PRAXAIR

SHIELDING GASES
SELECTION MANUAL

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Shielding Gases Selection Manual

During any arc welding process, oxygen and other atmospheric gases can react with the molten metal, causing defects that weaken the weld. The primary function of a shielding gas is to protect the molten weld metal from atmospheric contamination and the resulting imperfections. In addition to its shielding function, each gas or gas blend has unique physical properties that can have a major effect on welding speed, penetration, mechanical properties, weld appearance and shape, fume generation, and arc stability. A change in the shielding gas composition is usually considered an “essential variable” in most qualified welding procedures.

The primary gases used for electric welding and cutting are argon (Ar), helium (He), hydrogen (H_2), nitrogen (N_2), oxygen (O_2), and carbon dioxide (CO_2). The composition and purity of the gas or gas mixture should be tailored to meet the process, material, and application requirements. Shielding gases are used in either pure form or in blends of varying components. Therefore, the selection of a gas or gas mixture can become quite complex due to the many combinations available.

Selection of the most economical shielding gas or blend must be based on a knowledge of the gases available, volume requirements, their applications, and the overall effect they have on the welding process. Praxair’s Shielding Gas Selection Manual describes the arc plasma characteristics and basic properties of shielding gases, as well as their applications in the welding and cutting processes most frequently used by industry today. The processes discussed are Gas Tungsten Arc Welding (GTAW), Plasma Arc Welding (PAW), Plasma Arc Cutting (PAC), Gas Metal Arc Welding (GMAW), and Flux-Cored Arc Welding (FCAW). The shielding gases presented are Praxair’s Star™ Gases (pure gases) and Star Gas Blends, including StarGold™, Stargon®, HeliStar™ Mig Mix Gold™ and HydroStar™ blends.

Additional sections of this manual explain the economics of gas selection, various methods of gas supply, and the precautions and practices recommended to ensure a safe working environment.

History

The history of shielding gas development began late in the nineteenth century when Charles Lewis Coffin replaced the air in a box placed over a welding joint with a non-oxidizing atmosphere. Interest in the use of inert, non-oxidizing gases for welding was sporadic for the next forty years. Then in 1930, two U.S. patents were issued which are considered to be the first descriptions of the use of inert shielding gases for welding.

The first patent, issued to H. M. Hobart, described the use of helium with carbon or metallic arcs. The other, issued to P. K. Devers, described the use of argon and its mixtures for arc processes.

Early in the 1940s, Northrup Aircraft Company, Inc. first used an inert gas shielded welding process with a nonconsumable tungsten electrode. The process was developed specifically for the welding of magnesium for aircraft fabrication using helium as the shielding gas. Recognizing its possibilities, Praxair acquired the rights to the invention in 1942 and started an extensive research and development program to expand the use of the process. Introduced commercially in 1946 as the Heliarc process, it is today also known as Gas Tungsten Arc Welding (GTAW) or Tungsten Inert Gas (TIG).

A significant portion of this development work was devoted to the evaluation of argon and helium utilized as shielding gases, and to studies that identified the importance of gas purity in producing quality welds. Therefore, it was not until the postwar era, after Praxair pioneered the economical production of high-purity argon on a commercial scale, that GTAW became a practical reality.

In 1950, a patent was issued to Air Reduction Co. Inc. (Airco) covering a process later known as Gas Metal Arc Welding (GMAW), Metal Inert Gas (MIG) and Metal Active Gas (MAG). The initial application was for "spray arc" welding of aluminum in a helium atmosphere. At that time, the process was called SIGMA (Shielded Inert Gas Metal Arc). Extensive development work by Praxair, Airco, and others followed during the 1950s. The effort was dedicated to developing gas mixtures, wire chemistry, and equipment systems to improve and expand the application range of the process. This work led to the rapid growth of GMAW during the next thirty years and to its wide use today. It also provided the groundwork for the invention of Flux-Cored Arc Welding (FCAW) by Arthur Bernard in the late 1950s. His patent was assigned to the National Cylinder Gas Co. (NCG) in 1957, where the process was further developed and introduced for industrial use.

Also during the 1950s, Praxair developed, patented, and commercialized Plasma Arc Cutting and Welding Systems. Praxair researchers discovered that the properties of the open arc could be altered by directing the arc through a nozzle located between the electrode and the workpiece. This procedure greatly increased arc temperature and voltage, producing a highly constricted jet that was capable, depending upon its velocity, of either "plasma arc" cutting or welding. The basic patents covering this discovery were issued in April 1957.

All of these processes, which rely on shielding (or cutting) gases for effectiveness, are now in use all over the world and play a major role in the fabrication of products for the automotive, aerospace, railroad, trucking, and construction industries, to name a few.

CHAPTER 1

Properties of Electric Arcs and Gases

The unique properties of a gas or gas blend can have a dramatic influence on arc characteristics, heat input, and overall process performance. A basic understanding of the key electrical concepts and the fundamental physical properties of gases is necessary in order to select shielding gases wisely.

Basic Electrical Concepts

Electrons

It is convenient to think of electrons as negative charges that can move about freely in a circuit. They can be thought of simplistically as being piled up at the negative end of a circuit, waiting to flow to the other (positive) end. The positive terminal does not have enough electrons, the negative terminal has too many. When the two terminals are connected to each other by wires, the negative charges travel to the positive terminal *(figure 1).*

Welding power supplies can be thought of as a source of more electrons. As long as an electrical power supply is connected to a circuit, a negative terminal can never use up its surplus of electrons, and a positive terminal can never receive too many electrons.

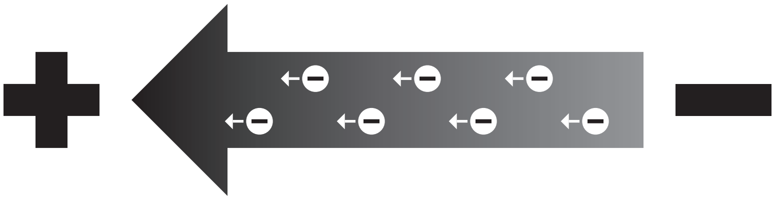


Figure 1 – Electron flow

Voltage

Voltage is the unit of pressure or electromotive force that pushes current, or electrons, through a circuit. One volt will push one ampere through a resistance of one ohm. Welding voltages typically range from 14 to 35 volts.

Ampere

An ampere is the unit of current, or the measure of the number of electrons that flow past a point in a circuit every second. The quantity of electrons is expressed in coulombs. One coulomb equals 6.25 billion electrons. One ampere is equal to one coulomb per second. Open arc welding amperages typically range from 15 to 400 amps.

Ohm

An ohm is the unit of resistance to current flow. One ohm is the quantity of resistance which produces a drop of one volt in a circuit carrying one ampere.

In a garden hose, the water pressure is similar to voltage and the quantity of water flowing is similar to amperage. Any restrictions in the hose, such as a kink, would produce resistance to the flow of water. The relationship of these variables is expressed by the equation:

$V \text{ (volts)} = I \text{ (amperes)} \times R \text{ (ohms)}.$

Welding Polarity

The direction of current flow influences the melting efficiency of the welding arc. Consequently, the control of the polarity in a welding system is very important. In GMAW, there are two welding polarity connections utilized: straight polarity and reverse polarity.

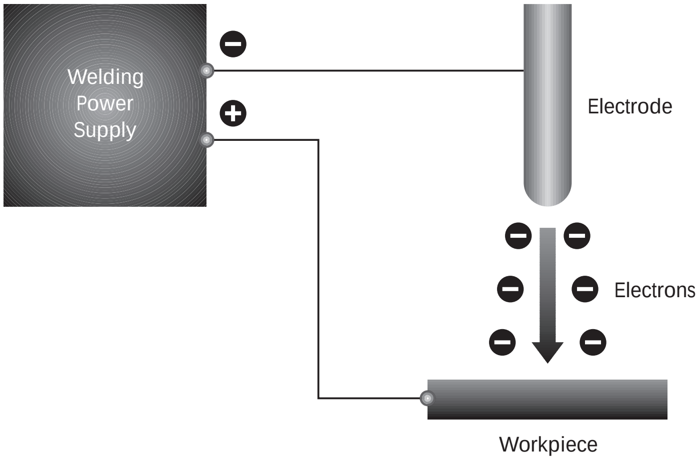


Figure 2 –
DC Electrode Negative (DCEN) connection

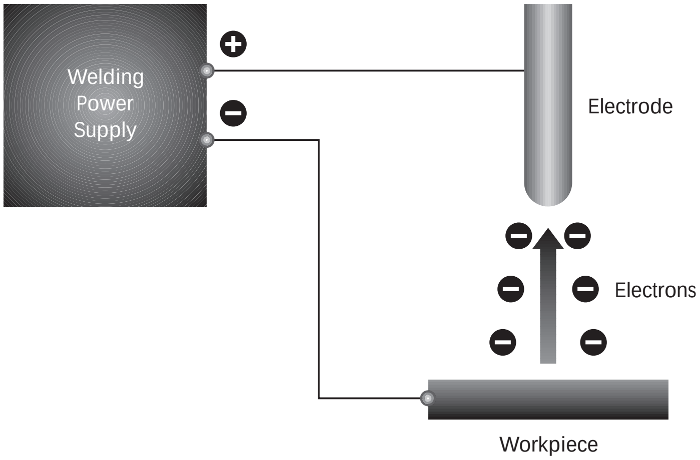


Figure 3 –
DC Electrode Positive (DCEP) connection

When the direct current (DC) straight polarity or the direct current electrode negative (DCEN) connection is used, the electrode is the nega-tive pole and the workpiece is the positive pole of the welding arc. *See figure 2.*

When the DC reverse polarity or the direct current electrode positive (DCEP) connection is used, the electrode is the positive pole and the workpiece is the negative pole *(figure 3)*.

When welding with direct current electrode negative (DCEN), the direction of electron flow is to the base metal, striking the weld area at high speed. At the same time, the positive argon ions flow to the welding electrode, breaking up surface oxides on their way.

In GMAW, by changing polarity to direct current electrode positive (DCEP), the heating effect of the electron flow is concentrated at the tip of the electrode. This contributes to the efficient melting of the wire electrode which provides molten metal and reinforcement for the weld. Welding penetration and productivity are increased with DCEP.

Another important characteristic of DCEP operation is the surface cleaning action it produces. This is especially true when welding aluminum and magnesium which have an invisible refractory oxide coating that must be removed in some matter to permit sound welds to be made. It is useful to remove this oxide prior to welding, as it has a higher melting point than the base material.

The surface cleaning action obtained with DCEP operation is probably the result of ion bombardment, which suggests that the flow of heavy gas ions produces a “sand-blasting” effect on the oxide film. This theory is supported by the fact that argon ions, which are about ten times heavier than helium ions, yield a greater degree of surface cleaning.

Applying these basic electrical concepts to a welding arc is complicated by the introduction of a shielding gas. In a normal electrical circuit, electrons (current) are pushed (by voltage) through a solid conductor, such as a copper wire, which has some degree of resistance (ohm). In a welding circuit, there is a break or gap between the electrode and the workpiece where there is no solid wire conductor. The supply of electrons, therefore, must come from the gas.

To provide the necessary electrons, the atomic structure of the gas must be physically changed to a state that will allow it to conduct electricity. The temperature of the welding arc facilitates this process.

In order to select the most appropriate shielding gas, it is important to understand a few of the fundamental characteristics that apply to these gases at the elevated temperatures present in welding arcs. The characteristics that have a major influence on gas selection criteria, such as heat input to the workpiece, penetration profile, the effect on metal transfer, arc starting and arc stability are of particular interest.

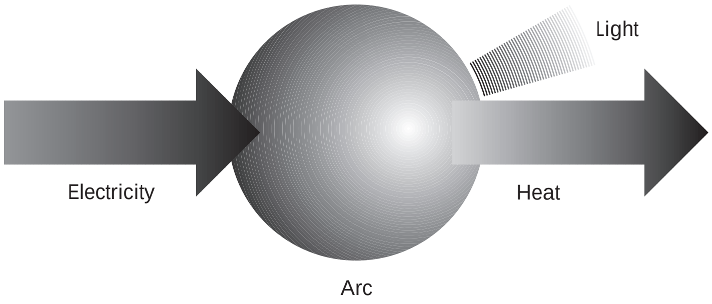


Figure 4 –
An (GMAW) arc is a (DCEP) conversion device

The Welding Arc

Conceptually, a welding arc can be thought of as a conversion device that changes electrical energy into heat *(figure 4)*.

The amount of heat that an arc produces from electricity depends upon many factors. One of the most important is arc current. When the arc current is increased, the amount of heat the arc produces is increased; the reverse is also true. Another factor which controls arc heat is arc length. Changes in the length of an arc will cause changes in the amount of heat available from the arc. Consequently, successful welding depends upon control of both the arc current and arc length. Most of the time, when considering manual welding, the arc current is controlled by the welding power supply and the arc length is controlled by the welder.

A welding arc has been defined as “A controlled electrical discharge between the electrode and the workpiece that is formed and sustained by the establishment of a gaseous conductive medium, called an arc plasma.”

An arc, or electrical flame, emits bright light, as well as ultraviolet and infrared radiation. Depending on the current level, arc temperatures may be very high, relative to the base metal melting point, producing enough heat to melt any known material. The characteristics of the arc depend on the shielding gas present in the arc environment because it affects the anode, cathode, and plasma regions found there. These regions are shown in *figure 5* and described on the next page.

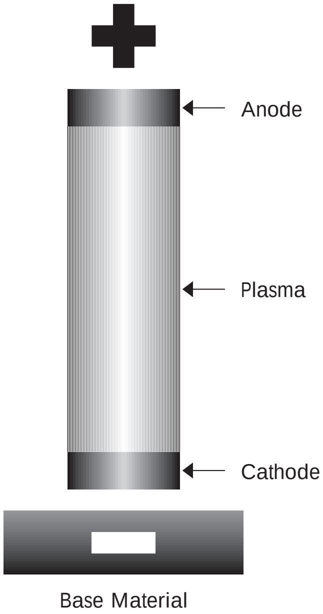
The Anode

The positive end of an arc is called the anode. It can be either the electrode or the workpiece, depending upon polarity of the system. The anode is the very thin, intensely bright area on the electrode or workpiece where the arc is attached. The anode voltage does not change when the electrode and workpiece are moved closer together or farther apart. The anode voltage depends on the composition of the filler material and the gas that surrounds it and is essentially constant for any set of materials.

The Cathode

The negative end of the arc is called the cathode. It also can be either the electrode or the workpiece, depending upon the polarity selected. The cathode is also a very thin bright area where the arc is attached. In aluminum welding, the cathode can appear as rapidly moving flashes of light at the edge of the arc attachment point to the aluminum surface. Cathode voltage is similar to anode voltage. It depends on materials in the immediate surroundings of the cathode zone and is essentially constant for any set of materials.

Figure 5 – The regions of an arc



Arc Plasma

An arc plasma is “A gas that has been heated by an electric arc to at least a partially ionized condition, enabling it to conduct an electric current.” It is the visible electrical flame, or arc, in the gap between the anode and cathode.

The arc voltage is the sum of the anode and cathode voltages plus the voltage across the arc plasma. With most welding processes, this voltage increases when the electrode and workpiece move farther apart and decreases as they move closer together. Arc voltage is also impacted by the electrical conductivity of the shielding gas selected.

Ionization Potential

The ionization potential is the energy, expressed in electron volts, necessary to remove an electron from a gas atom, making it an ion, or an electrically charged gas atom. All other factors held constant, the ionization potential decreases as the molecular weight of the gas increases. The significance of this is illustrated in *figure 6*, which shows a simplified atomic structure of argon and helium. Simplistically speaking, ionization potential can be described as a measurement of electrical conductivity of the arc shielding gas.

Argon, with eighteen electrons, is much heavier than helium, which has only two electrons. The force of attraction holding the outer electrons in their orbit is inversely proportional to the square of the distance from the nucleus. Simply stated, the energy required to remove an electron from the argon atom is significantly less than that required for helium. Specifically, it takes 15.7 electron volts to remove the first electron in argon compared to 24.5 electron volts in helium. At these energy levels, ionization of the gas begins in the arc gap, which creates the “free” electrons necessary to support current flow across the gap, forming the plasma.

Although other factors are involved in sustaining the plasma, these respective energy levels must be maintained for this to be accomplished.

From this relationship, it becomes readily apparent that, for equivalent arc lengths and welding currents *(see figure 7)*, the voltage obtained with a helium enhanced mixture is appreciably higher than it is with argon.

Since heat in the arc is roughly measured by the product of current and voltage (arc power), the use of helium yields a much higher available heat than does argon. This is one reason that helium is commonly referred to as a “hotter” gas *(see figure 8)*.

See Table 1, page 11 for specific values of molecular weight and ionization potential for the six pure shielding gases.

Arc starting and arc stability are also largely dependent on the ionization potential of the shielding gas selected. Gases with relatively low ionization potential, such as argon, give up electrons more easily, helping to initiate and maintain the arc in a stable operating mode.

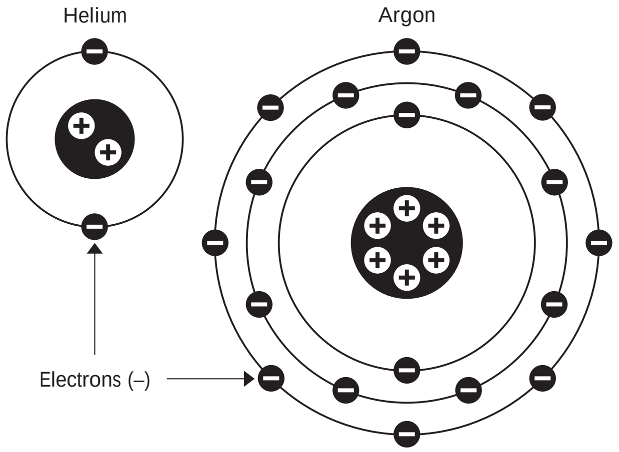


Figure 6 –
Atomic structures of argon and helium

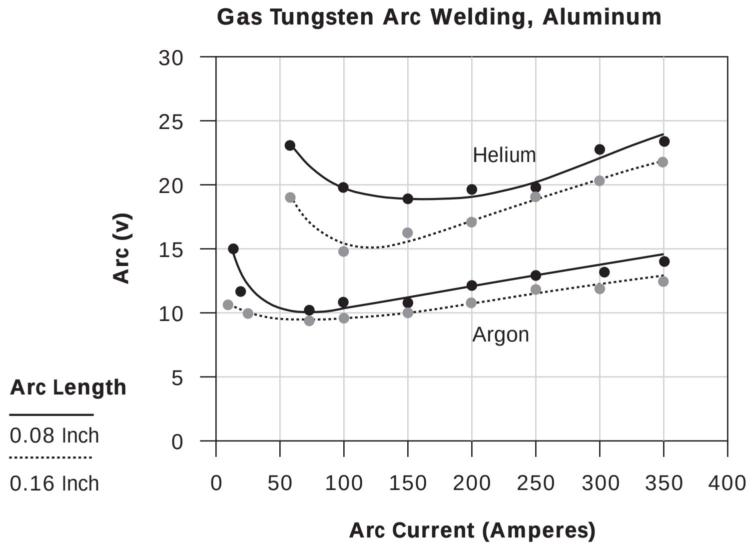


Figure 7 –
Voltage-current relationship
(alternative current, AC)

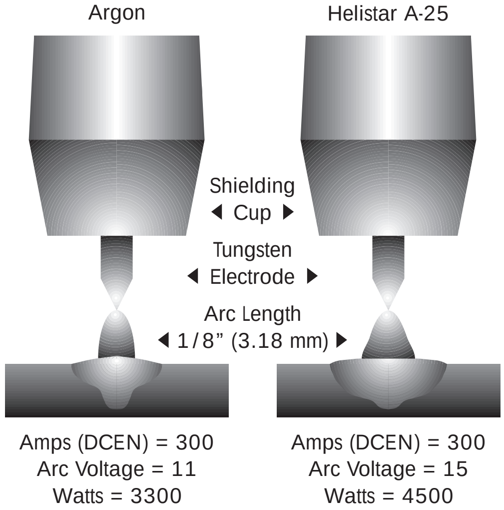
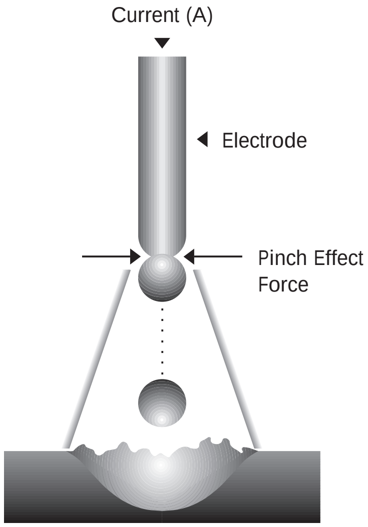


Figure 8 –
Increase of heat input with pure argon and argon/helium mixtures.

