation occurs, some chromium is tied up as carbides (lowering the level to <10.5%), and the corrosion resistance of the material is reduced.

This loss of corrosion resistance typically occurs in the HAZ, as shown in *figure 34*. When a sensitized weldment is put into service, the corrosion will occur just beside the weld (HAZ) and often penetrates through the base metal. Sensitized stainless steel weldments are sometimes referred to as "peppered weld metal" as the precipitate is dark in color and heavily oxidized.

The three most common methods available to avoid sensitization are:

1. Post weld heat treatment
2. Low carbon materials
3. Stabilized grades of materials and fillers

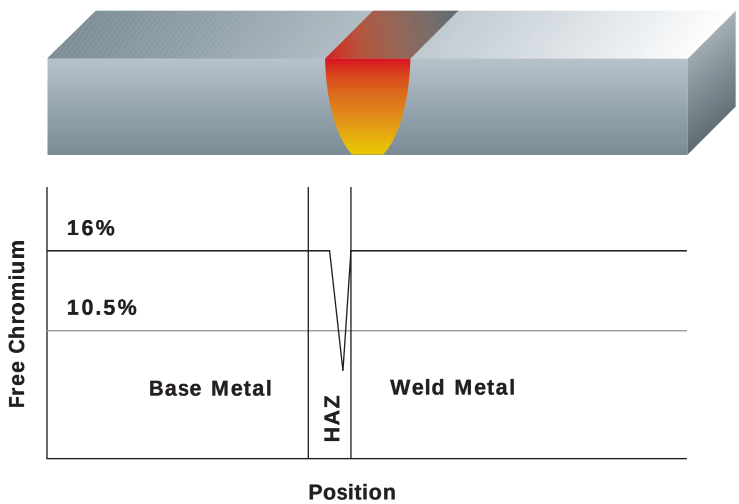


Figure 34 – Sensitization Reduces the Free Chromium Level in the HAZ

1. Use a post weld heat treatment

A postweld heat treatment entails heating the entire weldment to about 1900 F allowing the carbides to go back into solution in the matrix. The weldment is then cooled very rapidly to allow very little time for another precipitation reaction to occur. This technique does have problems because at 1900 F, stainless steels oxidize rapidly and so must be heated in an inert atmosphere to prevent oxides from forming. Another problem is that it is sometimes very difficult to cool a large weldment very quickly to prevent carbide precipitation. Because of these problems, this technique is not used very often.

2. Use low carbon materials

By reducing the level of carbon in the material, a low carbon or "L" grade material is produced. Typical examples are 304L, 308 ELC and 316L. If the available carbon is limited, the problem of sensitization is limited. Production of low carbon stainless steel is done using a steelmaking process known as argon/oxygen decarburization (AOD), patented by Praxair, Inc.

3. Use stabilized grades of materials and fillers

The stabilized grades of stainless steels contain titanium and niobium (columbium). These elements have a higher affinity for carbon than chromium does. This means if precipitation occurs, the carbon will preferentially combine with these elements so that the free chromium in the matrix is not reduced.

Technique and Equipment Set-Up

Technique is very important when welding any type of material, and gets more important as the alloy content increases. Torch angle, feed roll tension, burnback, arc and puddle position, vertical down welding technique, gaps, crater filling and arc starting will be discussed here.

A. Torch Angle

There is a specific amount of energy available from the arc to heat and melt the base metal. Torch angle plays a very important role in the shape of the bead and the depth of penetration into the base metal, as *figure 35* shows. A leading (or push) angle will use some of the arc energy to preheat the base metal before it is welded. Because of the elevated temperature of the base metal, the bead will cool more slowly. This allows the face of the weld to come to equilibrium and will give a relatively flat face. If a lagging (or drag) angle is used, very little of the arc energy goes into preheating the base metal, and deeper penetration is the result. Because of the lack of preheat, the bead will tend to be convex (humped) because the weld will cool more quickly.

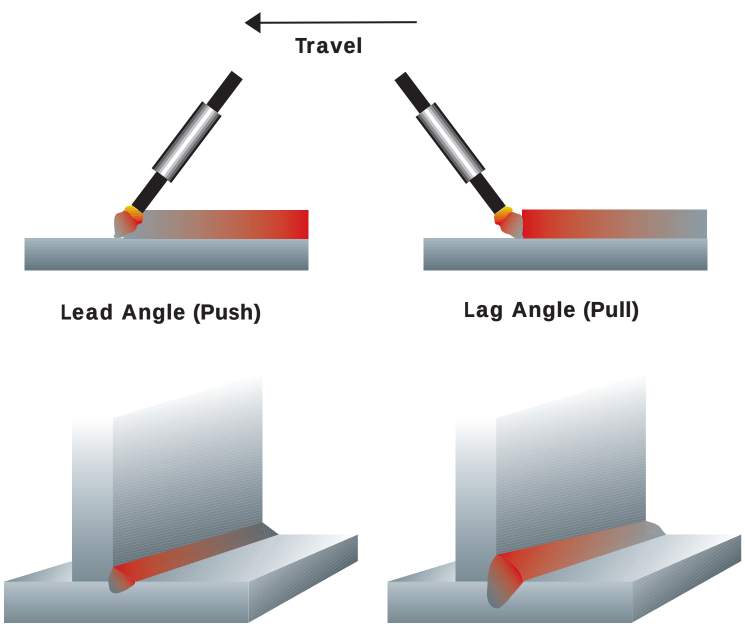
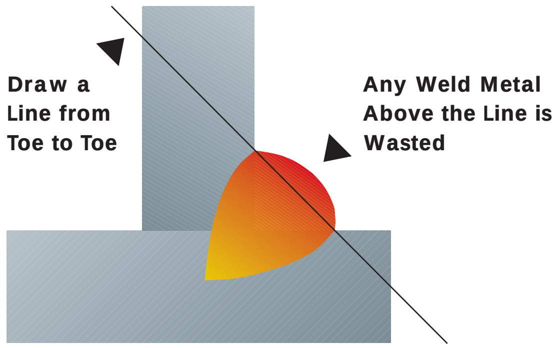