Figure 9 – Pinch Force



Electromagnetic Pinch Force

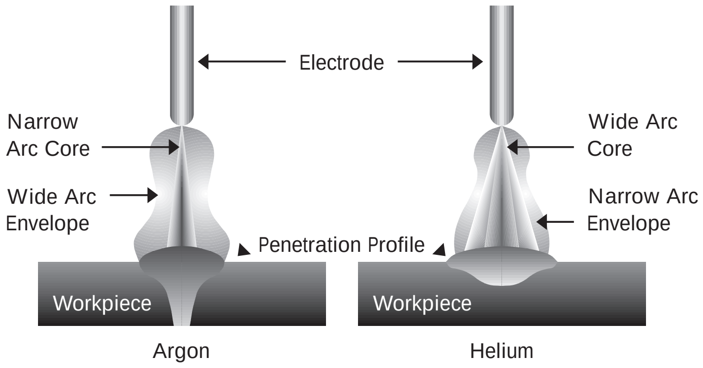
Electromagnetic pinch force has a strong effect on metal transfer. This pinch force is produced by current flow in a wire or electrode *(see figure 9)*. Every current-carrying conductor is squeezed by the magnetic field that surrounds it. When the GMAW electrode is heated close to its melting point and is in its eutectic state, the electromagnetic pinch force squeezes off drops of metal and assists in the transfer of the filler metal into the weld pool.

Physical Properties of Gases

Thermal Conductivity

The thermal conductivity of a gas is related to its ability to conduct heat. It influences the radial heat loss from the center to the periphery of the arc column. Pure argon, when used as a shielding gas has mild thermal conductivity, and produces an arc which has two zones: a narrow hot core and a considerably cooler outer zone *(see figure 10)*. As a result, the penetration profile of a typical weld fusion area is characterized by a narrow "finger" at the root and a wider top. A gas with high thermal conductivity conducts more of the heat outward from the arc core. This results in a broader, hotter arc. This type of heat distribution, which occurs with helium, argon-hydrogen, and argon/carbon dioxide mixtures is more uniform and produces a generally wider profile throughout the fusion zone.

Figure 10 – Comparison of arcs in argon and helium atmospheres



Dissociation and Recombination

When two or more atoms combine they form a molecule. Shielding gases such as carbon dioxide, hydrogen, and oxygen are molecules. For example, carbon dioxide is made up of one atom of carbon and two atoms of oxygen.

When heated to the high temperatures present in the arc plasma (12-15,000 F), these gases break down, or dissociate into their separate atoms. They are then at least partially ionized, producing free electrons and improved current flow. As the dissociated gas comes in contact with the relatively cool work surface, the atoms recombine, and it releases energy to the base material in the form of heat. This process does not occur with gases such as argon, which consists of a single atom. Therefore, for the same arc temperature, the heat generated at the work surface can be greater with gases such as carbon dioxide, hydrogen, and oxygen.

Reactivity

Reactivity, as it applies to shielding gases, is a comparative measurement of how readily a given shielding gas (at arc temperatures) will react with the elements in the puddle.

Argon and helium are completely non-reactive, or inert, and therefore have no chemical effect on the weld metal. Nitrogen is an inert gas, but, at the temperatures common to welding, it may react and have an adverse effect on weld chemistry.

Oxygen and carbon dioxide fall into a category of reactive gases known as oxidizers. These gases will react to form oxides with the molten metal in the arc and in the weld puddle. This property may contribute to causing welding fume.

Hydrogen is a reactive gas, but is reducing in the nature. Hydrogen will (preferentially) react with oxidizing agents, thereby helping to prevent the formation of oxides in the molten weld metal. However, hydrogen can produce detrimental effects such as underbead cracking, when used on some high strength and low alloy steels.

Surface Tension

In any liquid there is an attractive force exerted by the molecules below the surface upon those at the surface. An inward pull, or internal pressure is created, which tends to restrain the liquid from flowing. Its strength varies with the chemical nature of the liquid.

In welding, the surface tension between molten steel and its surrounding atmosphere has a pronounced influence on bead shape. If surface tension is high, a convex, irregular bead will result. Lower values promote flatter beads with minimum susceptibility for undercutting.

Pure argon shielding when used with GMAW is usually associated with high interfacial energy, producing a sluggish puddle and a high-crowned bead when mild steel welding is considered. This is partially attributed to the high surface tension of liquid iron in an inert atmosphere. For this reason, it is not recommended for use in MIG welding of mild steel. Iron oxides, however, have a considerably lower surface tension and thus promote good wetting to the parent metal. Therefore, the addition of small percentages of oxygen or carbon dioxide to argon when performing GMAW result in a more fluid weld puddle.

Gas Purity

Some base metals, such as carbon steel have a relatively high tolerance for contaminants. Others, such as aluminum, copper and magnesium, are fairly sensitive to impurities. Still others, such as titanium and zirconium, have extremely low tolerances for any impurity in the shielding gas.

Depending on the metal being welded and the welding process used, even minuscule gas impurities can have a detrimental impact on welding speed, weld surface appearance, weld bead coalescence, and porosity levels. These impurities can appear in several ways.

It is always possible that the gas can be contaminated as delivered; but it is more likely that it becomes contaminated somewhere between the supply and the end-use points. Praxair is equipped with the analytical equipment to determine purity levels anywhere in the gas supply system, and can assist in identifying the cause of gas purity problems and their solution.

See Table 2, page 12 for standard industry minimum purity levels for welding grade gases.

Gas Density

Gas density is the weight of the gas per unit volume. It is usually expressed in pounds per cubic feet. Gas density is one of the chief factors influencing shielding effectiveness. Basically, gases heavier than air require lower flow rates than gases that are lighter than air to achieve equivalent weld puddle protection. *See Table 1, page 11* for specific values.

The properties of the gases commonly used in welding and cutting and how they function in metal fabrication applications are discussed below.

Basic Gas Properties

Argon (Ar)

Slightly less than one percent of the earth's atmosphere is composed of argon, which is colorless, odorless, tasteless, and nontoxic. As an inert gas, argon does not react with other compounds or elements. Argon is about 1.4 times heavier than air and cannot sustain life. The inert properties of argon make it ideal as a shield against atmospheric contamination, thus it is used in many welding processes.

Argon promotes good arc starting characteristics and arc stability due to its low ionization potential.

Carbon Dioxide (CO_2)

Carbon dioxide (CO_2), a reactive gas, is about 1.5 times heavier than air. It is an odorless, colorless gas with a slightly pungent, acid taste and is slightly toxic. It will not sustain life or support combustion. Differing from other reactive gases such as oxygen, CO_2 can be used alone for GMAW shielding gas applications. Its relatively high oxidizing potential can be countered by the use of GMAW or FCAW wires higher in alloying elements, such as silicon and manganese.

Carbon dioxide is commonly mixed with argon to improve productivity and penetration in GMAW.

Helium (He)

Helium is the second lightest element, after hydrogen, and is lighter than air. Like argon, it is chemically inert and will not sustain life. Due to its high thermal conductivity and high ionization potential, helium is used as a shielding gas for welding applications when increased heat input is desired, and low tolerance for oxidizing elements exist such as with aluminum and magnesium welding.

Hydrogen (H_2)

Hydrogen, the lightest known element, is a flammable gas. Explosive mixtures can be formed when certain concentrations of hydrogen are mixed with oxygen, air, or other oxidizers. Hydrogen is not life sustaining. Small quantities are useful in gas blends for plasma cutting and some welding applications because of its high thermal conductivity and reactive nature. It is very useful when GMAW and GTAW – 300 series austenitic stainless steels.

Nitrogen (N_2)

Nitrogen is a colorless, odorless, and tasteless gas which forms 78 percent of the earth’s atmosphere (by volume). It is nonflammable, does not support combustion, and is slightly lighter than air. Nitrogen is inert except at arc welding temperatures, where it will react with some metals, such as aluminum, magnesium, and titanium. It is not recommended as a primary shielding gas with GMAW, but is commonly applied as an assist gas with laser cutting on stainless steels. It can be used in combination with other gases for some welding applications and is also widely used in plasma and laser cutting.

Oxygen (O_2)

Fifty percent of the earth’s crust and approximately 21 percent of the earth’s atmosphere (by volume) is oxygen. Oxygen combines with almost all known elements except rare or inert gases, and it vigorously supports combustion. Because of its highly oxidizing and combustion-supporting properties, oxygen is an ideal gas for increasing flame temperatures and improving performance for oxyfuel welding and cutting. Small amounts of oxygen may be added to argon for GMAW to increase arc stability and improve the wetting and shape of the weld bead when working with mild or stainless steels. It is also used to enhance cutting speeds with plasma and laser processes.

Table 1 – Shielding gas data

	Argon	Carbon Dioxide	Helium	Hydrogen	Nitrogen	Oxygen
Chemical Symbol	Ar	CO_2	He	H_2	N_2	O_2
Atomic Number	18	_	2	1	7	8
Molecular Weight	39.95	44.01	4.00	2.016	28.01	32.00
Specific Gravity, Air = 1	1.38	1.53	0.1368	0.0695	0.967	1.105
Density (lb/cu ft) at 0 C, 1 atmosphere	0.1114	0.1235	0.0111	0.0056	0.0782	0.0892
Ionization Potential (ev)	15.7	14.4	24.5	13.5	14.5	13.2
Thermal Conductivity (10^{-3} x Btu/hr-ft- F)	9.69 (32 F)	8.62 (32 F)	85.78 (32 F)	97.22 (32 F)	13.93 (32 F)	14.05 (32 F)
Cubic ft/lb	9.67	8.73	96.71	192	13.8	12.08
Cubic ft/gal	113.2	74.0	100.6	103.7	93.2	115.0

Table 2 – Gas purity and moisture content (welding grade)

	Product State	Minimum Purity (percent)	Maximum Moisture* (ppm)	Approximate Dewpoint at Maximum Moisture Content	
				F	C
Air	Liquid	99.98	120	- 40	- 40
Argon	Gas	99.995	10	- 77	- 60
	Liquid	99.997	6	- 83	- 64
Carbon Dioxide	Gas	99.5	34	- 60	- 51
	Liquid	99.8	13	- 73	- 58
Helium	Gas	99.95	32	- 61	- 51
	Liquid	99.995**	3	- 92	- 69
Hydrogen	Gas	99.95	8	- 80	- 63
	Liquid	99.995***	5	- 86	- 65
Nitrogen	Gas	99.7	32	- 61	- 51
	Liquid	99.997	5	- 86	- 65
Oxygen	Industrial	99.5	50	- 54	- 48
	Liquid	99.5	6	- 83	- 64

* Moisture specifications are measured at full cylinder pressure.

** Including neon

*** Including helium

Based solely on oxygen content. Minute traces of other inert gases (such as argon, neon, helium, etc.) which remain after oxygen removal are considered as nitrogen. (This is standard practice in the compressed gas industry.)

CHAPTER 2

Gas Tungsten Arc Welding (GTAW)

Process Description

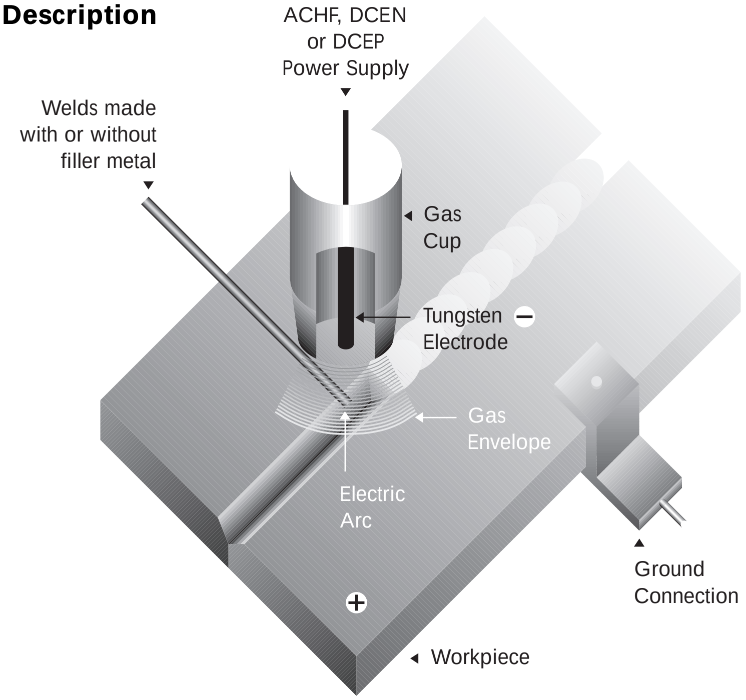


Figure 11 – Essentials of GTAW

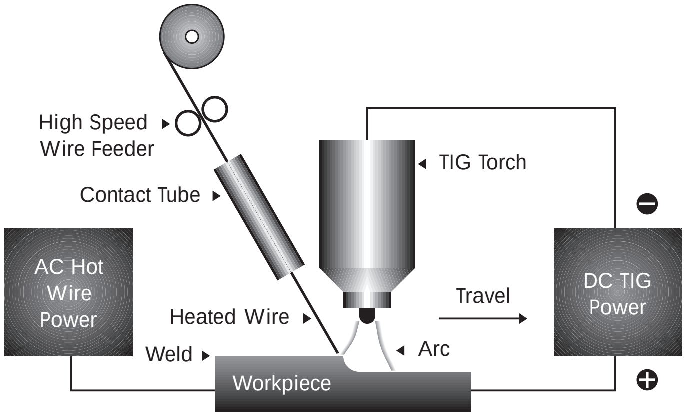


Figure 12 – Diagram of Gas Tungsten Arc hot wire system

Gas Tungsten Arc Welding (GTAW) is defined as “an open arc welding process that produces coalescence of metals by heating them with an electric arc between a tungsten electrode (nonconsumable) and the workpiece. The molten weld pool is protected by an externally supplied shielding gas. Pressure may or may not be used, and filler metal may or may not be used.” GTAW is also commonly referred to as TIG (Tungsten Inert Gas) or Heliarc welding although the American Welding Society refers to it as GTAW. *Figure 11* illustrates the essentials of GTAW.

The use of a nonconsumable tungsten electrode and inert shielding gases produces the highest quality welds of any open arc welding process. Welds are bright and shiny, with no slag or spatter, and require little or no post-weld cleaning. GTAW is easily used in all welding positions and provides excellent weld puddle control, especially on thin and intricate parts. It has found extensive use in the aircraft, aerospace, power generation, chemical, and petroleum industries.

Although usually thought of as a manual process, GTAW is often automated with or without filler wire for high-production applications. In 1969, Praxair introduced a variation to the process called “Hot Wire.” With this process, the filler wire is independently pre-heated to a molten state as it enters the weld puddle. This feature allows arc heat to be fully concentrated on melting the workpiece, not the wire *(see figure 12).* The Hot Wire process expands the versatility of automated GTAW by increasing deposition rates and travel speeds.

Gas Flow Rate

Gas flow rate, which can range from a few cubic feet per hour (cfh) to more than 60 cfh, depends on the current developed, the torch size, the shielding gas composition and the surrounding environment (drafts, etc.).

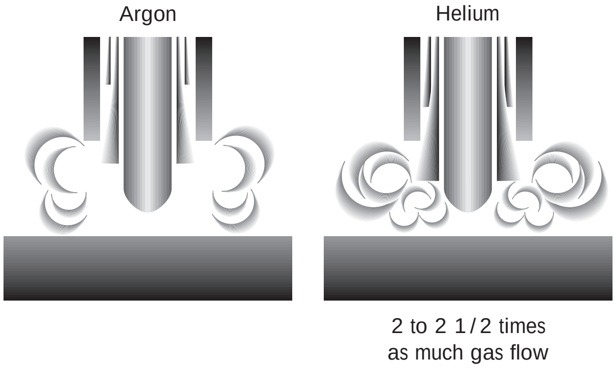


Figure 13 –
Shielding effectiveness of gas density (GTAW)

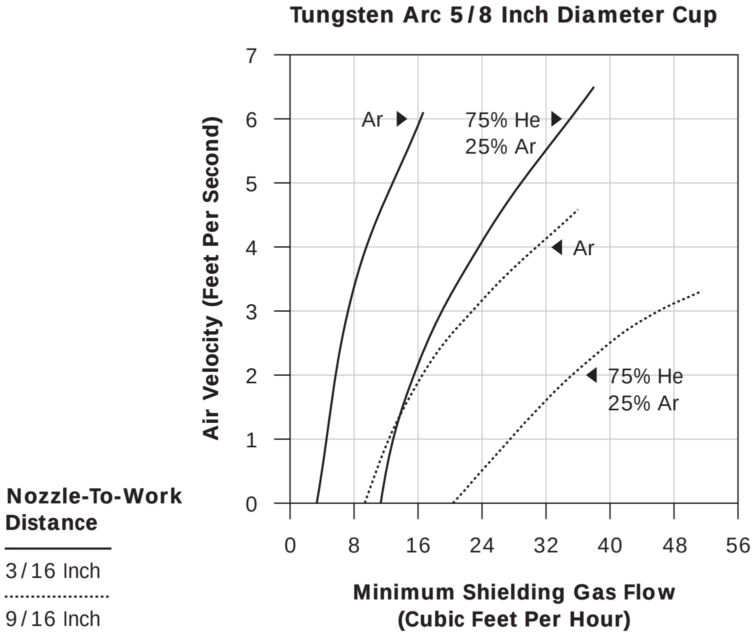


Figure 14 –
Relationship of flow requirements to cross-draft velocity

In general, a higher current will require a larger torch and higher flow rates. In addition, gas density, or the weight of the gas relative to air, has a major influence on the minimum flow rate required to effectively shield the weld.

Argon is approximately 1.4 times as heavy as air and ten times as heavy as helium. The significance of these differences in gas density relative to air is shown in *figure 13.*

Argon shielding gas is delivered to the arc zone by the torch nozzle. Its function is to provide a contaminant free blanket of shielding gas over the weld area. Because helium is much lighter than argon, to produce equivalent shielding effectiveness when welding in the flat position, the flow of helium must be two to two and one half times that of argon. The same general relationship is true for mixtures of argon and helium, particularly those high in helium content, although as argon content is increased, shielding gas flow is typically decreased. It should be noted that for overhead welding flow rates with helium mixtures can be reduced as the specific gravity of the gas is less than that of air.

Figure 14 shows the relationship of flow requirements to the cross-draft velocity for pure argon and for a 25% argon/75% helium mixture using two different nozzle-to-workpiece distances.

Gas flow rate must be selected with care.
It is not productive or economical to use more gas than necessary to achieve good shielding. High gas flows can pull air into the welding arc, often causing porosity in the weld.
To avoid wasting gas and contaminating the weld, use of an inexpensive critical flow device that restricts gas flow to an optimal range is often recommended.

Preflow and Postflow

When welding materials that are sensitive to oxidation (such as copper, aluminum and stainless steel), gas preflow and postflow will minimize contamination of the weld zone and electrode. A pre-flow of shielding gas removes moisture which may have entered the system and blankets the weld zone for optimum starting conditions. Changes in room temperature can cause air to move in and out of the end of a torch while not in use; moisture in the air condenses on the inside of the torch. A preflow of shielding gas for a period of time before the arc is initiated will remove the moisture.

Postflow works to minimize contamination of the weld pool in a different way. When the arc is turned off, the weld metal begins to cool. For a few moments, the weld metal remains hot enough to be contaminated by the surrounding air. To prevent this, the shielding gas is allowed to flow for several seconds after the arc is extinguished. The length of time varies on the size and temperature of the weld but a rule of thumb is one second for every ten amps of current. This will provide shielding to allow the weld to cool. The postflow of gas also protects the hot electrode from contamination.

Backup Shielding and Trailing Shields

It is sometimes necessary to use shielding gas on the underside of a weld to prevent oxidation of the hot weld bottom. As an example, backup shielding gas is used to purge the air from the interior of piping prior to and during welding. This procedure prevents contamination of the backside of the weld while the pipe is being welded from the outside.

The same gas may be used for backup and welding, but it is possible to use a gas blend for welding and another gas, such as pure argon, nitrogen, or an argon/hydrogen, nitrogen/hydrogen blend for the backup gas, depending on the workpiece material.

In some instances, the welding travel speed may be too great for the shielding gas to protect the weld until it has cooled. As the arc moves on, the solidified weld metal remains hot and oxidizes. A trailing gas shield can be used to prevent oxidation on the surface of the weld bead from occurring.

Shielding Gases for GTAW

Argon

Argon, an inert rare gas that makes up approximately 1% of the earth’s atmosphere, is the most commonly used shielding gas for GTAW. Its low thermal conductivity produces a narrow, constricted arc column and excellent electrical conductivity which allow greater variations in arc length with minimal influence on arc power and weld bead shape. This characteristic makes it the preferred choice for manual welding. In addition, argon provides good arc starting due to its low ionization potential.

For AC welding applications, high purity argon offers superior cleaning action, arc stability, and weld appearance.

While pure argon may be used for mechanized applications, argon/helium or argon/hydrogen blends are frequently selected to promote higher welding travel speeds. The hotter arc characteristics of these blends also make them more suitable for welding metals with high thermal conductivity, such as copper or stainless steel. Argon/hydrogen blends should only be used for welding austenitic stainless steels.

Helium

Helium, also an inert gas, has high thermal conductivity and high ionization potential, which require higher arc voltages than argon for a given current setting and arc length. *(See Chapter 1, figure 7, "Voltage-current relationship.")* This produces a hotter and broader arc which improves the depth of penetration and weld bead width.

The use of helium is generally favored over argon at the higher current levels which are used for welding of thicker materials, especially those having high thermal conductivity or relatively high melting temperatures. It is also often used in high-speed mechanized applications, although an addition of argon will improve arc initiation and cleaning action.

Although argon is widely used for AC welding of aluminum, helium has been successfully used for DCEN mechanized and high current AC welding of this material. It produces greater penetration and higher travel speeds. However, surface oxides must be cleaned from the weld joint to obtain acceptable results.

The physical properties of helium definitely offer advantages in some applications. However, due to it high ionization potential, it also produces a less stable arc and a less desirable arc starting characteristic than argon. Its higher cost and higher flow rates are also factors to be considered. In some cases, an argon mixture is used for igniting the arc and pure helium is used for welding. This technique is used for mechanized DCEN-GTAW welding of heavy aluminum.

Argon/Helium Blends

Praxair's HeliStar™ Blends
Each of these gases (argon and helium), as explained above, has specific advantages. Praxair's HeliStar blends (argon/helium blends) are used to increase the heat input to the base metal while maintaining the favorable characteristics of argon, such as arc stability and superior arc starting.

Praxair's HeliStar A-75
This blend is sometimes used for DC welding when it is desirable to obtain higher heat input while maintaining the good arc starting behavior of argon. It is a favorite choice when MIG welding thick aluminum (> 1/2").

Praxair's HeliStar A-50
This blend is used primarily for high-speed mechanized welding of nonferrous material under 3/4 inch thick.

Praxair's HeliStar A-25
The speed and quality of AC and DC welding of aluminum, copper and stainless steels can be improved with this blend. It is sometimes used for manual welding of aluminum pipe and mechanized welding of butt joints in aluminum sheet and plate. Praxair's HeliStar A-25 blend is also used for many of the GTAW hot wire applications to increase the energy input and accommodate the high filler metal deposition rates of the process.

Argon/Hydrogen Blends

Praxair's HydroStar™ Blends
Hydrogen is often added to argon to enhance its thermal properties. Hydrogen's reducing characteristics also improve weld puddle wetting and produce cleaner weld surfaces due to reduced surface oxidation. Hydrogen enhanced blends are commonly selected to weld 300 series stainless steels.

The higher arc voltage associated with hydrogen increases the difficulty of starting the arc. For this reason, the smallest addition of hydrogen consistent with the desired result is recommended. Additions up to 5% for manual welding and up to 10% for mechanized welding are typical. Ratios beyond this level typically cause porosity in GTAW.

Argon/hydrogen blends are primarily used on austenitic stainless steel, nickel, and nickel alloys. Hydrogen **is not** used to weld carbon or low-alloy steel, copper, aluminum, or titanium alloys since cracking or porosity will result from the absorption of hydrogen.

Warning
Special safety precautions are required when mixing argon and hydrogen. DO NOT attempt to mix argon and hydrogen from separate cylinders. See the Safety section in this handbook for more information.

Higher ratios of hydrogen may be mixed with argon (up to 35%) depending on the process selected. For example Praxair's HydroStar H-35 (65%Ar/35% H_2) is commonly used in plasma gouging.

Praxair's HydroStar blends are hydrogen-enhanced argon-based blends which are ideally suited for general purpose manual and mechanized GTAW of most commercially available austenetic stainless steels. It may be substituted for pure argon in many applications.

Praxair's HydroStar H-2 and H-5
These blends are used for manual GTAW applications on 300 series stainless steels. HydroStar H-5 blend is preferred on material thicknesses above 1/16 inch. These blends are also used for back purging on stainless pipe.

Praxair's HydroStar H-10
This blend is preferred for high-speed mechanized applications. It is used with 300 series stainless steels.

Praxair's HydroStar H-15
This blend, which contains 15% hydrogen, is used most often for welding butt joints in stainless steel (300 series) at speeds comparable to helium, and is typically 50 percent faster when compared with argon. HydroStar H-15 blend is frequently used to increase the welding speeds in stainless steel tube mills. It can be used on all thicknesses of stainless steel, although concentrations greater than 15% may cause weld metal porosity.

Praxair's HydroStar H-35
This blend, which contains 35% hydrogen, is used most often for conventional plasma arc cutting and gouging of stainless steel.

Oxygen and Carbon Dioxide

These gases are chemically reactive and should not be used with GTAW. Their high oxidation potential can cause severe erosion of the tungsten electrode at arc temperatures.

See Table 3, page 18 for the GTAW Shielding Gases Selection Guide.

Table 3 – Shielding Gases Selection Guide for GTAW

Material	Weld Type	Recommended Shielding Gas	Description
Mild Steel	Spot	Argon	Long electrode life; better weld nugget contour; easiest arc starting
	Manual	Argon	Best puddle control, especially for out-of-position welding
	Mechanized	Argon/Helium	High speeds; lower gas flows than with pure helium
		Helium	Higher speeds than obtained with argon; improved penetration
Aluminum and Magnesium	Manual	Argon	Best arc starting, good cleaning action and weld quality; lower gas consumption
		Argon/Helium	Higher welding speeds, greater weld penetration than argon
	Mechanized	Argon/Helium	Good weld quality, lower gas flow than required with straight helium, improved penetration
		Helium (dcsp)	Deepest weld penetration and greatest weld speeds; can provide cleaning action for aluminum and magnesium welding
Stainless Steel	Spot	Argon	Excellent control of penetration on light gauge materials
		Argon/Helium	Higher heat input for heavier gauge materials; faster travel speeds, improved weld puddle fluidity
	Manual	Argon	Excellent puddle control, controlled penetration
	Mechanized	Argon	Excellent control of penetration on light gauge materials
		Argon/Helium	Higher heat input, higher welding speeds possible
		Argon/ Hydrogen	Minimizes undercutting; produces desirable weld contour at low current levels, requires lower gas flows, ideal as a back purge gas on 300 series stainless steel
		Nitrogen/ Hydrogen	Suitable for back purging on 300 series stainless alloys
Copper, Nickel and Cu-Ni Alloys		Argon	Excellent puddle control, penetration and bead contour on thin gauge metal
		Argon/Helium	Higher heat input to offset high heat conductivity of heavier gauges, faster travelspeeds
		Helium	Highest heat input for sufficient welding speed on heavy metal sections
Titanium		Argon	High gas density provides better shielding
		Argon/Helium	Better penetration for manual welding of thick sections (inert gas backing required to shield back of weld against contamination)
Silicon Bronze		Argon	Reduces cracking of this hot short metal
Aluminum Bronze		Argon	Controlled penetration of base metal

Note:
Argon/helium blends usually require a water cooled torch and larger tungsten diameter due to increases in arc voltage.

CHAPTER 3

Plasma Arc Processes (PAW and PAC)

Plasma Arc Welding (PAW)

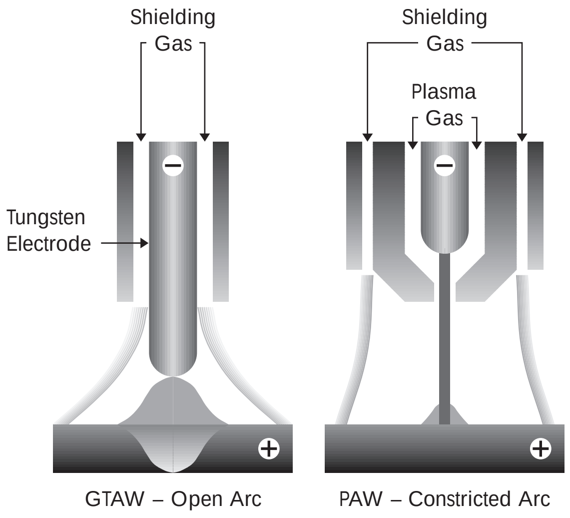


Figure 15 – Comparison of GTAW with PAW

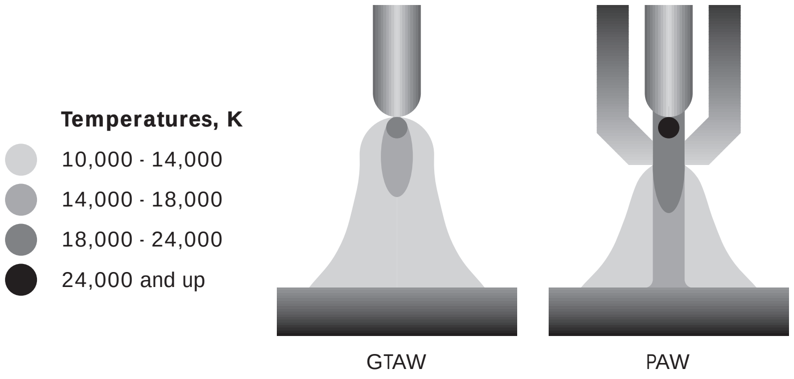


Figure 16 – Arc temperature profile

Process Description

Plasma Arc Welding (PAW) is an evolutionary step in the overall development of GTAW. Basically, the process uses an open, unrestricted gas tungsten arc that is "squeezed" through a copper nozzle. The result is a "constricted" arc that is longer, thinner, and more focused than a GTAW arc. *Figure 15* illustrates the essential difference between the GTAW and PAW processes.

The constriction process greatly increases arc voltage and the amount of ionization that takes place. In addition to raising arc temperature, the hottest area of the plasma is extended farther down toward the work surface *(figure 16)*. The overall result is a more concentrated heat source at a higher arc temperatures that greatly increases heat transfer efficiency; this promotes faster cutting and welding speeds.

PAW is defined as "an arc welding process that uses a constricted arc between a nonconsumable electrode and the weld pool (transferred arc) or between the electrode and the constricting nozzle (nontransferred arc), *see figure 17*. Shielding is obtained from the ionized gas supplied to the torch, which may be supplemented by an auxiliary source of shielding gas. The process is used without the application of pressure."

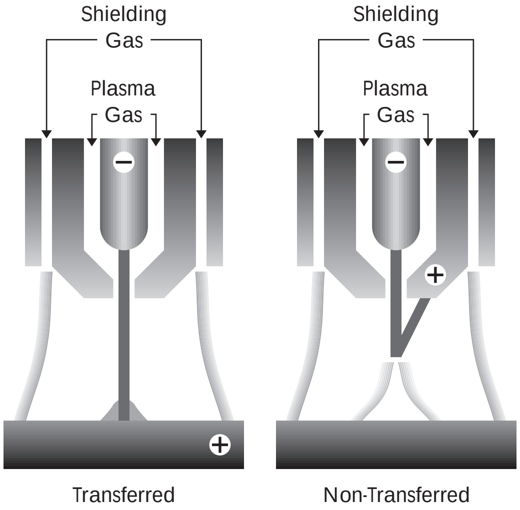


Figure 17 –
The two plasma arcs

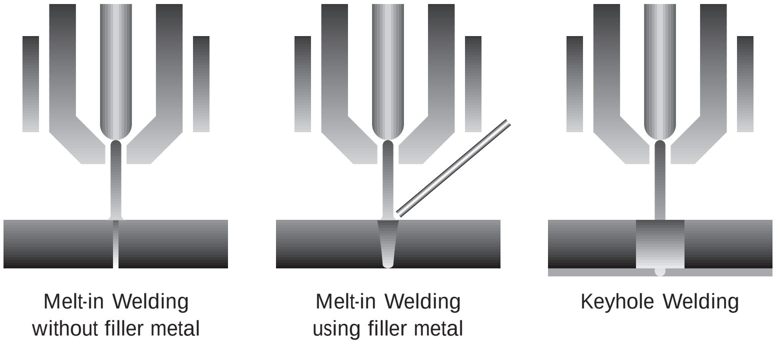


Figure 18 –
Plasma arc welding modes

The plasma process can produce two types of arcs. If the constricted plasma arc is formed between the electrode and the workpiece, it is said to have a "transferred arc." If the arc is produced between the electrode and the constricting nozzle, it is called "nontransferred arc." *See figure 17.*

Plasma arcs have an extremely wide range of operation. The nontransferred arc is used in special welding applications where it is not desirable to make the workpiece part of the electric circuit. It is also used for fusing nonmetallic materials, such as ceramics and certain types of glass. Operating currents range from 2 to 300 amps.

With the transferred arc, two basic welding methods are used: the Melt-in mode, (which can be used with or without filler metal), and Keyhole mode. *See figure 18* for illustrations of these methods.

Although similar to GTAW, the Melt-in method has some advantages due to its longer, more constricted arc shape. These include improved arc stability (particularly at low current levels), less distortion of the workpiece, higher potential welding speed, and greater tolerance to changes in torch-to-work distance. As shown in *figure 19*, the change in arc plasma area with a change in stand-off distance, is much greater with GTAW than with PAW. This has a major effect on heating of the work and, subsequently, on penetration and weld shape.

In Keyhole welding, the workpiece is fused through its entire thickness. The plasma jet pierces through the molten metal giving 100% penetration and forms a welding eyelet *(see figure 20)* which moves together with the arc in the direction of welding. Behind the plasma jet, the molten metal flows together again (as a result of surface tension), solidifies, and forms the completed weld.

Application of PAW

High-quality welds can be made with nickel, nickel-copper, nickel-iron-chromium, copper, heat resisting titanium, refractory alloy steels, and in nickel-chromium alloys up to approximately 0.3 inches thick. The process shows its greatest advantage when the keyhole approach is used in the thickness range of 0.062 to 0.0312 inches. The high-quality weld produced by the single pass keyhole technique is illustrated in *figure 21*.

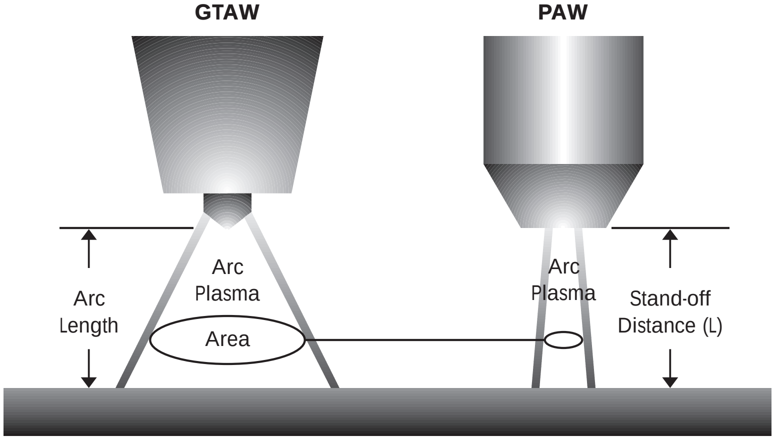


Figure 19 –
Variation of heating effect with stand off distances

Figure 20 –
PAW Keyhole welding

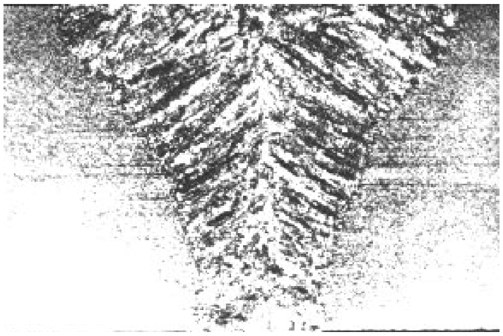


Figure 21 –
Cross-section of Keyhole weld

Shielding Gases for PAW

The physical configuration of PAW requires the use of two gases, a “plasma” or orifice gas and a shielding gas. The primary role of the plasma gas, which exits the torch through the center orifice, is to control arc characteristics and shield the electrode. It also effects the heat transfer properties to the base metal. The shielding gas, introduced around the periphery of the arc, shields or protects the weld. In many applications, the shielding gas is also partially ionized to enhance the plasma gas performance.

Low current (< 100 amps)

Argon is the preferred orifice gas because its low ionization potential ensures easy and reliable starting. Argon/helium and argon/hydrogen mixtures are also used for applications requiring higher heat input.

The choice of shielding gas is dependent on the type and thickness of the base material. When welding aluminum, carbon steel, and copper, the gases commonly used are argon, helium, and argon/helium mixtures. It is generally recommended that the percentage of helium be increased as the base-plate thickness increases. When welding low alloy steels, stainless steels, and nickel alloys, the aforementioned gases in addition to argon-hydrogen mixtures are used. *See Table 4, below* for low-current gas selection.

High Current (> 100 amps)

The choice of gas used when performing high current plasma arc welding also depends on the composition of the material to be welded. In all but a few cases, the shielding gas is the same as the orifice gas.

Table 4 – Low-Current Plasma Arc Welding Gas Selection Guide

Material	Thickness	Keyhole	Melt-in
Aluminum	Under 1/16"	Keyhole tech. not recommended	Argon or Helium
	Over 1/16"	Helium	Helium
Carbon Steel (Al. killed)	Under 1/16"	Keyhole tech. not recommended	Argon, Helium or HeliStar A-75
	Over 1/16"	Argon or HeliStar A-25	Argon or HeliStar A-25
Low Alloy Steel	Under 1/16"	Keyhole tech. not recommended	Argon, Helium, HydroStar H-2 or H-5
	Over 1/16"	Argon or HeliStar A-25	Argon or Helium
Stainless Steel	Under 1/16"	Keyhole tech. not recommended	Argon, Helium, HydroStar H-2 or H-5
	Over 1/16"	Argon, HeliStar A-25 HydroStar H-2 or H-5	Argon, Helium, HydroStar H-5
Copper	Under 1/16"	Keyhole tech. not recommended	Helium or HeliStar A-75
	Over 1/16"	Helium or HeliStar A-25	Helium
Nickel Alloys	Under 1/16"	Keyhole tech. not recommended	Argon, Helium, HydroStar H-2 or H-5
	Over 1/16"	Argon, HeliStar A-25	Argon, Helium, HydroStar H-5
Reactive Materials	Under 1/16"	Keyhole tech. not recommended	Argon
	Over 1/16"	Argon, Helium or HeliStar A-25	HeliStar A-75

Argon

Argon is suitable as the orifice and shielding gas for welding all metals, but it does not necessarily produce optimum welding results. In the Melt-in mode, additions of hydrogen to argon produce a hotter arc and offer more efficient heat transfer to the work. Limits on the percentage of hydrogen are related to its potential to cause cracking and porosity. However, when using the Keyhole technique, a given material thickness can be welded with higher percentages of hydrogen. This may be associated with the Keyhole effect and the different solidification pattern it produces.

Argon is used for welding carbon steel, high strength steel, and reactive metals such as titanium and zirconium alloys. Even minute quantities of hydrogen in the gas used to weld these materials may result in porosity, cracking, or reduced mechanical properties.

Argon/Helium Blends

Praxair's HeliStar™ Blends

Helium additions to argon produce a hotter arc for a given arc current. Argon/helium mixtures containing between 50% and 75% helium are generally used to make keyhole welds in heavier titanium sections and for fill and capping passes on all materials when the additional heat and wider heat pattern of these mixtures prove desirable.

Argon-Hydrogen Blends

Praxair's HydroStar™ Blends

Argon/hydrogen mixtures are used as the orifice and shielding gases for making keyhole welds in stainless steel, Inconel, nickel, and copper-nickel alloys. Permissible hydrogen percentages vary from 5% to 15%. *See Table 5, below* for high-current gas selection.