Figure 35 – Torch Angle Affects Penetration and Bead Shape

If a line were drawn between the toes of the weld as shown in *figure 36*, the weld metal above that line is wasted. If a fracture were to occur, it would start at the toe of the weld, not through the thick section. In fatigue service, a humped bead actually reduces the service life of the component. The decreased reentry angle (angle that the bead face makes with the base metal) tends to raise the stress level at the toe of the weld. A flat bead face distributes the stress more evenly across the joint. A slight drag angle does work well in a deep groove, and also in the first pass of a multi-pass weld. As a first pass, the benefit of increased penetration is obtained, but *it is critical to be sure to melt out the toes* of the first pass when the cap passes are put in. A lack of fusion at the toe of the first pass is a defect that will reduce the service life of the component.

Figure 36 – A Flat Face is the Best Bead Profile



B. Feed Roll Tension

Setting feed roll tension is important to improving consumable life and reducing downtime due to feeding problems. How many times have you seen a welder have a feeding problem "corrected" by increasing feed roll pressure? There are two main types of feed roll designs used for solid wires, one grooved and one flat roll, or two grooved rolls. Increasing feed roll tension on either design can actually put enough pressure on the wire to deform it between the feed rolls. *Figure 37* shows the shape of the wire as it leaves a two U-grooved roller set-up with excessive pressure. The "fin" will be scraped off as it feeds through the liner, and will make it more difficult to feed the wire as the excess material begins to clog the liner. Excessive pressure on the feed roll will wear out the feed rolls, plug up the liners and usually lead to burn-backs at the tip.

The best method of adjusting feed roll tension involves running about a foot of wire out of the gun. Bend the wire 180 to form a curved end and run the wire into a gloved hand. Pull the trigger and slowly adjust the feed roll pressure until the wire will make the turn and feed smoothly. At this feed roll pressure, the wire will feed without deforming and the rolls will slip if you get a burnback instead of "bird nesting."

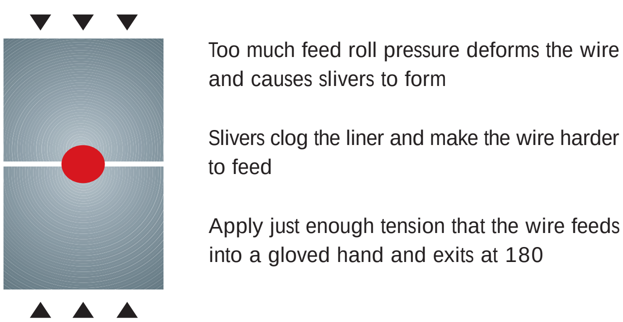
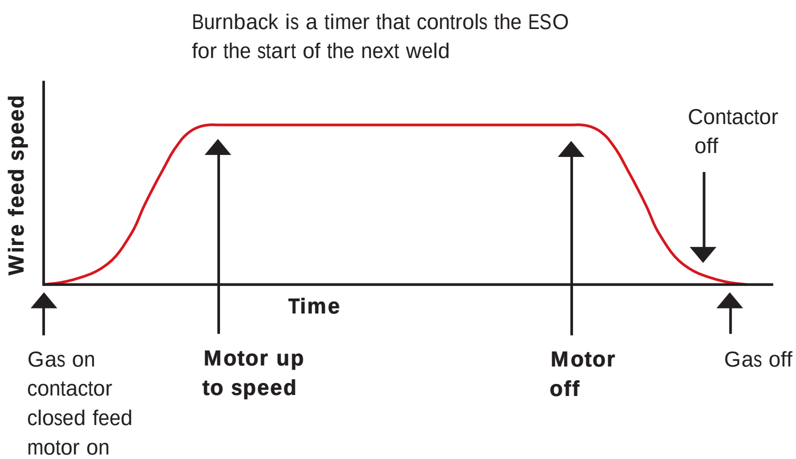


Figure 37 – Feed Roll Tension Adjustment

C. Burnback

The burnback control is designed to reduce the stick-out at the end of a weld and keep the wire from sticking in the puddle. When welding begins, the trigger on the gun closes the contacts in the welder, opens the gas solenoid, and starts the wire feed motor, as shown in *figure 38*. When you release the trigger at the end of the weld, the gas solenoid and the contactor can react very quickly. The motor has the inertia of the armature, the gearbox, and the feed rolls to overcome, so it does not stop instantly. What a burnback control does is put a timer in the circuit that delays the opening of the contactor and the closing of the gas solenoid. This allows the motor to spin down and the wire to continue to burn off so you don't have to try to start the next weld with too much stick-out. A short stick-out greatly improves the starting of the arc because more current is available.