Table 5 — High-Current Plasma Arc Welding Gas Selection Guide

Material	Thickness	Keyhole	Melt-in
Aluminum	Under 1/4"	Argon	Argon or HeliStar A-25
	Over 1/4"	Helium	Helium or HeliStar A-25
Carbon Steel (Al. killed)	Under 1/8"	Argon	Argon
	Over 1/8"	Argon	HeliStar A-25
Low Alloy Steel	Under 1/8"	Argon	Argon
	Over 1/8"	Argon	HeliStar A-25
Stainless Steel	Under 1/8"	Argon or HydroStar H-5	Argon
	Over 1/8"	Argon or HydroStar H-5	HeliStar A-25
Copper	Under 3/32"	Argon	Helium or HeliStar A-25
	Over 3/32"	Keyhole tech. not recommended*	Helium
Nickel Alloys	Under 1/8"	HydroStar H-5	Argon
	Over 1/8"	HydroStar H-5	HeliStar A-25
Reactive Materials	Below 1/16"	Argon	Argon
	Above 1/16"	Argon or Argon/Helium	HeliStar A-25

** The underbead will not form correctly. However, on Cu-Zn alloys a keyhole technique can be used.*

Note:
Gas selections shown are for both the orifice and shielding gas.

Plasma Arc Cutting (PAC)

Process Description

Plasma Arc Cutting is defined as “an arc cutting process that severs metal by melting a localized area with a constricted arc which removes the molten material with a high velocity jet of hot, ionized gas issuing from the constricting orifice.”

The major difference between PAC and PAW is the velocity of the orifice gas. In some cases, a shielding gas as well as a cutting, or orifice gas may be used (the shielding gas prevents oxidation of the cut surface.) The higher velocity gas used in PAC removes or blows away the molten material. The PAC process can be used to cut any electrically conductive metal if its thickness and shape permit full penetration by the plasma jet. Because the PAC process can be used to cut nonferrous materials, and is faster than oxy-fuel cutting in the less-than-two-inch thickness range for ferrous materials, it is ideal for many industrial applications.

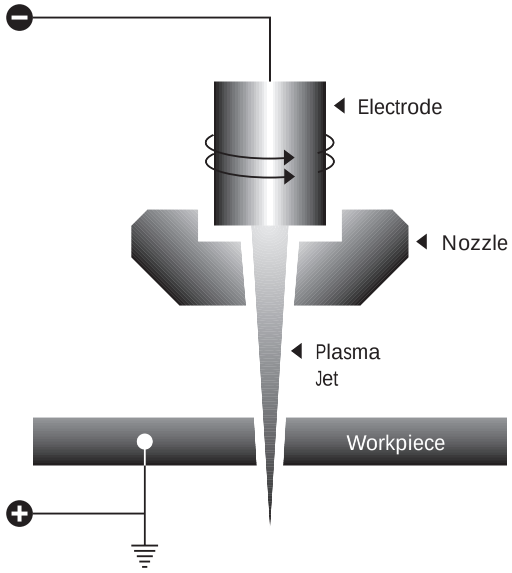


Figure 22 – Conventional Plasma Arc Cutting

Since PAC was introduced by Praxair in 1954, many process refinements, gas developments, and equipment improvements have occurred. The following sections describe the process variations that are in use today.

Conventional Plasma Arc Cutting

In conventional Plasma Arc Cutting, the arc is constricted by a nozzle only; no shielding gas is added. Generally the cutting gas (usually nitrogen or air) is tangentially injected around the electrode *(see figure 22).*

The swirling action of the gas causes the cooler (heavier) portions of the gas to move radially outward, forming a protective boundary layer on the inside of the nozzle bore. This helps prevent nozzle damage and extends its life. Electrode life is also improved since the arc attachment point (cathode spot) is forced to move about and distribute its heat load more uniformly. Until the introduction of Water Injection Plasma Arc Cutting in 1970 *(see page 26)* conventional Plasma Arc Cutting was the most popular technique. It is still the best method for cutting thicker stainless and aluminum plate.

Air Plasma Arc Cutting

Air Plasma Arc Cutting was introduced in the early 1960s for cutting mild steel. Oxygen in the air provides additional energy by creating an exothermic reaction with molten steel, boosting cutting speeds about 25 percent. Although this process can also be used to cut stainless steel and aluminum, the cut surface will be heavily oxidized and is often unacceptable for many applications. Electrode and tip life are also reduced when compared to the use of nitrogen as the plasma gas.

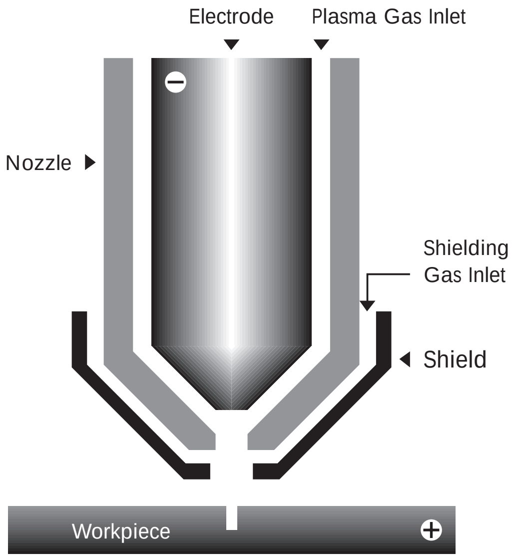


Figure 23 – Oxygen PAC nozzle

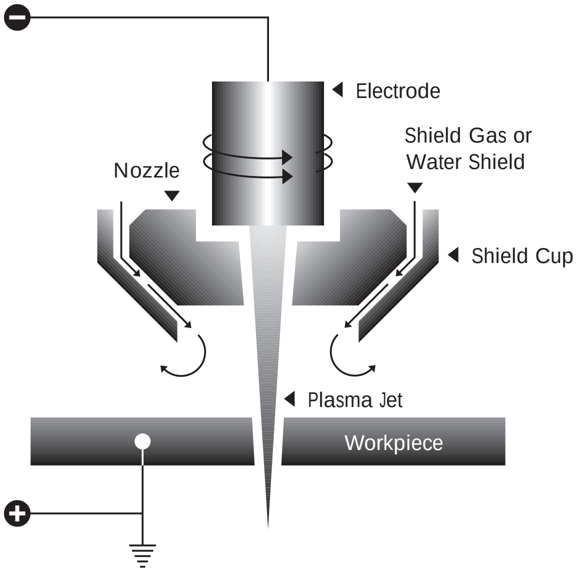


Figure 24 – Dual-flow Plasma Arc Cutting

Oxygen Plasma Arc Cutting

In Oxygen Plasma Arc Cutting, oxygen is used as the plasma (orifice) gas in place of nitrogen or air. The oxygen in the plasma stream has a similar effect on steel as with oxyfuel cutting; it produces an exothermic reaction which increases cutting speed. It is possible to achieve cutting speeds similar to nitrogen at much lower currents. Oxygen plasma cutting is used primarily on mild steel.

Limitations of Oxygen Plasma Arc Cutting

The conventional PAC process (with nitrogen) uses tungsten electrodes which cannot be used in an oxygen environment. Halfnium is substituted as the electrode material for oxygen cutting. The halfnium must be kept cool and the current capacity of the torch limited to ensure longer life *(see figure 23)*.

Dual-Flow Plasma Arc Cutting

Dual-Flow Plasma Arc Cutting is a slight modification of conventional Plasma Arc Cutting *(see figure 24)*. It incorporates most of the features of conventional Plasma Arc Cutting, but adds a secondary shielding gas around the nozzle.

Usually the cutting gas is nitrogen and the shielding gas is selected according to the metal to be cut. Cutting speeds are slightly better than “conventional” plasma arc cutting on mild steel; however, cut quality is not acceptable for many applications. Cutting speed and quality on stainless steel and aluminum are essentially the same as in conventional Plasma Arc Cutting.

Water Injection Plasma Arc Cutting

In Water Injection Plasma Arc Cutting, water is introduced inside the nozzle to provide additional arc constriction *(see figure 25)* and nozzle cooling.

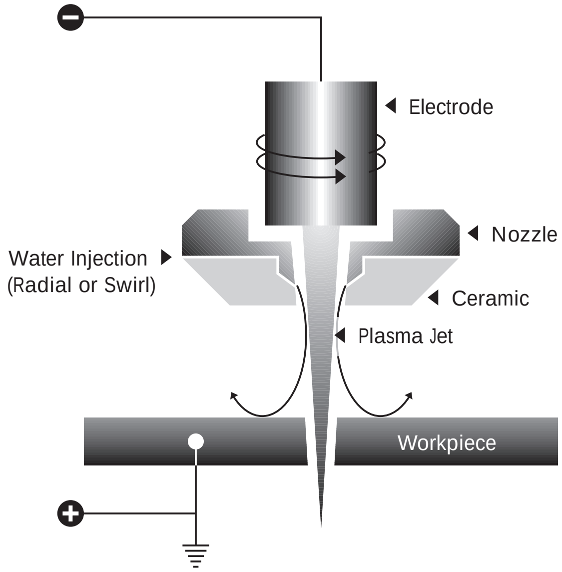
Two modes of water injection have been developed: Radial Injection (the water impinges the arc with no swirl component), and Swirl Injection (the water is introduced as a vortex swirling in the same direction as the cutting gas).

The increased arc constriction provided by the water improves cut squareness and increases cutting speed. The water also protects the nozzle since it provides cooling at the point of arc constriction. The water completely protects the bottom half of the nozzle from intense radiation, allowing complete insulation of the nozzle; hence, resistance to damage is greatly improved. This approach ensures component durability, superior cut quality and high cutting speeds.

Underwater Plasma Arc Cutting

Underwater Plasma Arc Cutting is ideally suited to numerically-controlled shape cutting and produces a comfortable noise level of 85 dBA or less under normal operating conditions. (Conventional Plasma Arc Cutting typically produces noise levels in the range of 105 to 115 dBA.) Underwater cutting virtually eliminates the ultraviolet radiation and fumes associated with conventional Plasma Arc Cutting.

Figure 25 – Water Injection Plasma Arc Cutting



In underwater PAC, the steel plate being cut is supported on a cutting table with the top surface of the plate two to three inches beneath the surface of the water. A device that locates the submerged top surface of the metal is critical to this fully-automated process. Accurate height control is maintained by a sensor that monitors arc voltage. Cutting speed and quality are comparable to those attained with plasma arc cutting by water injection.

Warning

It is hazardous to cut aluminum underwater. Hydrogen generated by the process can be trapped under the plate creating the potential for explosion.

Precision Plasma Arc Cutting

Precision Plasma Arc Cutting utilizes an improved nozzle design to increase arc constriction and dramatically increase energy density. Because of the higher energy density, the edge quality and squareness of the cut is improved, particularly on thinner material (3/8").

Recent developments in plasma torch design allow the operator to drag the nozzle on the material surface without the arcing problems normally associated with other PAC process variations *(see figure 26)*.

The Precision Plasma Arc Cutting process is employed in cutting sheet in the range of 20 gauge to 3/8". Conventional plasma can cut up to 2" thicknesses.

Gas Flow Rates

The orifice gas will often have a lower flow rate than the shielding gas, but both will vary as changes in cutting current are made to accommodate different base metals and thicknesses. Most PAC equipment use only an orifice gas with no shielding gas.

Gas flow with most PAC equipment is controlled by a gas pressure regulator and a flowmeter. The range of gas flow can vary between 1.0 and 100 standard cubic feet per hour (scfh) for the orifice gas and 8.0 and 200 scfh for the shielding gas, as determined by the cutting requirements. Because PAC equipment design can vary significantly between models, specific flow rates are not listed here.

Shielding and Cutting Gases for PAC

Inert gases, such as argon, helium, and nitrogen (except at elevated temperatures) are used with tungsten electrodes. Air may be used as the cutting gas when special electrodes, made from water-cooled copper with high temperature resistant inserts of metals like hafnium, are used. Recently, PAC units shielded by compressed air have been developed to cut thin gauge materials.

Virtually all plasma cutting of mild steel is done with one of four gas types: **(1)** Air, **(2)** Nitrogen with carbon dioxide shielding or water injection (mechanized), **(3)** Nitrogen/oxygen or air, and **(4)** Argon/hydrogen and nitrogen/hydrogen mixtures. The first two have become the standard for high-speed mechanized applications. Argon/hydrogen and nitrogen/hydrogen (20% to 35% hydrogen) are occasionally used for manual cutting, but dross formation is a problem with the argon blend. Dross is a tenacious deposit of resolidified metal attached at the bottom of the cut. A possible explanation for the heavier, more tenacious dross formed in argon is the greater surface tension of the molten metal. The surface tension of liquid steel is 30 percent higher in an argon atmosphere than in nitrogen. Air cutting gives a dross similar to that formed in a nitrogen atmosphere.

During cutting, the plasma jet tends to remove more metal from the upper part of the workpiece than from the lower part. This results in cuts with non-parallel cut surfaces which are generally wider at the top than at the bottom. The use of argon/hydrogen, because of its uniform heat pattern or the injection of water into the torch nozzle (mechanized only), can produce cuts that are square on one side and beveled on the other side. For base metal over three inches thick, argon/hydrogen is frequently used without water injection. Air is used as a low cost plasma gas, but specific precautions must be taken to ensure that it is moisture and oil free. *Table 6, page 28* lists the combinations of orifice and shielding gases that may be used with PAC.

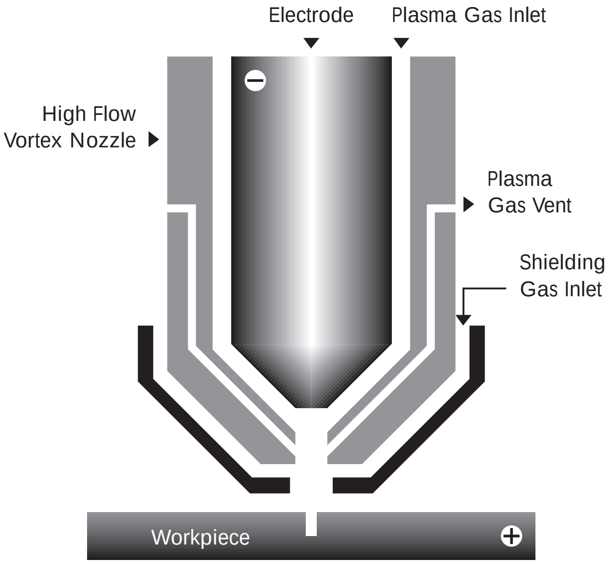


Figure 26 – Precision PAC nozzle

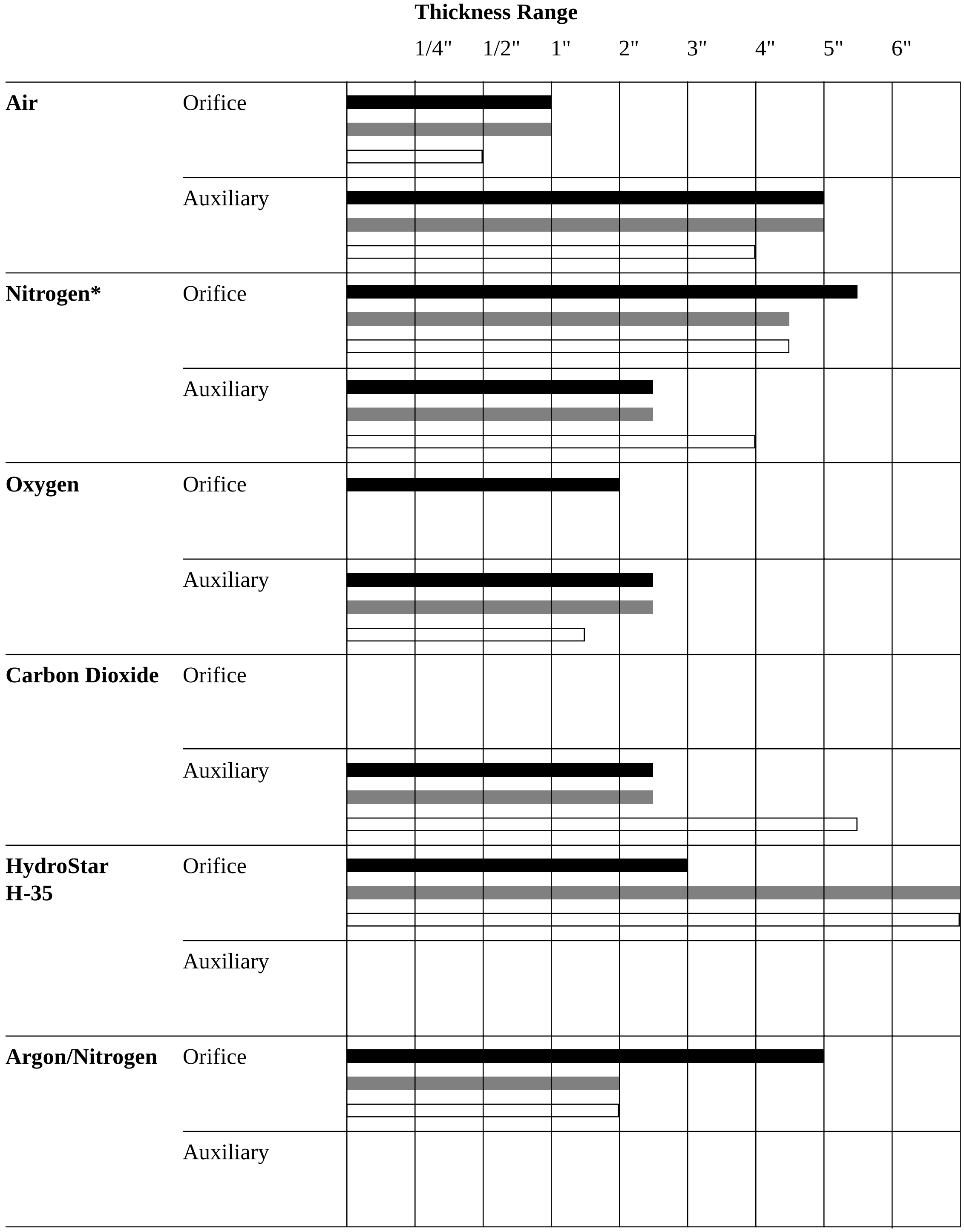
Table 6 – Gas Selection Guide for Plasma Arc Cutting

Key

■ Carbon Steel

▨ Stainless Steel and Nickel Alloys

☐ Aluminum



** For Water Injection Plasma Cutting, nitrogen is the preferred plasma gas.*

***Notes** – Depending upon equipment type the following applies:*
(1) An orifice gas is often used with no auxiliary gas.
(2) When multiple auxiliary gases are shown for a single orifice gas, only one auxiliary gas applies for a given application.
(3) Cutting speed and quality can vary with gas selection.
(4) This table is a composite based on gas requirements for currently available PAC equipment.
Use manufacturer’s recommendations for selecting gases.

CHAPTER 4

Gas Metal Arc Welding (GMAW)

Process Description

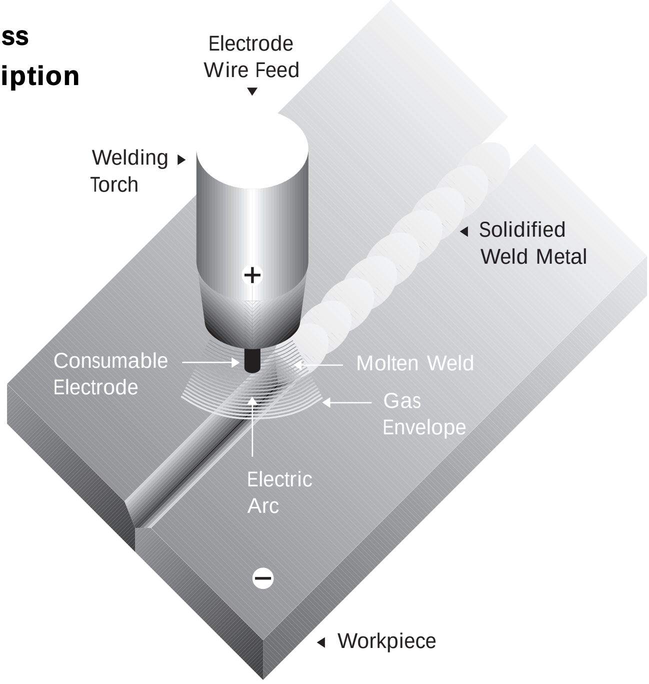


Figure 27 – Basic GMAW welding

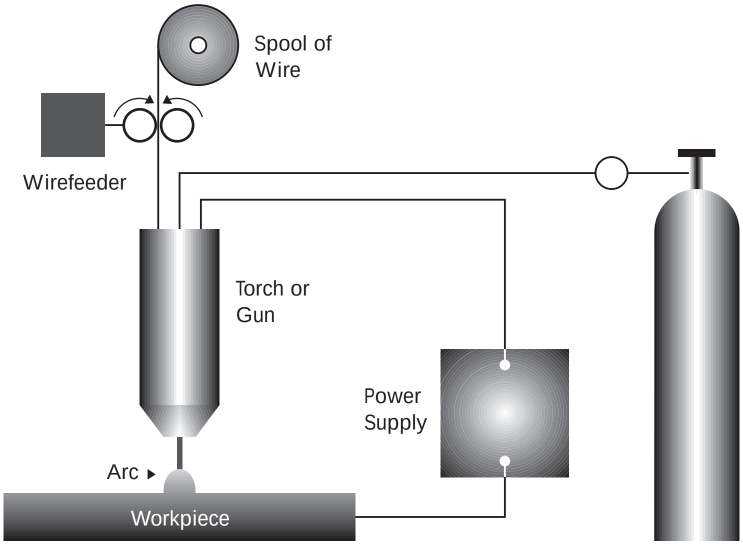


Figure 28 – Basic GMAW system

Gas Metal Arc Welding is defined as “an electric arc welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode and the workpiece. Shielding is obtained entirely from an externally supplied gas.” *Figure 27* shows the essential elements of a basic GMAW welding process.