Figure 38 – The Burnback Control is Essentially a Timer



Some wire feeders used for stainless steel will also have a post flow timer. This timer allows the gas to flow for an adjustable time period after the arc is extinguished to keep the crater protected by the shielding gas and prevent oxidation.

D. Arc and Puddle Position

It is very important to watch the position of your puddle in relation to the arc. In order to get good fusion into both pieces of base metal, the heat from the arc must be directed onto the base metal *(figure 39)*. If a very large fillet is attempted in one pass, the tendency is to try to hold the puddle back with the arc. The puddle will continue to advance, and trying to hold the puddle back with the arc will lead to incomplete fusion into the side walls. When the puddle rolls under the arc, the heat of the arc is no longer being put into the base metal, it is going into the puddle. This increases the temperature of the puddle and reduces the fusion into the walls. This is sometimes called "slugging" the joint. This is a very poor practice and leads to welds that will fail at well below their design strength.

If you get on top of the puddle, lack of fushion and cold-lap can result

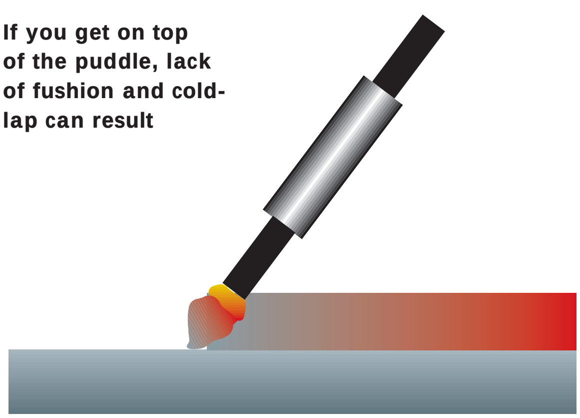
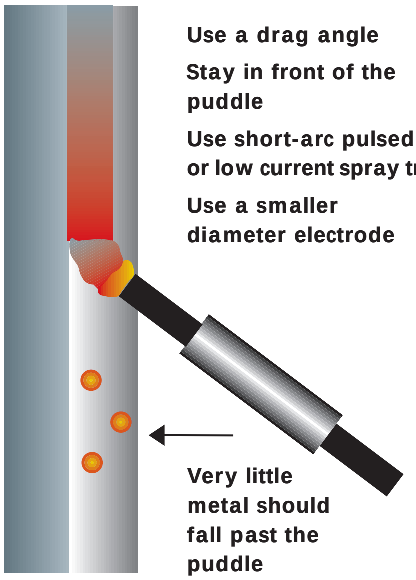


Figure 39 – Stay in Front of the Puddle with the Arc

E. Vertical Down Welding

Vertical down welding *(figure 40)* can be done properly, but the weld parameters must be set very carefully. The problem with vertical down welding is that it is very easy to get lack of fusion into the side walls. If you have watched a welder putting in a vertical down weld and seen the molten metal hitting the floor, this is very similar to “slugging” a joint mentioned before in that the only path to the floor is between the arc and the base metal. If the weld metal is taking this path, the arc energy cannot be going into the base metal. A high quality vertical down weld can be made in either short-arc or spray transfer, but the arc must stay in front of the puddle. Here is one more place where a lagging angle is beneficial, because the arc force can be used to hold the puddle in place as it begins to cool.

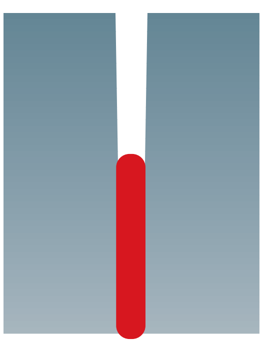
Figure 40 – Vertical Down Welding Can Produce a High Quality Joint



F. Gaps

Gaps can cause a lot of problems because they vary in consistency and also change the maximum heat input that the part can handle. A real problem arises on critical parts where depth of penetration is important, and, therefore, the heat input is near the upper end of the range that the part can handle. As soon as a gap appears, the heat input must be reduced, or burn-through will occur.

The best solution is to fix the parts so the gaps don’t exist, but, this is usually not possible. In a manual welding operation, the solutions are a lot easier than in a robotic operation. A welder is a lot smarter than a robot, and can quickly adjust conditions to reduce heat input. Increasing the electrical stick-out can reduce the heat input enough in some cases to eliminate the burn-through. Remember that increasing ESO reduces current and increases voltage slightly, reducing heat input.