GMAW is used to weld all commercially important metals, including steel, aluminum, copper, and stainless steel. The process can be used to weld in any position, including flat, vertical, horizontal, and overhead. It is usually connected to use direct current electrode positive (DCEP). It is an arc welding process which incorporates the automatic feeding of a continuous, consumable electrode that is shielded by an externally supplied gas *(see figure 28).* Since the equipment provides for automatic control of the arc, the only manual controls required by the welder for semiautomatic operation are gun positioning, guidance and travel speed.

Metal Transfer Modes in GMAW

The GMAW process has five distinctive metal transfer modes:

- Short circuiting
- Globular
- Spray
- Pulsed spray
- High-current density (rotational and nonrotational) spray.

The metal transfer mode is determined by many factors, including operating current, wire diameter, arc length or voltage, power supply characteristics, and shielding gas.

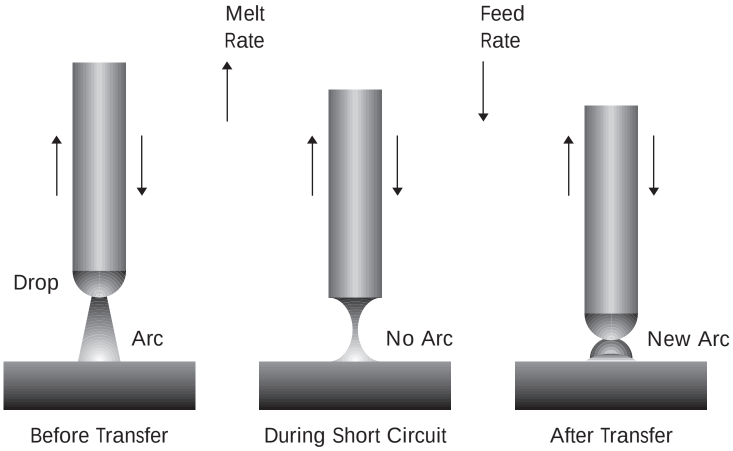


Figure 29 – Short-circuiting transfer

Short-Circuit Gas Metal Arc Welding (GMAW-S)

GMAW-S is defined as "a gas metal arc welding process variation in which the consumable electrode is deposited during repeated short circuits."

In the short-circuiting mode, metal transfer occurs when the electrode is in direct contact with the weld pool. In this mode of metal transfer, the relationship between the electrode melt rate and its feed rate into the weld zone determines the intermittent establishment of an arc and the short circuiting of the electrode to the workpiece.

Specifically, the electrode is fed at a constant speed at a rate that exceeds the melt rate. When it contacts the molten pool a short circuit occurs, at which time there is no arc. The current then begins to rise and heats the wire to a plastic state. At the same time, the wire begins to deform or neck down due to an electromagnetic pinch force. Eventually, the current value and resulting pinch force causes a drop of metal to transfer into the weld puddle. At this point, an arc is established. This sequence repeats itself approximately 50 to 250 times per second *(see figure 29).*

Since there is less "arc on time" established during the short circuit, the overall heat input is low, and the depth of fusion is relatively shallow; thus, care must be exercised in selecting the procedure and weld technique to assure complete fusion when welding thicker materials. Due to its low heat input characteristics, the process produces a small, fast-freezing weld puddle which make it ideal for welding in all positions. Short-circuiting transfer is also particularly adaptable to welding sheet metal with minimum distortion and for filling gapped or poorly fitted parts with less tendency for burn-through of the part being welded.

Globular Transfer

Globular Transfer is characterized by the transfer of molten metal in large drops across the arc. This transfer mode takes place when the current and arc voltage are between the short-circuiting and spray transfer current and voltage levels; it occurs with all types of shielding gas. Carbon dioxide yields this type of transfer at all usable welding currents above the short circuiting range. Globular transfer is characterized by a drop size approximately two to four times greater than the diameter of the electrode *(see figure 30).*

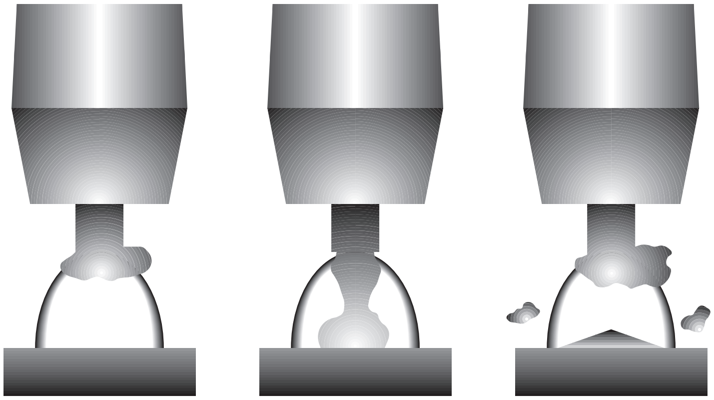


Figure 30 – Globular transfer

With carbon dioxide, the droplet is not propelled across the arc, due to the repelling forces acting upward toward the wire tip. These forces tend to hold the droplet on the end of the wire. During this time the drop grows in size and eventually either transfers by gravity due to its weight, or short circuits across the arc gap.

Spray Transfer

In Spray Transfer, the molten metal is propelled axially across the arc in small droplets. In a gas blend of at least 80% argon *(see table 7, page 39),* when combined with the proper operating conditions, the electrode metal transfer changes from globular to a spray or spray-like mode. The minimum current and voltage levels required vary for any given electrode diameter. The change takes place at a value called the globular-spray transition current. Spray transfer in argon is characterized by a constricted arc column and pointed electrode tip *(see figure 31).*

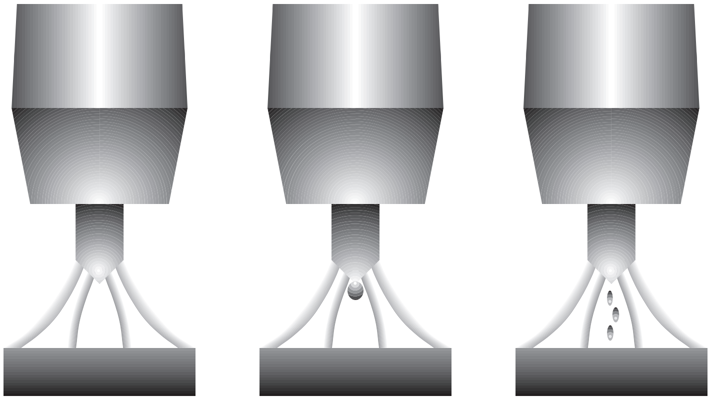


Figure 31 – Spray transfer

Molten metal transfers across the arc as small droplets equal to or less than the electrode diameter. The metal transfer is axially directed to the workpiece. Since the metal droplets are small, the transfer rate can be as high as several hundred droplets per second. Due to puddle fluidity, spray transfer is limited to the flat or horizontal welding position.

Pulsed Gas Metal Arc Welding (GMAW-P)

In this variation, the power source provides two output levels: a steady background level, too low in magnitude to produce any transfer, but able to maintain an arc; and a pulsed, high-output level which causes melting of droplets from the electrode which are then transferred across the arc. This pulsed high output (peak) occurs at regular controlled intervals. The current can be cycled between a high and low value at up to several hundred cycles per second. The net result is to produce a spray arc with average current levels much below the transition current required for a particular diameter and type of electrode.

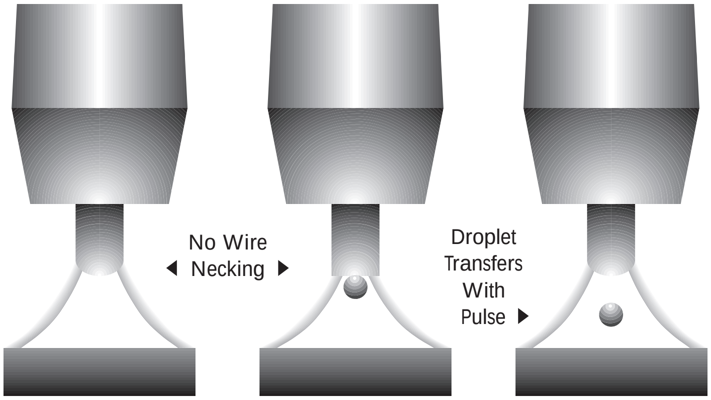


Figure 32 – Pulsed spray transfer

In pulsed spray welding the shielding gas must be able to support spray transfer. Metal is transferred to the workpiece only during the high current pulse. Ideally, one droplet is transferred during each pulse *(see figure 32).*

The pulsing rate can be varied depending on the base material, thickness, wire diameter and weld position. The control of background current maintains the arc and heat input. The resulting lower average current level allows the joining of base metals less than 1/8 inch thick with a spray type metal transfer. Pulsed spray welding may be used in all positions. Welding fume levels are the lowest obtainable with solid wire GMAW.

High Current Density Metal Transfer

High current density metal transfer is a name given to a GMAW process having specific characteristics created by a unique combination of wire feed speed, wire extension, and shielding gas. Weld metal deposition rates can range between 10 and 30 pounds per hour, whereas most GMAW Spray Arc is in the 8 to 12 pound/hr range. The arc characteristics of high density metal transfer are further divided into rotational spray transfer and nonrotational spray transfer.

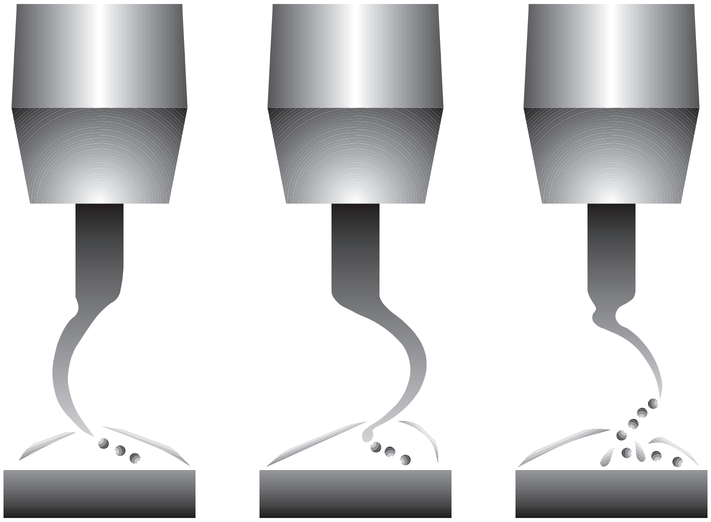


Figure 33 – Rotational spray transfer

When using a solid carbon steel wire, a high wire feed speed is combined with a long electrode extension and an argon/carbon dioxide/oxygen shielding gas to create an arc phenomenon known as rotational spray arc transfer. The long electrode extension creates high resistance heating of the wire electrode causing the electrode end to become molten. The electro-mechanical forces generated by the current flow in the wire cause the molten wire end to rotate in a helical path *(see figure 33)*.

The shielding gas affects the rotational transition current by changing the surface tension at the molten electrode end. Praxair's Stargon and StarGold O-5 blends *(see pages 36-38)* produce rotational spray transfer at deposition rates of 10 to 30 pounds per hour with 0.035 and 0.045 diameter wires using contact-tip to workpiece distances (ESO) of 7/8 inch to 1 1/2 inch.

Nonrotational spray high current density transfer is produced when the molten wire end does not rotate. This also develops a deposition rate range of 10 to 30 pounds per hour. Rotation is suppressed when the thermal conductivity of the shielding gas increases and the surface tension of the molten electrode end increases. The droplet rate decreases resulting in larger droplets across the arc. Shielding gases with carbon dioxide or helium additions, such as Praxair's Stargon and HeliStar CS shielding gases *(see page 38)*, will raise the rotational spray transition current and suppress the tendency for the arc to rotate. The arc appears elongated and diffuse but looks similar to conventional spray transfer. The plasma stream is axial and narrower than rotational spray transfer. Because the heat source is more concentrated, the depth of fusion is greater than rotational spray transfer at the same welding current.

Metal-Cored Electrodes

Metal-cored wire welding is considered a variation of GMAW. A metal-cored wire operates like a solid wire, has generally low fume levels, no slag and a high deposition efficiency (95 percent or better) despite its cored-type construction.

A metal-cored wire is a composite filler metal electrode consisting of a metal tube filled with alloying materials. These metal powders provide arc stabilization and fluxing of oxides. Metal-cored wires provide high deposition rates with excellent deposition efficiency, and can be used to weld in all positions. They are used successfully in applications where fit-up is poor.

Metal-cored wires are designed to give quality welds over some rust and mill scale using argon-based shielding gases. They generally have a higher level of deoxidizers which provides a good bead profile with excellent puddle control. This type of wire combines the high deposition rate of flux-cored wires with the approximate deposition efficiency and fume levels of a solid wire. The weld metal mechanical properties are comparable to carbon steel solid wires and, as with solid wires, little slag is formed on the weld bead surface.

The advantages of metal-cored wires are:

- High deposition rate
- High deposition efficiency (95 percent or better)
- Quality welds over light rust and mill scale
- Low spatter levels
- Little slag clean-up
- Easy to use
- All position welding capability
- Low fume levels
- Greater resistance to undercut
- Improved performance with poor base metal fit up
- Large variety of alloys available

Metal-cored carbon steel wires operate best in an argon/carbon dioxide blend (8 to 20% carbon dioxide) or an argon/carbon dioxide/oxygen blend, while stainless wires operate well with a argon/oxygen (1 to 2% oxygen) or an argon/CO_2 blends (2 to 10%).

Shielding Gases for GMAW

Argon

Argon is used on nonferrous base metals such as aluminum, nickel, copper, magnesium alloys, and reactive metals, such as zirconium and titanium. Argon provides excellent arc welding stability, penetration, and bead profile on these base metals. When welding ferrous-based metals, argon is usually mixed with other gases, such as oxygen, helium, carbon dioxide, or hydrogen.

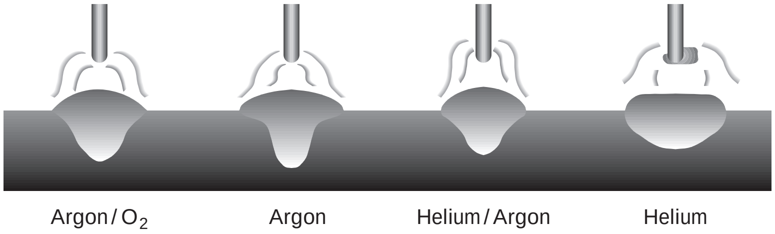
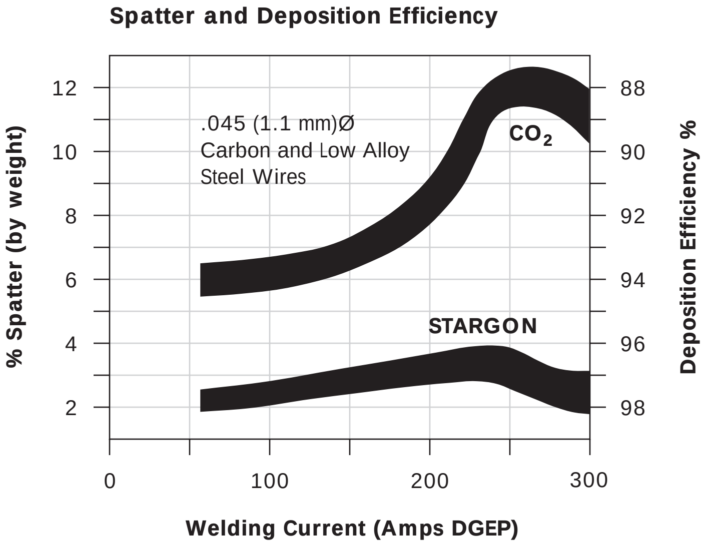


Figure 34 – GMAW weld bead profiles with several shielding gases



To approximate spatter for 0.062 inches (1.6 mm) Ø wire add 50A to welding current.
To approximate spatter for 0.035 inches (0.89 mm) Ø wire subtract 50A to welding current.

Figure 35– Typical spatter levels with two common shielding gases

The low ionization potential (good electrical conductivity) of argon helps create an excellent current path and superior arc stability. Argon produces a constricted arc column with high current density which causes the arc energy to be concentrated over a small surface area. The result is a penetration profile, having a distinct “finger like” shape, as shown in *figure 34.*

Carbon Dioxide

Carbon dioxide, a reactive gas, dissociates into carbon monoxide and free oxygen in the heat of the arc. Oxygen then combines with elements transferring across the arc to form oxide in the form of slag and scale, and also helps to generate a great deal of fumes. Although carbon dioxide is an active gas and produces oxidation of the weld material, sound welds can be consistently achieved with careful filler metal selection.

Carbon dioxide is often used for welding carbon steel because it is readily available and produces good welds at low cost. However, the low cost per unit of gas does not always translate to the lowest cost per foot of deposited weld. Other factors, such as lower deposition efficiency due to spatter loss, high levels of welding fume, poor weld bead profile and reduced tensile strength can influence the final weld cost and should be carefully considered.

Carbon dioxide will not support spray transfer. Metal transfer is restricted to the short circuiting and globular modes. A major disadvantage of carbon dioxide is harsh globular metal transfer with its characteristic spatter *(see figure 35).*

The weld surface resulting from use of carbon dioxide shielding is usually heavily oxidized. An electrode with higher amounts of deoxidizing elements is needed to compensate for the loss of alloying elements across the arc.

Welded parts may require a cleaning operation prior to painting which can more than offset the lower cost of CO_2 shielding gas. The advantages of carbon dioxide are good depth and width of fusion and the achievement of acceptable mechanical properties.

Helium

Helium is a chemically inert gas that is used for welding applications requiring higher heat inputs. Helium may improve wetting action, depth of fusion, and travel speed. It does not produce the stable arc provided by argon. Helium has greater thermal conductivity than argon and produces a wider arc column. The higher voltage gradient needed for stable operation generates a higher heat input than argon, promoting greater weld pool fluidity and better wetting action. This is an advantage when welding aluminum, magnesium, and copper alloys.

Argon/Oxygen Blends

Praxair's StarGold™ Blends

The addition of small amounts of oxygen to argon greatly stabilizes the welding arc, increases the metal transfer droplet rate, lowers the spray transition current, and enhances bead shape. The weld pool is more fluid and stays molten longer, allowing the metal to flow out towards the weld toes. Welding fume may be reduced with these mixtures.

Praxair's StarGold O-1

Primarily used for spray transfer on stainless steels, one percent oxygen is usually sufficient to stabilize the arc and improve the droplet rate and bead appearance.

Praxair's StarGold O-2

This blend is used for spray arc welding of carbon steels, low-alloy steels and stainless steels. It provides better wetting action than the 1% oxygen mixture. Weld mechanical properties and corrosion resistance of welds made with 1% and 2% oxygen additions are similar. However, bead appearance will be darker and more oxidized for the 2% blends with stainless steels.

Praxair's StarGold O-5

This blend provides a more fluid but controllable weld pool. It is the most commonly used argon/oxygen mixture for general carbon steel welding. The additional oxygen permits higher travel speeds.

Argon/Carbon Dioxide Blends

Praxair's StarGold and Mig Mix Gold™ Blends

Argon/carbon dioxide blends are used with carbon, low-alloy and some stainless steels. Greater amounts of carbon dioxide when added to argon and used at higher current levels, increase spatter.

In conventional GMAW, slightly higher current levels must be exceeded when using argon/carbon dioxide in order to establish and maintain stable spray transfer. Above approximately 20% carbon dioxide, spray transfer becomes unstable and periodic short-circuiting and globular transfer occurs.