Use short-arc pulsed spray or low current spray transfer

Use smaller electrodes

Reduce the CO_2 in the shielding gas

Increase ESO (stick-out)

Figure 41 – Welding Gaps

Another solution that can work well, especially in robotic operations or manual operations where the gaps are numerous, is to reduce the electrode diameter. A .035" (.9mm) wire will give you the same deposition rate as an .045" (1.2 mm) at about 20-30 amps less because of the higher resistance of the smaller electrode. A change to short-arc or pulsed spray transfer should be considered if spray transfer is being used. Short-arc and pulsed spray transfer fill gaps better due to the reduced heat input obtained at similar deposition rates.

G. Crater Filling

The crater is the last bit of weld metal to freeze at the end of a weld. Due to the shrinkage that occurs as the weld metal cools, the crater will sometimes appear concave. This can cause problems because it is highly strained weld metal with very little reinforcement because of the concavity. Highly strained weld metal with very little reinforcement can develop cracks very easily. Porosity in the crater is also possible. The solution to this is to spend a little more time filling in the crater before ending the weld. This will add a little more weld metal to increase the reinforcement and also put some additional energy into the weld to slow the cooling rate. Slowing the cooling rate will allow more time for the gases in solution to escape through the surface of the weld.

H. Arc Starting

Initiating the arc is mainly a function of the current available. The biggest cause of poor arc starting is too much stick-out. The extra resistance heats the wire and reduces the current available for arc initiation. When the wire has heated enough to soften it buckles and the arc goes out. Then the whole process begins again, leaving little stubs of wire at the start of the weld.

Another problem seen on a regular basis is poor connections on the work and the hot leads. When copper is new, it is bright and highly conductive. As it ages, the copper surface oxidizes and acts as an insulator. This resistance causes the cables to get hot during welding. The current rise begins when the arc starts is slowed by the additional resistance in the welding circuit. Replacement of the poor connections will restore arc starting. Sealing the exposed copper with a liquid electrical tape will prevent oxidation from occurring.

At higher current levels, also consider the slope and inductance setting on the power supply. A steep slope or high inductance setting is designed to limit short-circuit current. If the material to be welded is not too thin, a flat slope and/or minimum inductance will improve the arc starting by increasing the rate of current rise.

Weld Discontinuities and Problems

The AWS defines discontinuities as interruptions in the typical structure of a weldment. A discontinuity only becomes a defect when the component is rendered unserviceable.

A. Lack of Fusion

Lack of fusion is little or no penetration and tie-in to the base metals, as shown in *figure 42*. This can be caused by many different reasons; some of the common ones are:

1. Torch Not Centered: This concentrates the heat of the arc on only one of the pieces. If both pieces to be joined are not melted by the arc, the molten puddle will have a tendency to lie on top of the second piece without fusing to it.

2. Poor Torch Oscillation: If a welder makes "little circles" with the torch, it is easier to make a pretty bead, but there is a good chance for lack of fusion. As the torch moves back into the puddle, the molten metal doesn't stop and wait. It continues to advance, but without the benefit of the intense heat of the arc to melt the base metal. The puddle just lies on top of the work instead of fusing to it. Exaggerated oscillation produces the same problem.

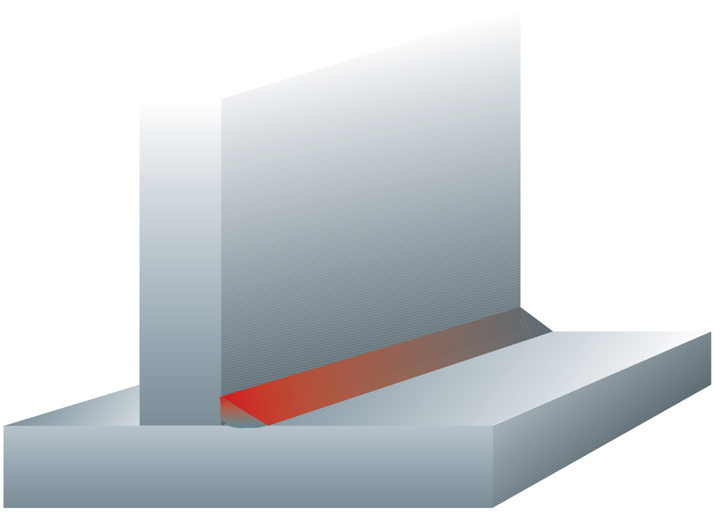


Figure 42 – Lack of Fusion

3. Excessive Travel Speed: If the travel speed is too high, it is possible to not spend enough time to allow fusion with the base metal. There is a minimum amount of heat required for every welding joint, because the base metal can cool the puddle very rapidly after it is deposited.

4. Vertical Down Welding is notorious for lack of fusion at the toes (where the weld metal intersects the base metal) and very little penetration. This lack of fusion can also occur in flat and horizontal positions where it is called overlap, or cold lap. Lack of fusion in vertical down welds is usually caused by getting on top of the weld puddle. This prevents the arc from adequately heating the base material to produce proper fusion. An old slang term for this defect is "fingernailing" because if it is bad enough, you can insert a fingernail beneath it.

5. Travel Speed too Slow: It is similar to improper torch oscillation. The heat from the arc is used to further heat the already molten puddle and raise its temperature instead melting the base metal.

6. Current too Low can also cause lack of fusion. This is usually only a problem on thicker sections, where the base metal pulls heat out of the puddle very rapidly.

7. Incorrect Welding Parameters is the last major cause for lack of fusion. This category would include all the variables covered plus incorrect ESO (electrical stick-out), torch angle wrong, incorrect shielding gas, etc.

B. Porosity

Porosity *(figure 43)* can be a significant problem, and not easily solved. The biggest causes are probably **contamination** of the shielding gas, followed by filler metal and base metal contamination. A leak anywhere in the distribution system from a leaking fitting in the ceiling to a loose hose fitting at the feeder will allow gas to leak out and air to diffuse into the shielding gas. Molten weld metal holds a lot more nitrogen, oxygen and hydrogen (from moisture in the air) than solid metal. As the weld puddle freezes, the gases come out of solution and form porosity.

Another form of **contamination** can come from the base metals. It is against better welding practice to weld over paint, marker lines, water, rust, oil and heavy mill scale. Paint and markers are typically made of hydrocarbons. The heat from the arc breaks down these compounds to release hydrogen, carbon and other contaminants into the weld pool.

Porosity can also be caused by excessive **tip-to-work distance.** This can create turbulence in the shielding gas column, aspirating oxygen and nitrogen from the atmosphere which then react with the high temperature weld metal.

This also occurs when **the torch angle from vertical is too great.** When the torch angle is too severe, a venturi is set up between the gas nozzle and workpiece. This pulls in a great deal of atmospheric air, contaminating the shielding gas.

Additional causes of porosity are **shielding gas flow too low** and **shielding gas flow too high.** At low rates, the gas cannot exclude the atmosphere. At high flows, turbulence in the gas column causes mixing with the atmosphere.

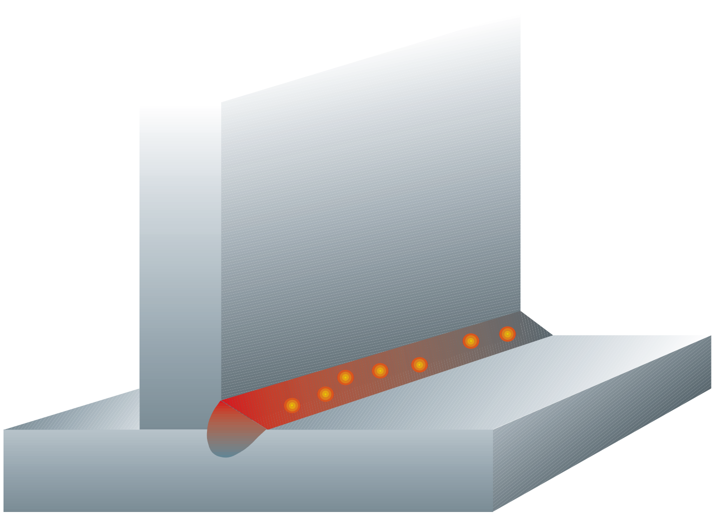


Figure 43 – Porosity in a Weld

Drafts, winds and fans can also cause porosity. All of these sources disturb the shielding gas column and must be controlled. Sometimes just moving a fan a few degrees is enough to solve a problem. Barriers must sometimes be put between the welding area and an open door. This can usually be something as simple as a welding screen.

As mentioned under gas losses, a dirty torch can cause porosity by blocking and disturbing the laminar flow of the shielding gas. Spatter adherence to the nozzle is an obvious culprit, as is spatter on the gas diffuser.

If the operating voltage is too high, problems can occur because the arc will have a tendency to wander, especially on fillets. As the arc seeks the closest point, it can disturb the gas column enough to cause turbulence and entrain air.

A further cause of porosity is **excessive torch oscillation.** Too much torch oscillation can cause porosity because it is possible to either induce turbulence or even run out from under the gas column.

C. Burn-Through

Burn-through is usually caused by **excessive current** for the application, as shown in *figure 44*. Sometimes an easy solution is to increase your ESO (electrical stick-out.) This reduces heat input into the part.

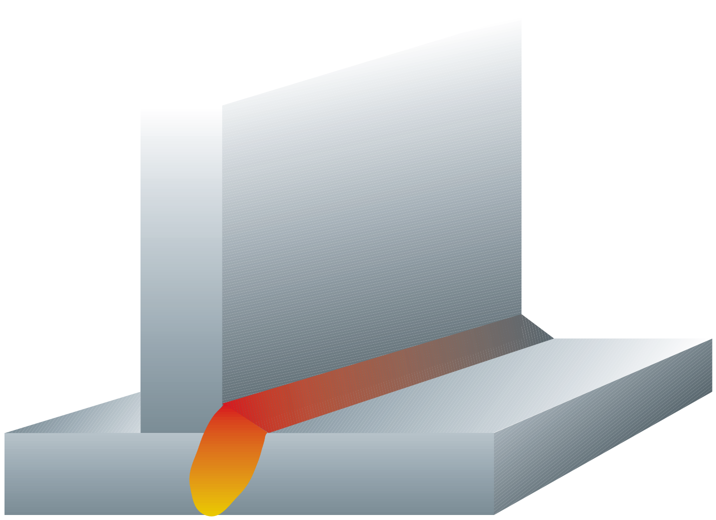


Figure 44 – Burn-Through

Another problem can be that **the travel speed is too low.** Traveling too slowly increases heat input greatly. When possible, increase the travel speeds and make multiple passes, if necessary.