Praxair's StarGold C-5

Used for pulsed spray transfer and conventional spray transfer with a variety of material thicknesses. A 5% mixture may be used for GMAW-P of low alloy steels for out-of-position welding. This blend provides good arc stability when welding over mill scale and a more controllable puddle than a argon/oxygen blend.

Praxair's Mig Mix Gold

This blend performs similarly to C-5, but its increased heat input provides a wider, more fluid weld puddle in either short-circuit, spray or pulsed spray transfer.

Praxair's StarGold C-10
This blend performs similarly to Praxair's Mig Mix Gold but its additional CO_2 content provides a wider, more fluid weld puddle. This blend is frequently recommended for use with metal-cored wires.

Praxair's StarGold C-15
Used for a variety of applications on carbon and low-alloy steel. In the short-circuiting mode, maximum productivity on thin gauge metals can be achieved with this blend. This is done by minimizing the excessive melt-through tendency of higher carbon dioxide mixes, while increasing deposition rates and travel speeds. As the carbon dioxide percentages are lowered from the 20% range (maximum spray arc levels), improvements in deposition efficiency occur due to decreasing spatter loss. This blend will support the spray arc mode of transfer.

Praxair's StarGold C-20
May be used for short circuiting or spray transfer welding of carbon steel.

Praxair's StarGold C-25
Commonly used for GMAW with short-circuiting transfer on carbon steel. It was formulated to provide optimum droplet frequency on short-circuiting transfer using .035 and .045 diameter wire. Praxair's StarGold C-25 blend operates well in high current applications on heavy base metal. It promotes good arc stability, weld pool control, and weld bead appearance. This blend will not support spray type metal transfer. StarGold C-25 can also be used with flux-cored wires (see manufacturer's recommendations).

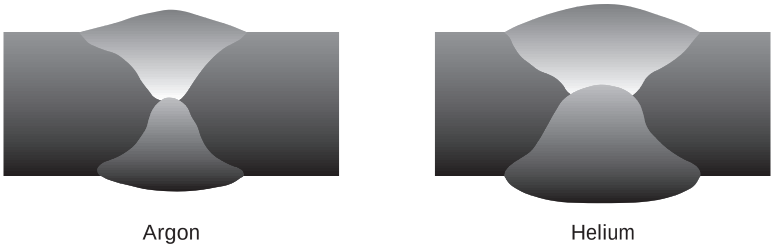


Figure 36 –
Effect of argon and helium shielding gases on weld profile when welding aluminum (DCEP)

Praxair's StarGold C-40
This mixture is recommended for use with some flux cored wires where improved arc stability, reduced spatter levels and improved performance over light surface contamination are desirable.

Praxair's StarGold C-50
This mixture is used for short arc welding of pipe, particularly when contaminants are present on the surfaces to be welded.

Argon/Helium Blends

Praxair's HeliStar™ Blends
Helium is often mixed with argon to obtain the advantages of both gases. Argon provides good arc stability and cleaning action, while helium promotes wetting with a greater width of fusion.

Argon/helium blends are used primarily for nonferrous base metals, such as aluminum, copper, nickel alloys, magnesium alloys, and reactive metals. Helium additions to an argon-based gas increase the effective heat input. Generally, the thicker the base metal, the higher the percentage of helium. Small percentages of helium, as low as 20%, will affect the arc. As the helium percentage increases, the required arc voltage, spatter, and weld width to depth ratio increase, while porosity is minimized *(see Figure 36)*. The argon percentage must be at least 20% when mixed with helium to produce and maintain a stable spray transfer.

Praxair's HeliStar A-25
This blend is used for welding nonferrous base metals when an increase in heat input is needed and weld bead appearance is of primary importance. It is ideal for both GMAW and GTAW of aluminum alloys.

Praxair's HeliStar A-50
Helistar A-50 blend is used primarily for high-speed mechanized welding of nonferrous materials under 3/4 inch thick.

Praxair's HeliStar A-75
This blend is used for mechanized welding of aluminum greater than 3/4" in the flat position. It increases heat input and reduces porosity of welds made in copper and copper alloys.

Argon/Oxygen/Carbon Dioxide Blends

Praxair's Stargon™ Blends
These three component mixtures provide versatility due to their ability to operate in short-circuiting, globular, spray, pulsed or high-density transfer modes. Several ternary compositions are available and their use depends on the desired metal transfer mode and welding position.

The advantage of this blend is its ability to shield carbon steel and low-alloy steel of all thicknesses using any metal transfer mode applicable. Praxair's Stargon blend produces stable welding characteristics and mechanical properties on carbon and low-alloy steels and some stainless steels. On thin gauge base metals, the oxygen constituent promotes arc stability at very low current levels (30 to 60 amps) permitting the arc to be kept short and controllable. This helps minimize excessive melt-through and distortion by lowering the total heat input to the base material. Stargon is generally used for spray arc welding, providing high deposition rates and often higher travel speeds than carbon dioxide.

Argon/Helium/Carbon Dioxide Blends

Praxair's HeliStar™ Blends
Helium and carbon dioxide additions to argon increase the heat input to the weld, which improves wetting, fluidity, and weld bead profile.

Praxair's HeliStar CS
This blend has been developed for spray and pulsed spray welding of both carbon and low-alloy steels. It can be used on all material thicknesses in any position. This blend can produce high quality welds over rust, oil and mill scale when compared with conventional two-part mixtures. It produces good mechanical properties and weld puddle control.

Praxair's HeliStar SS
HeliStar SS is used for short arc, spray, and pulsed spray arc welding of stainless steel. It provides a higher welding speed, a broad weld with a flat crown and good color match, reduced porosity, and excellent alloy retention with good corrosion resistance.

Praxair's HeliStar A-1025
Helistar A-1025 blend is widely used for short-circuiting transfer welding of stainless steel in all welding positions. The carbon dioxide content is kept low to minimize carbon pick-up and assure good corrosion resistance, especially in multipass welds. The argon and carbon dioxide additions provide good arc stability and increased depth of weld fusion. The high helium content provides significant heat input to overcome the sluggish nature of the stainless steel weld pool.

See Table 8, pages 40-42 for a Gas Selection Guide for GMAW.

Table 7 – Globular-to-spray transition currents

Electrode Type	Wire Dia. (inch)	Shielding Gas	Minimum Spray Arc Current (amp)
Low Carbon Steel (ER70S-3 or ER70S-6)	0.023	98% Argon/2% O_2	135
	0.030	98% Argon/2% O_2	150
	0.035	98% Argon/2% O_2	165
	0.045	98% Argon/2% O_2	220
	0.062	98% Argon/2% O_2	275
	0.035	95% Argon/5% O_2	155
	0.045	95% Argon/5% O_2	200
	0.062	95% Argon/5% O_2	265
	0.035	92% Argon/8% CO_2	175
	0.045	92% Argon/8% CO_2	225
	0.062	92% Argon/8% CO_2	290
	0.035	85% Argon/15% CO_2	180
	0.045	85% Argon/15% CO_2	240
	0.062	85% Argon/15% CO_2	295
	0.035	80% Argon/20% CO_2	195
	0.045	80% Argon/20% CO_2	255
	0.062	80% Argon/20% CO_2	345
Stainless Steel	0.035	99% Argon/1% O_2	150
	0.045	99% Argon/1% O_2	195
	0.062	99% Argon/1% O_2	265
	0.035	Argon/Helium/CO_2	160
	0.045	Argon/Helium/CO_2	205
	0.062	Argon/Helium/CO_2	280
	0.035	Argon/Hydrogen/CO_2	145
	0.045	Argon/Hydrogen/CO_2	185
	0.062	Argon/Hydrogen/CO_2	255
Aluminum	0.030	Argon	95
	0.047	Argon	135
	0.062	Argon	180
Deoxidized Copper	0.035	Argon	180
	0.045	Argon	210
	0.062	Argon	310
Silicon Bronze	0.035	Argon	165
	0.045	Argon	205
	0.062	Argon	270

Table 8 –
Shielding Gas Selection Guide for GMAW

Material	Thickness	Transfer Mode	Recommended Shielding Gas	Description
Carbon Steel	Up to 14 gauge	Short Circuiting	StarGold C-8, C-15, C-25 Stargon	Good penetration and distortion control to reduce potential burnthrough; good gap-bridging ability
	14 gauge – 1/8"	Short Circuiting	StarGold C-8, C-15, C-25 Stargon	Higher deposition rates without burnthrough; minimum distortion and spatter; good puddle control for out-of-position welding
	Over 1/8"	Short Circuiting	StarGold C-15, C-25 Stargon CO_2	High welding speeds; good penetration and puddle control; applicable for out-of-position welds
		Globular	StarGold C-8, C-25 CO_2	Suitable for high current and high speed welding
		Short Circuiting	StarGold C-50	Deep penetration; low spatter, high travel speeds; good out-of-position welding
		Short Circuiting and Globular (Buried Arc)	CO_2	Deep penetration and fast travel speeds but with higher burnthrough potential; high current mechanized welding
		Spray Arc	StarGold O-1, O-2, O-5 Stargon	Good arc stability; produces a more fluid puddle as O_2 increases; good coalescence and bead contour; good weld appearance and puddle control
		Short Circuiting and Spray Transfer	StarGold C-5, C-8	Applicable to both short circuiting and spray transfer modes; has wide welding current range and good arc performance; weld puddle has good control which results in improved weld contour
		High Density Rotational Transfer	Stargon StarGold C-8 HeliStar CS	Used for high deposition rate welding where 15 to 30 lbs/hr is typical; special welding equipment and techniques are sometimes required to achieve these deposition levels
	Gauge	Pulsed Spray	StarGold C-5 Stargon HeliStar CS	Used for both light gauge and out-of-position weldments; achieves good pulsed spray stability over a wide range of arc characteristics and deposition ranges
		Short Circuiting	Stargon StarGold C-5 HeliStar CS	Good coalescence and bead contour with excellent mechanical properties

Table 8 –
Shielding Gas Selection Guide for GMAW (continued)

Material	Thickness	Transfer Mode	Recommended Shielding Gas	Description
Alloy Steel	Up to 3/32"	Short Circuiting	StarGold C-8, C-15 Stargon	High welding speeds; good penetration and puddle control; applicable for out-of-position welds; suitable for high current and high speed welding
		Spray Arc (High Current Density and Rotational)	StarGold O-5 Stargon HeliStar CS	Reduces undercutting; higher deposition rates and improved bead wetting; deep penetration and good mechanical properties
	Over 3/32"	Pulsed Spray	StarGold O-2, C-5, C-8 Stargon	Used for both light gauge and heavy out-of-position weldments; achieves good pulsed spray stability over a wide range of arc characteristics and deposition ranges
Stainless Steel*	Up to 14 gauge	Short Circuiting	StarGold O-2 Stargon	Good control of burnthrough and distortion; used also for spray arc welding; puddle fluidity sometimes sluggish, depending on the base alloy
	Over 14 gauge	Short Circuiting Transfer	HeliStar SS, A-1025 StarGold O-2 Stargon	Low CO_2 percentages in He mix minimize carbon pick-up, which can cause intergranular corrosion with some alloys; helium improves wetting action; CO_2 percentages over 5% should be used with caution on some alloys; applicable for all position welding
		Spray Arc	HeliStar SS StarGold O-1, C-5, C-10 Mig Mix Gold	Good arc stability; produces a fluid but controllable weld puddle; good coalescence and bead contour; minimizes undercutting on heavier thicknesses
		Spray Arc	StarGold O-2	Can be used on more sluggish alloys to improve puddle fluidity, coalescence and bead contour
		Pulsed Spray	HeliStar SS StarGold O-1, O-2 Stargon	Used for both light gauge and heavy out-of-position weldments; achieves good pulsed spray stability over a wide range of arc characteristics and deposition ranges

** Stargon and StarGold C-5 and C-10 shielding gases may be used for certain stainless steel welding. Call your Praxair Shielding Gases representative for specific information.*

Table 8 –
Shielding Gas Selection Guide for GMAW (continued)

Material	Thickness	Transfer Mode	Recommended Shielding Gas	Description
Copper, Nickel and Copper-Nickel Alloys	Up to 1/8"	Short Circuiting	HeliStar SS StarGold O-1, O-2	Good arc stability, weld puddle control and wetting
	Over 1/8"	Short Circuiting	HeliStar SS, A-1025	Higher heat input of helium mixtures offsets high heat conductivity of heavier gauges; good wetting and bead contour; using 100% helium on heavier material thicknesses improves wetting and penetration; can be used for out-of-position welding
		Pulsed Spray	HeliStar SS, A-50, A-75 Argon StarGold O-1, O-2	Used for both light gauge and heavy out-of-position weldments; achieves good pulsed spray stability over a wide range of arc characteristics and deposition ranges
Aluminum	Up to 1/2"	Spray Arc	Argon	Best metal transfer, arc stability, and plate cleaning; little or no spatter; removes oxides when used with DCEP (Reverse Polarity)
		Spray Arc	HeliStar A-25, A-50	High heat input; produces fluid puddle, flat bead contour, and deep penetration; minimizes porosity
	Over 1/2"	Spray Arc	Helium HeliStar A-25	High heat input; good for mechanized welding and overhead; applicable to heavy section welding
		Pulsed Spray	Argon	Good wetting; good puddle control
Magnesium Titanium and other reactive materials	All thicknesses	Spray Arc	Argon	Excellent cleaning section; provides more stable arc than helium-rich mixtures
		Spray Arc	HeliStar A-25, A-50, A-75	Higher heat input and less chance of porosity; more fluid weld puddle and improved wetting

CHAPTER 5

Flux-Cored Arc Welding (FCAW)

Process Description

Flux-Cored Arc Welding is defined as “an arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding gas from a flux contained within the tubular electrode, with or without additional shielding from an externally supplied gas, and without the application of pressure.” FCAW is also known as Cored-Rod Welding or Cored-Wire Welding.

When the process is used with an externally supplied shielding gas, the process equipment is virtually identical to that of GMAW *(See figure 37)*. FCAW is principally intended for use with carbon steel, stainless steel, and low-alloy steels. The process can use DCEP or DCEN polarity, depending on the flux composition.

Ⓐ Power Supply
Ⓑ Workpiece
Ⓒ Welding Torch
Ⓓ Wire Feed Motor
Ⓔ Wire Reel
Ⓕ Welding Control
Ⓖ Shielding Gas

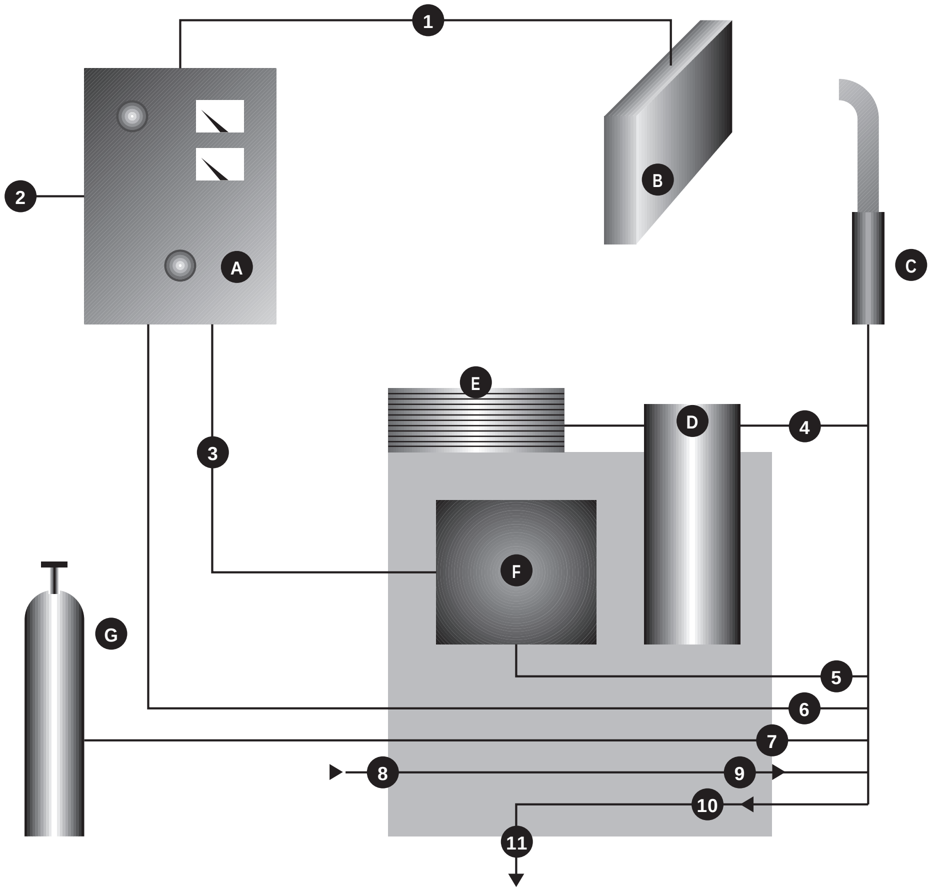


Figure 37 – Flux-Cored Arc welding equipment

① Power Cable (negative)
② To Primary Power 230/460/575 V
③ 115 VAC In – Welding Contactor Control
④ Wire Conduit
⑤ Torch Switch
⑥ Power Cable (positive)
⑦ Shielding Gas from Cylinder or Bulk Supply
⑧ Cooling Water In
⑨ Cooling Water to Torch (optional)
⑩ Cooling Water from Torch (optional)
⑪ Cooling Water Out (optional)

Flux Effects

The constituents in the flux influence the characteristics of the arc and its welding performance. They can increase penetration, clean foreign matter from the workpiece surface, influence the speed of welding and affect the mechanical properties of the weld deposit.

The flux contains deoxidizers, slag formers, arc stabilizers, and alloying materials as required. The FCAW process typically generates more fumes and spatter than solid wires using the same shielding gases. Recent developments have resulted in the production of a "new generation" of cored wires with significantly reduced levels of welding fume.

During welding, the flux is heated by the arc as the electrode is consumed. The chemical reactions occurring in the flux create gases which help shield the arc and the weld zone. Carbon dioxide is generally used for additional shielding with flux-cored wires greater than 1/16" diameter. Argon/carbon dioxide, and other argon-based mixtures are used with smaller diameter wires which are designed for enhanced all-position performance and increased productivity.

Metal Transfer

The same metal transfer variations found in GMAW are also found in FCAW. However, in FCAW, the transfer typically is not spatter free. There are more short circuits and exploding gas bubbles which generate weld spatter.

Small-diameter cored wires using an argon-based shielding gas can develop any of the three modes of metal transfer: short-circuit, globular, or spray-like, and most can weld in all positions.

The large-diameter cored wires that use argon-based gases are capable of a globular or spray-like transfer, while large-diameter wires using carbon dioxide transfer metal by a globular mode only.

Shielding Gases for FCAW

Carbon Dioxide

The majority of large-diameter flux-cored wires that require a secondary shielding gas use carbon dioxide. They are generally used for welding over rust and mill scale on heavy plate. Flux-cored wires designed for welding stainless steel frequently use CO_2; Argon/CO_2 blends can be used to enhance productivity and reduce base metal distortion.

Argon/Carbon Dioxide Blends

Many small-diameter cored wires use argon-based shielding gases. These gas blends provide greater weld puddle control and are preferred by welders because of ease of use. CO_2 content varies from 5-25% depending upon the wire formulation. Follow manufacturer's recommendations for optimum performance. Utilize a push welding technique with small diameter wires and argon-based blends.

Argon/Oxygen Blends

Small amounts of oxygen may be added to argon for welding carbon steels; however, shielding gas blends, such as argon/5% oxygen, are used primarily on clean base materials.

See Table 9, below for a Gas Selection Guide for FCAW.