Incorrect wire diameter is also a cause of burn-through. Reducing the wire diameter allows you to weld at lower currents but at the same deposition rate with reduced heat input. One more variable that can cause additional heat is using the **incorrect shielding gas.** The shielding gas can be tailored to the application to help control the heat input.

Excessive gaps can also be a cause of burn-through, as every manual welder knows. This is easy to forget on robots and mechanized welds, and sometimes mysterious burn-through occurs because the robot can't compensate by changing conditions when faced with gaps like a welder can. If the parts can't be made to fit better, gaps can be pre-welded or "stringered" with a short bead prior to final welding.

D. Undercut

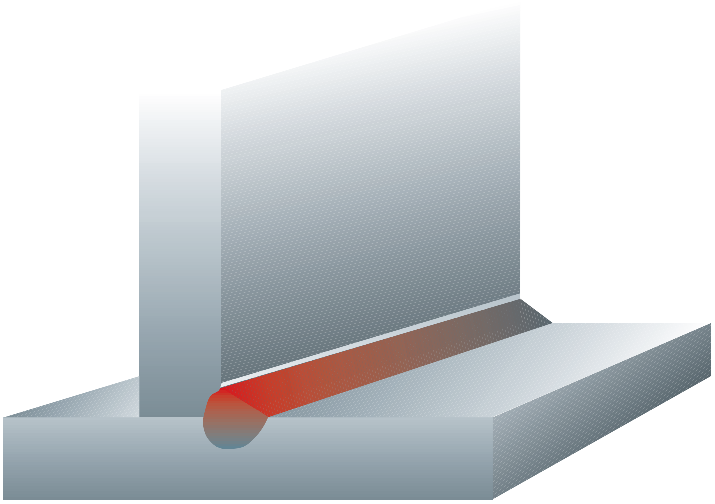


Figure 45 – Undercut on the Upper Leg of a Fillet Weld

Undercut *(figure 45)* has three main causes. The first is **excessive voltage,** which can cause the arc to wander. The melted area of the base metal is too large for the puddle to flow into and fill the undercut area. **High travel speeds** can lead to undercut for the same reason. The heat input is too low to allow the weld metal to flow and the bead is generally convex. On horizontal fillets, undercut can be caused by **incorrect torch position.** If the torch is positioned on the vertical leg, there is no way for the weld metal to flow uphill against the force of gravity. Repositioning the torch 1-2 wire diameters out from the root on the horizontal plate will eliminate the undercut. Undercut is a very serious defect on high strength materials because it greatly increases the strain in the material just below the notch and increases its sensitivity to hydrogen cracking.

E. Spatter

Spatter is usually caused by operating outside acceptable parameters for the desired metal transfer mode. For example, operating in the spray transfer mode with an .045" diameter electrode and a 8% Ar/2% O_2 gas requires about 200 amps and 27 volts. Reducing the wire feed speed or increasing the ESO will reduce the current and produce spatter.

Too low a voltage will also cause spatter. Reducing voltage below 24 will cause spatter. The key here is arc volts. The power supply may indicate that it is putting out 27 volts, but there is still spatter. Use a volt meter and measure the voltage from the positive connection at the wire feeder to the workpiece while welding. It is possible that there is 100 feet of work leap with two frayed, oxidized connections. The 27 volts at the machine may be only 25 volts at the arc due to the resistance in the cables and connections.

F. Cracking

Cracking *(figure 46)* in stainless steels can be a problem and is usually caused by:

High Restraint – A highly restrained part will not allow the material to move to relieve the stresses of the weld metal during cooling. This also leads to local stresses beyond the yield strength of the material.

Poor Bead Shape – A convex bead will greatly increase the stress at the toes of the weld. The increased thickness of the center of the bead forces the stress into the toes, and can rapidly exceed the yield strength of the material. A concave bead may not have the required effective throat to withstand the design forces, and crack through the throat. The optimum fillet shape is a flat face with the toes blending into the side walls very smoothly.

Contamination – Contamination of the weld puddle from material on the base metal, the filler metal, or in the shielding gas can cause cracking. These cracks are generally found in the weld crater.

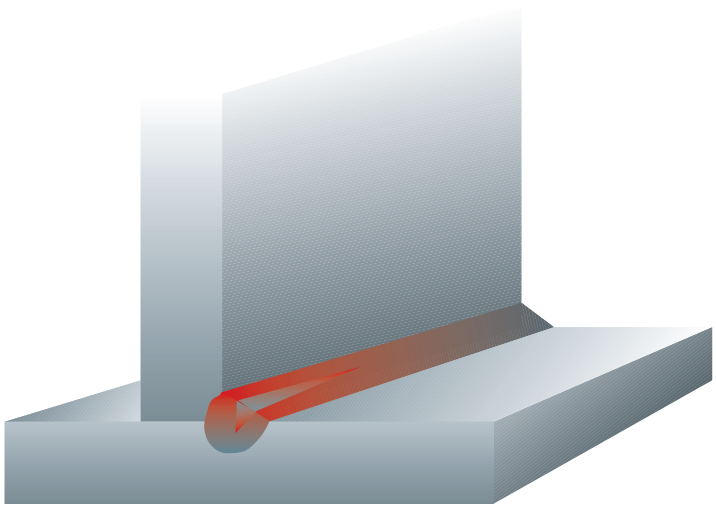


Figure 46 – Centerline and Underbead Cracking

G. Sensitization of Alloying Elements

Sensitization or the grain boundary precipitation of chromium carbide cannot be seen or detected in any way during welding. Some of the things to do to minimize the possibility of sensitization are:

Ensure that base metals and filler metals remain as clean as possible – Any contamination that contains hydrocarbons in any form can cause problems. The arc heat causes hydrocarbons such as an oil or grease to dissociate into its component elements. Since one is generally carbon, that can add to the carbon content of the weld metal and lead to sensitization.

Make sure that you use the specified shielding gas – Gases with over about 5% CO_2 should not be used for low carbon stainless welding. The CO_2 in the shielding gas can increase the carbon content of the weld metal and lead to sensitization.

Make sure that you use the specified electrode – If you were to use a 308 filler instead of a 308L, the carbon level in the weld pool would increase and potentially cause a problem with sensitization. If a stabilized grade is specified (e.g., 321 or 347), be sure that no other electrode is substituted.

Precautions and Safe Practices

Precautions and Safe Practices for Welding and Cutting

Always read the safety information and the Material Safety Data Sheet (MSDS) supplied by the manufacturers of gases, materials and equipment used in welding operation. This information will recommend safe practices that will protect you from health hazards such as fumes, gases and arc burns. Recommendations concerning ventilation and protective devices should be carefully followed.

To weld and cut safely, you must have a thorough knowledge of the welding process and equipment you will be using, and all of the hazards involved. The information found here is excerpted from Praxair's *Precautions and Safe Practices for Electric Welding and Cutting* (P52-529). Also see Praxair's *Precautions and Safe Practices for Gas Welding, Cutting and Heating* (P-2035), *Safety Precautions* (P-3499) and the MSDS for each of the gases.

Fumes and Gases Can Harm Your Health

Keep your head out of the fumes. Do not breathe fumes and gases caused by the arc. Use enough ventilation. The type and the amount of fumes and gases depend on the equipment and supplies used. Air samples can be used to find out what respiratory protection is needed.

Provide enough ventilation wherever welding and cutting are performed. Proper ventilation can protect the operator from the evolving fumes and gases. The degree and type of ventilation needed will depend on the specific welding and cutting operation. It varies with the size of the work area, on the number of operators and on the types of materials to be welded or cut. Potentially hazardous materials may exist in certain fluxes, coatings and filler metals. They can be released into the atmosphere during welding and cutting. In some cases, general natural-draft ventilation may be adequate. Other operations may require forced-draft ventilation, local exhaust hoods or booths or personal filter respirators or air-supplied masks. Welding inside tanks, boilers or other confined spaces requires special procedures, such as the use of an air-supplied hood or hose mask.

Sample the welding atmosphere and check ventilation system if workers develop unusual symptoms or complaints. Measurements may be needed to determine whether adequate ventilation is being provided. A qualified person, such as an industrial hygienist, should survey the welding operations and surrounding environment.

Do not weld on plate contaminated with unknown material. The fumes and gases which are formed could be hazardous to your health. Remove all paint and galvanized coatings before welding.

More complete information on health protection and ventilation recommendations for general welding and cutting can be found in the American National Standard Z49.1, Safety in Welding and Cutting. This document is available from the American Welding Society, P.O. Box 351040, Miami, FL 33135.

Electric Shock Can Kill You

Do not touch live electrical parts.
To avoid electric shock follow the recommended practices listed below. Faulty installation, improper grounding and incorrect operation and maintenance of electrical equipment can be sources of danger.

1. Ground all electrical equipment and the workpiece. Prevent accidental electrical shocks. Connect power supply, control cabinets and workpiece to an approved electrical ground. The work lead is not a ground lead. It is used to complete the welding circuit. A separate connection is required to ground the work, or the work lead terminal on the power supply may be connected to ground. Do not mistake the work lead for a ground connection. *See figure 47.*

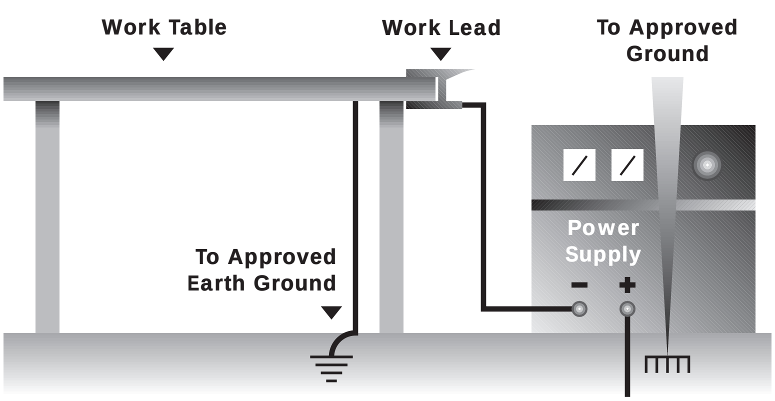


Figure 47 – Illustration of Grounding Electrical Equipment and the Workpiece

2. Use the correct cable size. Sustained overloading will cause cable failure and result in possible electrical shock or fire hazard. Work cable should be the same rating as the torch cable.