Table 9 – Shielding Gas Selection Guide for FCAW*

Material	Recommended Shielding Gas	Description
Carbon Steel	StarGold C-5, C-10, C-15	For wires so formulated: Small-diameter cored wire; spray transfer; excellent alloy retention, quiet arc, good bead profile, low smoke, fume and spatter
	StarGold C-25	Small- and large-diameter cored-wire, short-circuiting and globular transfer; excellent alloy retention, quiet arc, good bead profile, low smoke, fume, and spatter
	Carbon Dioxide	Small- and large-diameter cored-wire, short-circuiting and globular transfer; wide penetration profile, higher smoke and spatter levels, greater loss of alloying elements
Stainless Steel	StarGold O-2 Carbon Dioxide	Small-diameter cored wire, spray transfer, good bead profile, little smoke and spatter, lower fume, clean welds

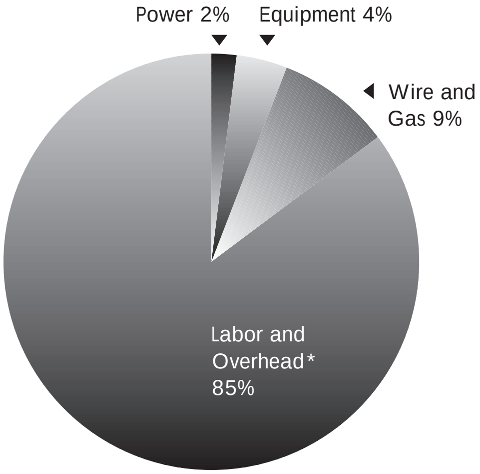
** Please refer to the wire manufacturer's recommendations when selecting shielding gases with flux-cored consumables.*

CHAPTER 6

The Economics of Gas Selection for GMAW

When considering the total cost of welding, it is important to understand how the choice of consumables can influence overall costs. It is not the "cost per pound" or "cost per cubic foot" for the consumables that is really important, it is their impact on productivity and possible labor savings that really counts.

Figure 38 – Welding costs



* For industrialized nations

Figure 38 illustrates how total consumables costs relate to overall welding cost for industrialized nations (North America, Europe, Japan, etc.). From this chart it can be seen that if the labor cost could be reduced by 10% through productivity improvements (such as increased travel speed, less overweld, minimum post-weld cleanup, etc.), significant savings would be generated overall. These hidden savings would far exceed a 10% reduction in the price of wire or shielding gas. Many times the focus on cutting the cost of consumables misses the larger objective of significant cost reductions that accrue through labor/overhead savings.

Labor and Overhead

The dominant cost factors in most welding operations are labor and overhead. The proper selection of shielding gas and wire electrode can reduce these costs by increasing welding speed and duty cycle, while also decreasing post-weld cleanup time. The effect of proper shielding gas selection on the welding operation can result in a significant reduction in overall cost.

Effect of Shielding Gas on Welding Speed

If welding speed can be increased, labor and overhead charges per unit of weld will decrease accordingly; this decreases bottom-line welding costs. Maximum welding speed is largely dependent upon the shielding gas selected and its inherent heat transfer properties, oxidizing potential, and metal transfer characteristics. Gases with high thermal conductivity produce the hottest and most fluid weld puddle. Gases with high oxidizing potential are more effective at reducing surface tension of the weld puddle to provide better wetting of the weld bead to the base material. Inert gas blends that promote spray transfer provide the highest level of wire electrode deposition efficiency and generally higher travel speeds.

In addition to the shielding gas and weld bead size, other factors that affect welding speed include current and voltage, weld position (flat, vertical up, etc.), joint fit-up, and the mode of travel (manual vs. mechanized). Maximum usable welding speed for any grouping of consumables is higher in mechanized applications with clean plate and very good fit-up. In manual welding, operator skill is often the limiting factor, as all shielding gases are capable of producing welds at speeds higher than the capabilities of the operator.

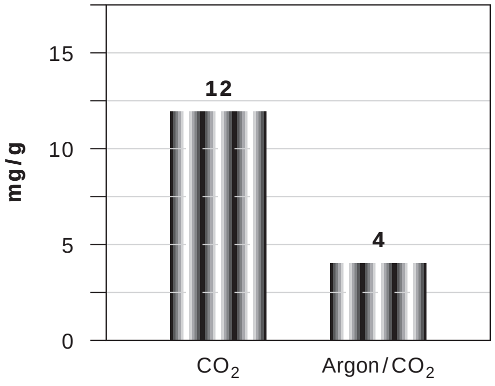
If welding is mechanized, carbon dioxide (CO_2) is capable of producing a higher speed weld on thin gauge material when burn-through is not a problem. However, when fit-up is poor or burn-through problems are evident, argon blends with lower carbon dioxide percentage (by volume) will more consistently achieve the desired results.

Plate surface conditions can also have a major effect on welding speed and bead appearance. Heavy rust, mill scale, or oil can reduce the travel speed and will adversely affect weld bead appearance. The use of clean, sand-blasted plate or plate with only a light mill scale minimizes these problems.

Welding speeds increases for Gas Tungsten Arc Welding (GTAW) and Plasma Arc Welding (PAW) can be easily measured directly with the substitution of the gas or the gas blend. On the other hand, when considering Gas Metal Arc Welding (GMAW), additional factors must be taken in account (i.e. wire feed speed and arc voltage) in order to achieve the full potential improvement.

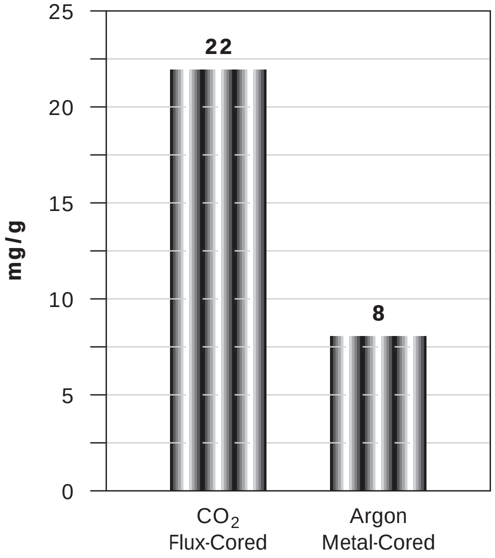
Effect of Shielding Gas on Duty Cycle and Cleanup

Operator duty cycle is the amount of time an operator is actually welding versus time spent on related activities such as setup, cleanup, or other non-welding functions. When carbon dioxide shielding is used, spatter will accumulate in the gas nozzle of the welding gun and interfere with proper shielding of the weld puddle. Spatter can also accumulate on the contact tip and interfere with wire feeding. **Removal of spatter from nozzles, tips, and the finished workpiece decreases the duty cycle of the welder.** Since the use of argon-based shielding gases can greatly decrease the amount and size of the spatter generated, there is significantly less cleanup required thus maintaining the duty cycle at a higher level than when CO_2 is used. The lower spatter levels associated with argon blends also means more welding between required cleanup periods, greater operator comfort, and less chance of operator injury resulting from contact with hot spatter.



mg/g =
miligrams of
fume per gram
of deposited
weld metal

Figure 39 –
Fume levels
(CO_2 vs. argon/CO_2 blends)



mg/g =
miligrams of
fume per gram
of deposited
weld metal

Figure 40 –
Fume levels
(CO_2 flux-cored vs. argon metal-cored)

Weld spatter is weld metal that does not become part of the weld itself. This is “lost” material and increases the overall material costs for welding. This spatter loss is reflected in the “deposition efficiency” of the welding process. As spatter losses decrease, deposition efficiency increases. As can be seen in the table below, the wide range of efficiencies for the gas-shielded arc processes are largely a result of the different gas blends that can be used. The use of argon blends will result in the highest levels of deposition efficiency.

Typical Deposition Efficiencies

GTAW (TIG):	95-100%
GMAW (MIG):	88-98%
GMAW-P:	97-99%
FCAW (gas shield):	85-90%
FCAW (self shield):	75-85%
PAW (Plasma arc):	95-100%
SMAW (stick):	50-65%

Use of the proper shielding gas will ensure that the deposition efficiency is as high as possible for the process used. For example, the deposition efficiency of a MIG operation using 100% CO_2 shielding is typically 88-92%. By replacing CO_2 with an argon/10% CO_2 shielding gas blend, the efficiency was increased to 95-97%. More of the wire purchased ended up as deposited weld metal. Fumes and gases are created by the effect of the intense heat of the arc on the consumable used and the interaction between the ultra-violet radiation of the arc and its surrounding atmosphere. Significantly less fume is generated by argon-shielded welding processes as is shown in the *figures 39 and 40.* This means that it will be easier to maintain an acceptable working environment for the welder, and there will be less cost associated with filtering and recirculating shop air near welding operations.

Consumable Costs

When determining consumable costs, the wire and shielding gas price should be considered together because of the effect shielding gas has on deposition efficiency. The lowest price wire and gas may also produce the worst deposition efficiency. Although the initial cost may be higher, the recommended wire and argon based shielding gas combination may increase deposition efficiency and result in lower overall cost *(see table 10).*

Highly oxidizing shielding gases such as pure carbon dioxide, require welding wires with additional deoxidizers. This is due to the loss of micro alloys from the reactivity of the CO_2 in the welding arc. If 100% CO_2 shielding is changed to argon with 8% CO_2 added, a less expensive welding wire may be substituted because of the good alloy retention feature of argon-based shielding gases. This change may result in as much as a 25% savings in wire cost while maintaining mechanical properties, ease of operation, and increasing welding travel speed.

Table 10 – The effect of shielding gas on wire cost (CO_2 vs. argon/CO_2 blends)

To determine the extent to which differences in bead shape and overweld affect wire cost, examine the following 3/16" and 1/4" fillet weld examples:

	3/16" Fillet		1/4" Fillet	
	CO_2	Ar/CO_2*	CO_2	Ar/CO_2*
Deposition Efficiency (%)	89	97	89	97
Lbs. of Weld Metal Required per Foot (lb/ft)	0.100	0.080	0.151	0.128
Lbs. of Wire Required per Foot (lb/ft)	0.109	0.082	0.170	0.132
Wire Cost per Foot @ $0.65/lb** ($/ft)	0.076	0.057	0.116	0.086
Extra Wire Cost per Foot of Using CO_2 ($/ft)	0.019		0.030	

* Contains 92% argon/8% CO_2.

** The wire cost will vary depending on AWS type, diameter, geographical location and quantity purchased.

Total Cost of a Shielding Gas

Shielding gas costs are typically between 1% to 5% of total welding costs, depending on the deposition rate of the application being considered. A typical cost comparison between an argon-based gas mixture and carbon dioxide is shown in the accompanying analysis *(table 11)*. It can be seen that even though the argon blend costs substantially more than the carbon dioxide ($ 0.100 vs. $ 0.025 per cubic foot), it is still a small percentage of the overall welding cost.

When the increase in duty cycle (from 40 to 45% due to less postweld cleanup and equipment maintenance) and deposition efficiency (from 89% to 97% due to considerably reduced spatter and fume) resulting from the use of argon are considered, the total cost per foot of weld is less with an argon mixture than with CO_2 ($ 0.796 vs. $0.881 per foot).

Table 11 – Cost comparison per foot of wire (CO_2 vs. argon/CO_2 blends)

	CO_2	Argon/CO_2
a. Shielding Gas Cost ($/ft^3)	0.025	0.100
b. Gas Flow Rate (ft^3/h)	35	35
c. Welding Speed (in/min)	22	22
1. Shielding Gas Total Cost (1) ($/ft)	**0.008**	**0.032**
d. Labor and Overhead Rate ($/h)	35	35
e. Operator Duty Cycle (4)	0.40 (40%)	0.45 (45%)
2. Labor and Overhead Total Costs (2) ($/ft)	**0.800**	**0.710**
f. Wire Cost ($/lb)	0.65	0.65
g. Deposition Efficiency (5)	0.89 (89%)	0.97 (97%)
h. Lbs. of Weld Metal Required for 3/16" fillet (lb/ft)	0.100	0.080
3. Wire Total Cost (3) ($/ft)	**0.073**	**0.054**
4. Total (1 + 2 + 3) ($/ft)	**0.881**	**0.796**
5. Savings Using Argon/CO_2 Blend ($/ft)		**0.085**

Note 1: Pricing reflects cylinder gases supply. The shielding gas and wire costs will vary depending on the geographical location, quantity purchased and supply method.

Note 2: The foregoing computations were based on average figures obtained from different sections of the country. To determine how your operation might fare by substituting an argon mixture for CO_2, simply insert the correct numbers for your area and your company in the appropriate columns.

(1) **Shielding Gas Total Cost =**

$$\frac{a \times b}{\dfrac{c \times 60\ (\text{min/h})}{12\ (\text{in/ft})}}$$

(2) **Labor and Overhead Total Costs =**

$$\frac{d}{\dfrac{c \times e \times 60\ (\text{min/h})}{12\ (\text{in/ft})}}$$

(3) **Wire Total Cost =**

$$\frac{f \times h}{g}$$

(4) Operator duty cycle is the amount of time an operator is actually welding versus time spent on related activities such as setup, cleanup, or other non-welding functions.

(5) Deposition Efficiency in arc welding is the ratio of the weight of deposited weld metal to the net weight of the filler metal used.

Deposition Efficiency (%) =

$$\frac{\text{Deposited Weld Metal}}{\text{Filler Metal Consumed}}$$

Another cost analysis is shown in *table 12 and figure 41*, where the company currently uses 100% CO_2 shielding with solid wire. They purchase approximately 70,000 of wire/year and employ a total of 54 welders on all shifts/day. The increase in welding speed of 38% (13 in/min to 18 in/min), the 3% increase in welder duty cycle, and the decrease in overwelding (shown by the required weld metal per foot of fillet weld), generated savings of over one quarter of a million dollars per year. In addition, fume generation rates were substantially reduced; this, too, will lead to additional cost savings.

Table 12 – Cost comparison per foot of weld (CO_2 vs. argon/ CO_2 blends)

	CO_2	Argon/CO_2
a. Shielding Gas Cost ($/ft^3)	0.010	0.025
b. Gas Flow Rate (ft^3/h)	40	40
c. Welding Speed (in/min)	13	18
1. Shielding Gas Total Cost (1) ($/ft)	**0.006**	**0.011**
d. Labor and Overhead Rate ($/h)	35	35
e. Operator Duty Cycle (4)	0.30 (30%)	0.33 (33%)
2. Labor and Overhead Total Costs (2) ($/ft)	**1.795**	**1.179**
f. Wire Cost ($/lb)	0.65	0.75
g. Deposition Efficiency (5)	0.88 (88%)	0.96 (96%)
h. Lbs. of Weld Metal Required for 1/4" fillet (lb/ft)	0.155	0.135
i. Fume Generation Level (mg/g)	12	4
3. Wire Total Cost (3) ($/ft)	**0.115**	**0.106**
4. Total (1 + 2 + 3) ($/ft)	**1.916**	**1.296**
5. Savings Using Argon/CO_2 Blend ($/ft)		**0.620**
6. Yearly Savings		**$ 285,000**

Note 1: Pricing reflects bulk gases supply. The shielding gas and wire costs will vary depending on the geographical location, quantity purchased and supply method.

Note 2: The foregoing computations were based on average figures obtained from different sections of the country. To determine how your operation might fare by substituting an argon mixture for CO_2, simply insert the correct numbers for your area and your company in the appropriate columns.

(1) **Shielding Gas Total Cost =** $$\frac{a \times b}{c \times \frac{60\ (\text{min/h})}{12\ (\text{in/ft})}}$$

(2) **Labor and Overhead Total Costs =** $$\frac{d}{c \times e \times \frac{60\ (\text{min/h})}{12\ (\text{in/ft})}}$$

(3) **Wire Total Cost =** $$\frac{f \times h}{g}$$

(4) Operator duty cycle is the amount of time an operator is actually welding versus time spent on related activities such as setup, cleanup, or other non-welding functions.

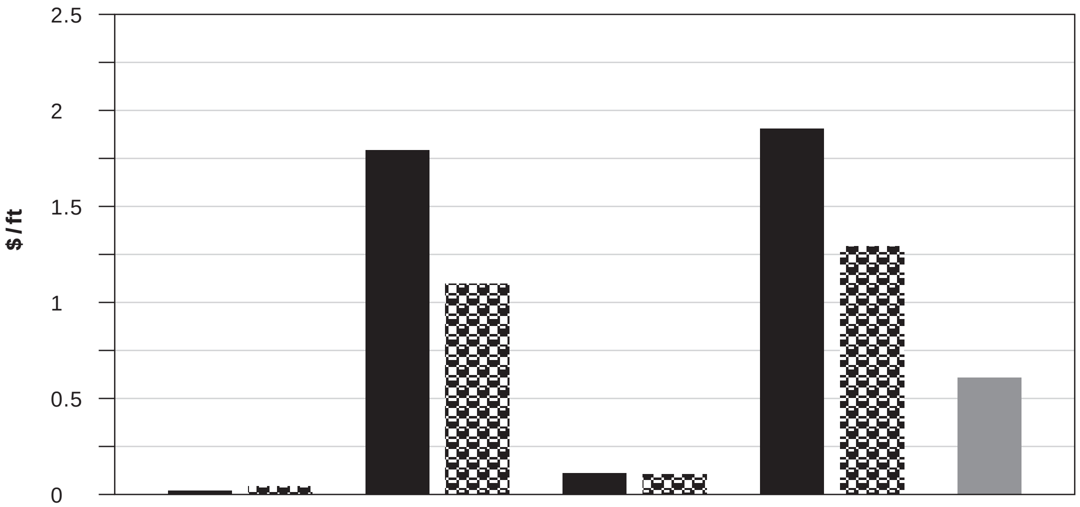
(5) Deposition Efficiency in arc welding is the ratio of the weight of deposited weld metal to the net weight of the filler metal used.

Deposition Efficiency (%) = $$\frac{\text{Deposited Weld Metal}}{\text{Filler Metal Consumed}}$$

Figure 41 – Cost comparison per foot of weld (CO_2 vs. argon/ CO_2 blends)

■ CO_2

▨ Ar/CO_2



70,000 lb of wire/year

54 total welders all shifts

Total yearly savings – $ 285,000

	Gas ($/ft)	Labor and Overhead ($/ft)	Wire ($/ft)	Total ($/ft)	Savings ($/ft)
CO_2	0.006	1.795	0.115	1.916	
Ar/CO_2	0.011	1.179	0.106	1.296	0.620

Gas Supply

Shielding gases are available in vapor form with high pressure cylinders and in liquid form with transportable or stationary storage tanks (the product is vaporized prior to being used). The cost of the product, as well as the distribution system, depends upon the gas blend used, consumption patterns, location of equipment, and the presence of a gas distribution piping system *(see chapter 7 for more details).*

A second portion of gas cost is managing the amount of gas used in the welding operation. Pipelines should be frequently inspected for leaks and repaired as appropriate. Cylinder gas blends should be purchased from a reliable supplier in order to be certain that product composition and quality does not vary from the top to the bottom of the cylinder. This minimizes the return of unused product as a result of poor shielding gas performance.

The use of metered orifices in place of flowmeters can significantly reduce gas consumption on a per station basis.

Praxair works with customers on a individual basis to select the distribution system that will control gas flow and mixture consistency most efficiently. Praxair will make recommendations about sizing a system correctly, the proper use of regulation and mixing equipment, and flowmeters to help ensure economical gas consumption.

CHAPTER 7

Gas Supply Systems

After a shielding gas or gas blend has been selected, it is necessary to consider which of the various gas supply systems is best for the application. This chapter describes the most frequently used cylinder and bulk supply systems.

Cylinder Storage Systems

When gas volume requirements are small, individual cylinders of argon, helium, carbon dioxide, oxygen, or blends of these gases can be used directly in the welding operation. If the consumption rate increases, two or more cylinders can be manifolded together in banks to provide a greater source of supply and to reduce the amount of cylinder handling *(see figure 42).*

A manifold usually has two independent sets of controls to permit alternate or simultaneous operation of the two cylinder banks. Empty cylinders can be replaced with full ones after shutting down one or both cylinder banks. Liquid gases supplied in cylinders may be substituted for gaseous cylinders to increase volumes.

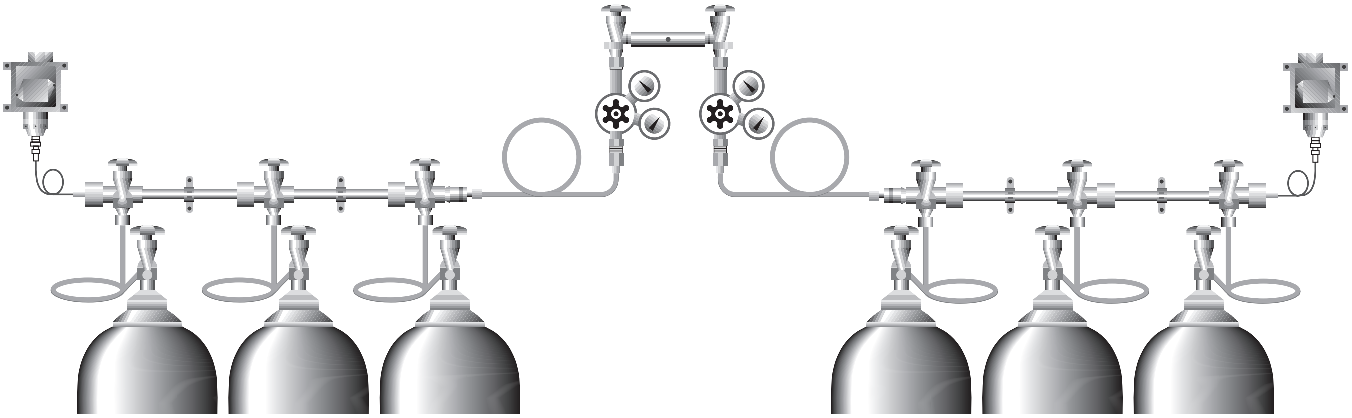


Figure 42 – Manifold system

High-Pressure Cylinders

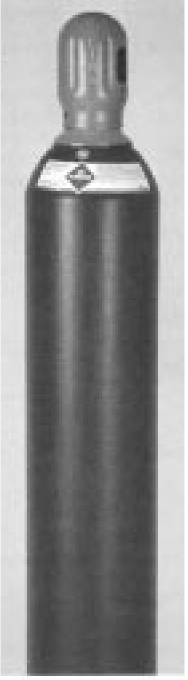


Figure 43 – High-pressure cylinders

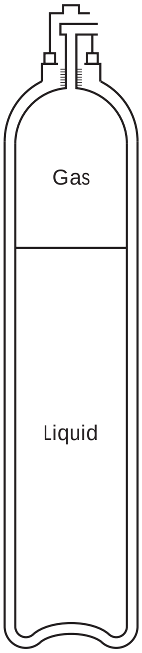
Since gases have a relatively low density, the volume of gas at atmospheric pressure can be considerably reduced by compressing it into a cylinder under greater pressure. These cylinders must be constructed to withstand the high pressures and meet the requirements of the Department of Transportation (DOT) which govern transportation of these cylinders *(see figure 43).*

Identification of Gases in Cylinders

The gas in a compressed gas cylinder is identified by the chemical or trade name marked on the cylinder. The cylinder must be labeled in accordance with the requirements of the Occupational Safety and Health Administrations (OSHA) Hazard Communication Standard.

While cylinders are painted in various colors and combinations of colors, these colors do not provide identification of gas contents and should not be used for that purpose. Suppliers do not intend that users rely on cylinder color to identify gas content.

Carbon Dioxide Supply



Note:
At 70 F there are 8.76 cubic feet of carbon dioxide per pound.

Figure 44 – Standard carbon dioxide gas cylinder

Carbon dioxide welding grade gas is available in either cylinders or bulk containers. The most widely used container is the high-pressure steel cylinder, approved by the Department of Transportation (DOT).

At 70 F, a full carbon dioxide gas cylinder contains both liquid and gas. Liquid carbon dioxide takes up approximately two-thirds of the space in the cylinder; the rest is filled with carbon dioxide in gaseous form.

Gas Mixing

Shielding gases are often used in a blend to optimize the arc welding process. Gas mixers, first developed by Praxair in the early 1950s, are used to accurately mix two or more gases into a required blend. They are available for single weld stations or entire plants.

Mixers can provide blends that meet very tight tolerances, assuring the user that they are consistently receiving the correct blend. Often, mixers are equipped with analyzers and alarm devices or that signal when mixture tolerances are not met. Pure gases can be purchased and blended to meet changing production requirements by changing the mixer settings.

Warning
Do not mix hydrogen with other gases from separate cylinders. Always purchase hydrogen blends ready-mixed.

Pre-Blended Mixtures

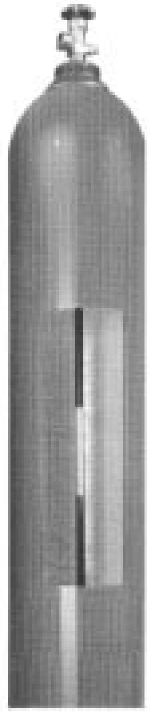


Figure 45 – Cylinder with Praxair's Star Blend mixing system

Many gas cylinders contain Praxair's Star blends mixing system (patented). Each cylinder is evacuated and purged prior to filling to ensure that the cylinder contains only the prescribed gases. Praxair's mixing system solves the problem of gas stratification and assures gas consistency throughout the use of a cylinder *(see figure 45).*

Bulk Storage Systems

Figure 46 – Tube trailer

For users with consumption in the range of 15,000 to 50,000 ft^3/mo., bulk storage systems should be considered. They can result in savings in space and cost. Bulk systems consist of permanent receivers or tube trailers *(see figure 46)* into which the gas is pumped from trailers, or exchanged as required.

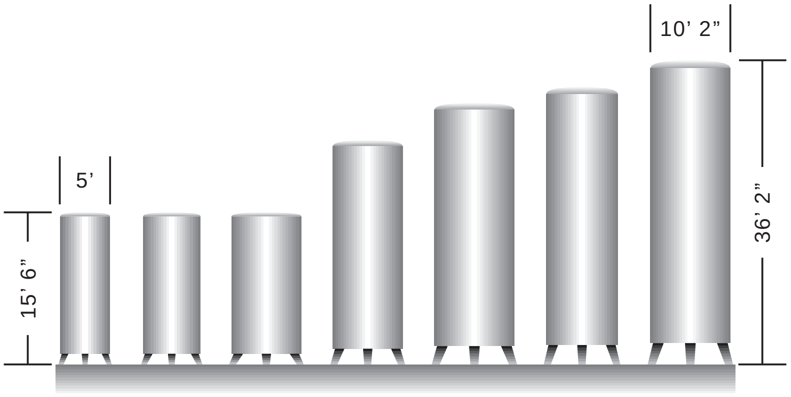


Figure 47 – Liquid storage tanks

Another storage system for gas consumption of approximately 25,000 ft^3/mo. or greater is a liquid storage tank *(see figure 47)* which is filled from trailer trucks or railway tank cars. The liquid is converted into gas through a vaporizer and piped to each destination within the plant. Liquid storage systems are not generally applicable for liquid helium.

The liquid storage tanks in *figure 47* are typical of the many thousands of cryogenic tanks in existence today. Standard capacities range from 250 to 11,000 gallons; custom designs to hold up to 60,000 gallons are available. Praxair engineers, designs, installs, and services entire bulk liquefied gas delivery systems including tanks, vaporizers, instrumentation, computer controls for mixture regulation, and total safety controls.

Inert Gas Distribution Systems

When individual cylinders are used to supply a gas, a pressure regulator is attached to the cylinder to reduce the exiting gas pressure to a safe working level. A flowmeter, connected to the welding equipment by tubing with appropriate fittings, is used to maintain preset gas flow rates.

When large volumes are required or where there are multiple weld stations, it may be preferable to install a distribution piping system.

A system of this type contains main and secondary distribution lines. The gas supply, mixing device (supplied if necessary), main distribution line, and shut-off valves form the basis for the system. Secondary, or branch lines to station valves near the welding machines at various locations throughout the plant are also included. These lines are equipped with valves that allow the lines to be purged.

A typical secondary line has a station valve that is connected to the welding machine though a pressure regulator and flowmeter (often a combined unit). This is connected to the welding machines by an inert gas hose or tubing with appropriate fittings and a solenoid-operated shut-off valve.

It is recommended that the design, materials, fabrication, inspection, and tests meet the requirements of ANSI B 31.3, “Petroleum Refinery Piping.” The designer is cautioned that the code is not a design handbook. The code does not do away with the need for competent engineering judgment.

The Compressed Gas Association pamphlet, Industrial Practices for Gaseous Transmission and Distribution Piping Systems, contains additional information about pipelines.

CHAPTER 8

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 operations. 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), *Precautions and Safe Practices for Gas Welding, Cutting and Heating* (P-2035). Also see Praxair's *Safety Precautions* (P-3499 A), *Condensed Safety Information – Compressed Gases and Cryogenic Liquids* (P-12-237), *Guidelines for Handling Compressed Gas Cylinders & Cryogenic Liquid Containers* (P-14-153).

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 the 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 other 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, 550 N.W. LeJeune Road, Miami, FL 33126.

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 48.*

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.

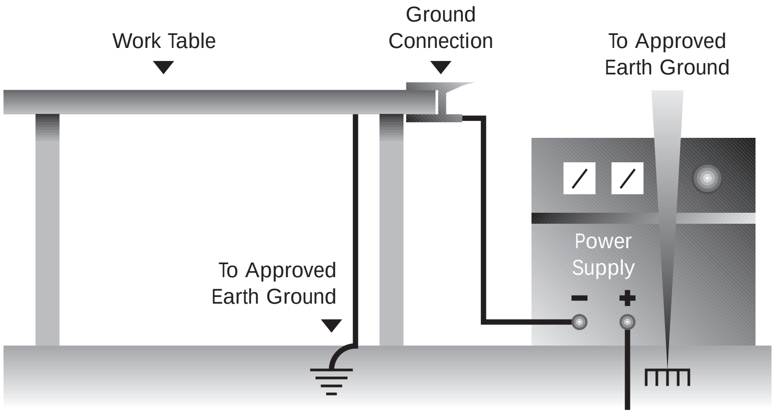


Figure 48 –
Illustration of grounding electrical equipment and the workpiece

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 Z,49.1, Safety in Welding and Cutting available from the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126, 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 protection.

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 protect 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.

Precautions and Safe Practices for Shielding Gases

To handle shielding gases safely, you must have a thorough knowledge of the characteristics of the gases you use, including the hazards. This section includes information about the major hazards of shielding gases.

Read and understand Praxair's *Safety Precautions for Gases* (P-3499) and *Condensed Safety Information, Compressed Gases and Cryogenic Liquids* (P-12-237).

Nitrogen, Argon, Helium and Carbon Dioxide

Warning
Nitrogen, argon, helium, and carbon dioxide can all cause rapid asphyxiation and death if released in confined, poorly ventilated areas.

Nitrogen, argon, and helium as liquids or cold gases and carbon dioxide as cold gas may cause severe frostbite to the skin or eyes. Do not touch frosted pipes or valves with bare skin.

Use a pressure-reducing regulator when withdrawing gaseous nitrogen, argon, helium, or carbon dioxide from a cylinder or other high-pressure source.

Hydrogen

Danger
Hydrogen is a flammable gas. A mixture of hydrogen with oxygen or air in a confined area will explode if ignited by a spark, flame, or other source of ignition. A hydrogen flame is virtually invisible in well-lighted areas.

Hydrogen as a liquid or cold gas may cause severe frostbite to the eyes or skin. Do not touch frosted pipes or valves.

Always use a pressure-reducing regulator when withdrawing gaseous hydrogen from a cylinder or other high-pressure source.

Take every precaution against hydrogen leaks. Escaping hydrogen cannot be detected by sight, smell, or taste. Because of its lightness, it has a tendency to accumulate beneath roofs and in the upper portions of other confined areas.

Do not mix hydrogen with other gases from separate cylinders. Always purchase hydrogen blends ready-mixed.

Oxygen

Warning
Oxygen supports and can greatly accelerate combustion. Oxygen, as a liquid or cold gas, may cause severe frostbite to the skin or eyes. Do not touch frosted pipes or valves.

Always use a pressure-reducing regulator when withdrawing gaseous oxygen from a cylinder or other high-pressure source.

Read all labels on containers of liquid or gaseous oxygen and observe all safety precautions on the label. If a label is missing or illegible, do not use the product. Make no assumptions about what is in the container; return it to the supplier.

Keep combustibles away from oxygen and eliminate ignition sources. Many substances which do not normally burn in air and other substances which are combustible in air may burn violently when a high percentage of oxygen is present.

Material Safety Data Sheets (MSDS)

The Occupational Safety and Health Act regulations, published in the Code of Federal Regulations (CFR), 29CFR 1910.1200, requires that MSDS be provided to users of hazardous materials. The physical and chemical hazards of materials used in welding, including gas mixtures can be evaluated on the basis of the information provided.

The MSDS provides guidance which can be applied to any specific welding application.

Praxair provides an MSDS for each pure gas, pure liquid or shielding gas mixture. See the following list for the appropriate MSDS numbers:

Pure Gases and Liquids

Product	Gas – MSDS#	Liquid – MSDS#
Argon	P-4563	P-4564
Carbon Dioxide	P-4574	–
Helium	P-4602	P-4600
Hydrogen	P-4604	P-4603
Nitrogen	P-4631	P-4630
Oxygen	P-4638	P-4637

Praxair's Mixtures	Product	Description	MSDS #
Argon/Oxygen	StarGold O-1 StarGold O-2 StarGold O-5	1% Oxygen/99% Argon Mixture 2% Oxygen/98% Argon Mixture 5% Oxygen/95% Argon Mixture	P-4718 P-4719 P-4720
Argon/Carbon Dioxide	StarGold C-5, C-10, C-15, C-20, C-25, C-40, C-50	Argon/Carbon Dioxide Mixtures	P-4715
	MigMix Gold	Argon/Carbon Dioxide Mixtures	P-4715
Argon/Carbon Dioxide/ Oxygen	Stargon	Argon/Carbon Dioxide/Oxygen Mixture	P-4718
Helium/Argon	HeliStar A-25, A-50, A-75	Helium/Argon Mixtures	P-4716
Helium/Argon/ Carbon Dioxide	HeliStar A 1025, CS, SS	Helium/Argon/Carbon Dioxide Mixtures	P-4713
Hydrogen/Argon	HydroStar H-2	Hydrogen/Argon Mixtures - Nonflammable	P-4860
	HydroStar H-5, H-10, H-15, H-35	Hydrogen/Argon Mixtures - Flammable	P-4861

For more information call 1-800-PRAXAIR.

APPENDIX A

a-z

Glossary

Arc blow — The deviation of an arc from its normal path because of magnetic forces.

Arc force — The axial force developed by an arc plasma.

Arc length — The distance from the tip of the electrode or wire to the workpiece.

Arc welding deposition efficiency — The ratio of the weight of filler metal deposited to the weight of filler metal melted. (%)

Arc welding electrode — A part of the welding system through which current is conducted that ends at the arc.

As-welded — The condition of the weld metal, after completion of welding, and prior to any subsequent thermal or mechanical treatment.

Automatic — The control of a process with equipment that requires little or no observation of the welding, and no manual adjustment of the equipment controls.

Backhand welding — A welding technique where the welding torch or gun is directed opposite to the direction of welding.

Brazing (B) — A welding process where the coalescence of materials is produced by heating them in the presence of a filler metal having a melting point above 450 C (840 F) but below the melting point of the base metal. The filler metal is distributed between the closely fitted surfaces of the joint by capillary action.

Buttering — A process that deposits surfacing metal on one or more surfaces of a joint to provide metallurgically compatible weld metal for the subsequent completion of the weld.

Cold lap — Incomplete fusion or overlap.

Constant current power source — An arc welding power source with a volt-ampere output characteristic that produces a small welding current change from a large arc voltage change.

Constant voltage power source — An arc welding power source with a volt-ampere output characteristic that produces a large welding current change from a small arc voltage change.

Contact tube — A system component that transfers current from the torch gun to a continuous electrode.

Cryogenic — Refers to low temperatures, usually -200 F or below.

Density — The ratio of the weight of a substance per unit volume; e.g. mass of a solid, liquid, or gas per unit volume at a specific temperature.

Deposited metal — Filler metal that has been added during welding, brazing or soldering.

Dew point — The temperature and pressure at which the liquefaction of a vapor begins, usually applied to condensation of moisture from the water vapor in the atmosphere.

Direct current electrode negative (DCEN) — The arrangement of direct current arc welding leads in where the electrode is the negative pole and workpiece is the positive pole of the welding arc.

Direct current electrode positive (DCEP) — The arrangement of direct current arc welding leads in where the electrode is the positive pole and workpiece is the negative pole of the welding arc.

Duty cycle — The percentage of time during a time period that a power source can be operated at rated output without overheating.

Electrode extension — The length of electrode extending beyond the end of the contact tube.

Filler material — The material to be added in making a welded, brazed, or soldered joint.

Fillet weld — A weld of approximately triangular cross section which joins two surfaces approximately at right angles to each other in a lap joint, T-joint, or corner joint.

Flammable Range — The range over which a gas at normal temperature (NTP) forms a flammable mixture with air.

Flat welding position — A welding position where the weld axis is approximately horizontal, and the weld face lies in an approximately horizontal plane.

Forehead welding — A welding technique where the welding torch or gun is directed toward the direction of welding.

Gas Metal Arc Welding (GMAW) — An arc welding process where the arc is between a continuous filler metal electrode and the weld pool. Shielding from an externally supplied gas source is required.

Gas Tungsten Arc Welding (GTAW) — An arc welding process where the arc is between a tungsten electrode (nonconsumable) and the weld pool. The process is used with an externally supplied shielding gas.

Heat-affected zone — That section of the base metal, generally adjacent to the weld zone, whose mechanical properties or microstructure have been altered by the heat of welding.

Hot crack — A crack formed at temperatures near the completion of weld solidification.

Incomplete fusion — A weld discontinuity where fusion did not occur between weld metal and the joint or adjoining weld beads.

Incomplete joint penetration — A condition in a groove weld where weld metal does not extend through the joint thickness.

Interpass temperature — In a multipass weld, the temperature of the weld area between passes.

Kerf — The width of the cut produced during a cutting process.

Manual welding — A welding process where the torch or electrode holder is manipulated by hand.

Mechanized welding — Welding with equipment where manual adjustment of controls is required in response to variations in the welding process. The torch or electrode holder is held by a mechanical device.

Metal cored electrode — A composite tubular electrode consisting of a metal sheath and a core of various powdered materials, producing no more than slag islands on the face of the weld bead. External shielding is required.

Molecular Weight — The sum of the atomic weights of all the constituent atoms in the molecule of an element or compound.

Pilot arc — A low current arc between the electrode and the constricting nozzle of a plasma torch which ionizes the gas and facilitates the start of the welding arc.

Plasma Arc Cutting (PAC) — An arc cutting process using a constricted arc to remove the molten metal with a high-velocity jet of ionized gas from the constricting orifice.

Plasma Arc Welding (PAW) — An arc welding process that uses a constricted arc between a nonconsumable electrode and the weld pool (transferred arc) or between the electrode and the constricting nozzle (non-transferred arc). Shielding is obtained from the ionized gas issuing from the torch.

Plasma Spraying (PSP) — A thermal spraying process in which a nontransferred arc is used to create an arc plasma for melting and propelling the surfacing material to the substrate.

Porosity — A hole-like discontinuity formed by gas entrapment during solidification.

Preheat temperature, *welding* — The temperature of the base metal immediately before welding is started.

Pull gun technique — Same as backhand welding.

Pulsed spray welding — An arc welding process variation in which the current is pulsed to achieve spray metal transfer at average currents equal to or less than the globular to spray transition current.

Push angle — The travel angle where the electrode is pointing in the direction of travel.

Root opening — A separation at the joint root between the workpieces.

Self-shielded Flux Cored Arc Welding (FCAW-S) — A flux cored arc welding process variation in which shielding gas is obtained exclusively from the flux within the electrode.

Shielded Metal Arc Welding (SMAW) — An arc welding process where the arc is between a covered electrode and the weld pool. Decomposition of the electrode covering, provides the shielding.

Spatter — Metal particles expelled during welding that do not form a part of the weld.

Standard Temperature and Pressure (STP) — An internationally accepted reference base where standard temperature is 0 C and standard pressure is one atmosphere, or 14.6960 psia.

Stress-relief heat treatment — Uniform heating of a welded component to a temperature sufficient to relieve a major portion of the residual stresses.

Thermal conductivity — The quantity of heat passing through a plate.

Underbead crack — A crack in the heat-affected zone generally not extending to the surface of the base metal.

Undercut — A groove melted into the base plate adjacent to the weld toe or weld root and left unfilled by weld metal.

Vapor Pressure — The pressure exerted by a vapor when a state of equilibrium has been reached between a liquid, solid or solution and its vapor. When the vapor pressure of a liquid exceeds that of the confining atmosphere, the liquid is commonly said to be boiling.

Viscosity — The resistance offered by a fluid (liquid or gas) to flow.

Welding leads — The workpiece lead and electrode lead of an arc welding circuit.

Welding wire — A form of welding filler metal, normally packaged as coils or spools, that may or may not conduct electrical current depending upon the welding process used.

Weld metal — The portion of a fusion weld that has been completely melted during welding.

Weld pass — A single progression of welding along a joint. The result of a pass is a weld bead or layer.

Weld pool — The localized volume of molten metal in a weld prior to its solidification as weld metal.

Weld reinforcement — Weld metal in excess of the quantity required to fill a joint.

Wetting — The phenomenon whereby a liquid filler metal or flux spreads and adheres in a thin continuous layer on a solid base metal.

Wire feed speed — The rate at which wire is consumed in welding.

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