3. Make sure all electrical connections are tight, clean and dry. Poor electrical connections can become heated and even melt. They can also cause poor welds and produce dangerous arcs and sparks. Do not allow water, grease or dirt to accumulate on plugs, sockets or electrical units.

4. Moisture and water can conduct electricity. To prevent shock, it is advisable to keep work areas, equipment and clothing dry at all times. Fix water leaks immediately. Make sure that you are well insulated. Wear dry gloves, rubber-soled shoes, or stand on a dry board or platform.

5. Keep cables and connectors in good condition. Improper or worn electrical connections can cause short circuits and can increase the chance of an electrical shock. Do not use worn, damaged or bare cables.

6. Avoid open-circuit voltage. Open-circuit voltage can cause electric shock. When several welders are working with arcs of different polarities, or when using multiple alternating-current machines, the open-circuit voltages can be additive. The added voltages increase the severity of the shock hazard.

7. Wear insulated gloves when adjusting equipment. Power should be shut off and insulated gloves should be worn when making any equipment adjustment to assure shock protection.

8. Follow recognized safety standards. Follow the recommendations in American National Standard Z49.1, Safety in Welding and Cutting available from the American Welding Society, P.O. Box 351040, Miami, FL 33135, and also the National Electrical Code, NFPA No. 70, which is available from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

Warning

Arc rays and spatter can injure eyes and burn skin. Wear correct eye, ear and body protections.

Electric arc radiation can burn eyes and skin the same way as strong sunlight. Electric arcs emit both ultraviolet and infrared rays. Operators, and particularly those people susceptible to sunburn, may receive eye and skin burns after brief exposure to arc rays. Reddening of the skin by ultraviolet rays becomes apparent seven or eight hours later. Long exposures may cause a severe skin burn. Eyes may be severely burned by both ultraviolet and infrared rays. Hot welding spatter can cause painful skin burns and permanent eye damage.

Be sure you are fully protected from arc radiation and spatter. Cover all skin surfaces and wear safety glasses for protection from arc burns and burns from sparks or spatter.

1. Keep sleeves rolled down. Wear gloves and a helmet. Use correct lens shade to prevent eye injury. Choose the correct shade from the table below. Observers should also use proper protection.

Filter Recommendations
(Adapted from ANSI Safety Standard Z49.1)

Application	Lens Shade No.*
MIG (Gas Metal and Flux Cored Arc)	
60 to 160 amps	11
160 to 250 amps	12
250 to 500 amps	14

**As a rule of thumb, start with a shade that is too dark to see the arc zone. Then go to a lighter shade which gives sufficient view of the arc zone without exerting a strain on your eyes.*

2. Protect against arc flashes, mechanical injury or other mishaps. Wear spectacles or goggles with No. 2 shade filter lens and side shields inside the welding helmet or hand shield. Helpers and observers should wear similar protection.

3. Wear protective clothing such as heat resistant jackets, aprons and leggings. Exposure to prolonged or intense arc radiation can cause injury. Thin cotton clothing is inadequate protection. Cotton deteriorates with this type of radiation.

4. Wear high, snug-fitting shoes. Avoid wearing low or loose shoes which would allow hot spatter to get inside.

5. Wear cuffless pants. By wearing pants with no cuffs, you eliminate a dangerous spark and spatter trap. Pant legs should overlap shoe tops to prevent spatter from getting into your shoes.

6. Wear clean clothes. Do not wear clothing that has been stained with oil and grease. It may burn if ignited by the heat of the arc.

7. Wear ear protection, not only where there is noise, but where there is a chance that spatter or sparks could get into your ears.

8. Wear a leather cap or other protection to shield the head from sparks or spatter.

9. Protect neighboring workers from exposure to arc radiation. Shield your station with metal or heat resistant shields. If your station cannot be shielded, everyone within about 75 feet should wear eye protection when welding or cutting is in progress. Assure proper ventilation.

10. Do not breathe welding fumes.

11

Conclusion

Hopefully, this course has given you a little better understanding of the Gas Metal Arc Welding of stainless steels. With the knowledge you already have, and this booklet to use as a reference, it is hoped that you're now a more informed welder and your job has been made easier.

Please call your local Praxair engineering representative with any questions that you have in the future.

WORLD HEADQUARTERS
Praxair, Inc.
39 Old Ridgebury Road
Danbury, CT 06810-5113
Tel: 1-800-PRAXAIR
(1-800-772-9247)
(716) 879-4077
Fax: 1-800-772-9985
(716) 879-2040
Internet: www.praxair.com
e-mail: info@praxair.com

P-8137A 2M 9/99