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Gas shielding technology for welding and brazing

Welding is a common method that allows two metallic materials to be joined together with high structural integrity. When joints need to be leak-tight, light-weight, or free of contaminant-trapping seams or surface asperities, welding tends to be specified.

There are many welding techniques, each with its own advantages and disadvantages. Some of these techniques include Forge Welding, Gas Tungsten Arc Welding, Friction Stir Welding, and Laser Beam Welding to name a few. Whichever technique is used, the objective is a structural joint that meets the requirements of a particular component or assembly. A key practice in producing quality welds is the use of shielding gas. This article discusses various weld techniques, quality of the welds, and importance of shielding gas in each of those techniques.

Metallic bonds, or joints, are produced when metals are put into intimate contact. In the solid-state “blacksmith welding” process, now called Forge Welding (FOW), the site to be joined is pounded into intimate contact. The surfaces to be joined usually need to be heated to make it easier to deform the metal. The surfaces are sprinkled with a flux to melt surface oxides and given a concave shape so that surface contamination can be squeezed out of the joint as the surfaces are pounded together; otherwise the surface contamination would be trapped in the joint and would weaken the weld. In solid-state welding processes surface oxides or other contamination are typically squeezed out of the joint in “flash.”

Fusion welding, as opposed to solid-state welding, is performed at higher melting temperatures and with the exposed molten metal surface has an even greater tendency for atmospheric interaction to produce weld contamination. In fusion welding processes a heat source sufficiently intense to cause local melting is applied to the seam to be welded, and, ideally, the molten metal simply flows together and solidifies as a welded joint as the heat source continues on. Bulk weld metal contamination as well as surface contamination is encountered in fusion welding processes. Contamination is typically resisted by shielding the hottest, most reaction-prone surfaces.

References to gas shielding appear soon after the introduction of the Carbon Arc Welding (CAW) process in the early 1880's. Although the CAW process is ostensibly unshielded, the carbon arc is not entirely inert. Carbon from the electrode reacts with the atmosphere to produce a shielding effect (as carbon does when reducing iron ore in blast furnaces) but can also carburize steels to the point of producing brittle welds under suitable conditions.

In his U.S. Patent No. 419,032 dated January 7, 1890 Charles L. Coffin, President of the Welded Steel Barrel Corp., makes the claim, “My invention relates to welding metals electrically; and it consists in performing the welding operation in a non-oxidizing medium.” Coffin's welding process was performed in a sealed box filled with a non-oxidizing medium, which could be a liquid as well as a gas.

In the late 1880's consumable metal electrode processes came into use. This was the familiar “stick” welding process, today given the name Shielded Metal Arc Welding (SMAW). The word “shielded” is used because today coatings that decompose and either produce a molten slag that flows over and shields the molten weld puddle or emit a

shielding gas. Coatings for welding electrodes emerged in the early 1900's. The shielding provided by coated electrodes is not adequate for avoidance of contamination in aluminum and magnesium.

Gas Tungsten Arc Welding (GTAW).

In 1941 the "Heliarc" process was invented by Russell Meredith at Northrop Aircraft Company with a view at producing magnesium airframes. The patent was bought by the Linde Division of Union Carbide Corporation, which marketed a "Heliarc" welding torch and which brought out a torch where cheaper argon replaced helium as the inert shielding gas. This was the origin of the Gas Tungsten Arc Welding (GTAW) process, informally known as "TIG," i.e. Tungsten Inert Gas, welding.

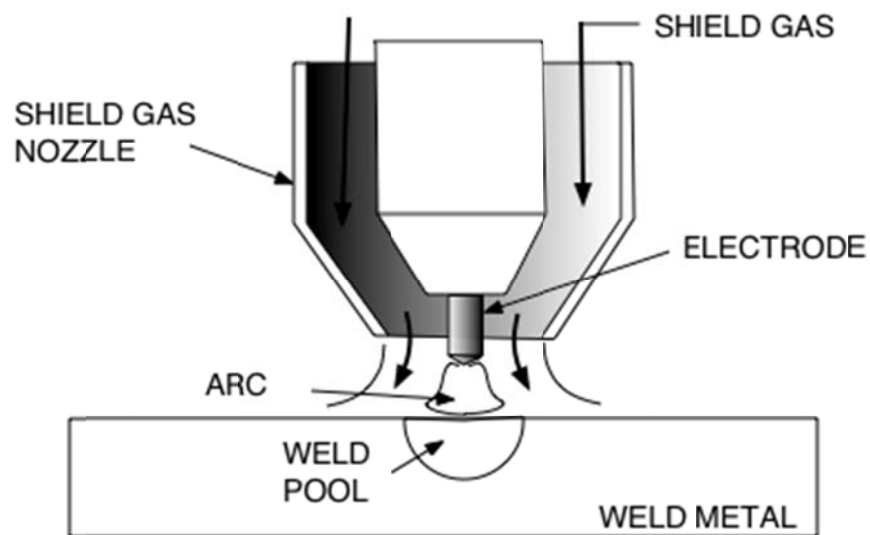


Fig. 1. Schematic of GTAW welding torch nozzle.

In the GTAW process a tungsten electrode is used. The electrode can withstand the high temperatures and melts at around 3,380 degrees Centigrade. It is not as reactive as carbon. The tungsten electrode is surrounded by a nozzle emitting a flow of inert shield gas. Atmospheric contaminant gases are swept away in the shield gas flow as they diffuse inward from the edges of the shield gas column. This can be seen in Figure 1. The higher the shield gas flow rate, the lower the contaminant concentration that reaches the hot metal at the arc contact site.

The shield gas column may be distorted by motion of the welding torch which can reduce the thickness of gas barrier between arc contact and contaminating atmosphere. If not too severe, this can be compensated by increasing the shield gas flow rate. At very high flow rates the gas column flow can become turbulent, entraining contaminating atmosphere, and the shielding effect is lost. If the weld metal is sufficiently reactive to be damaged at temperatures outside the gas column, additional shielding may be required. A hot root surface (the opposite side of the workpiece from the welding torch) may be protected by a "backup purge". This backup purge will flood the hot length of root pass with an inert or non-reactive gas emitted from a box, or similar fixture, with a slot in the

upper surface close to the weld root. A hot crown surface (on the side of the welding torch) may be protected using a “trailing shield,” a box following the torch and emitting inert or non-reactive gas to flood the hot metal trailing the torch. This can be seen in Figure 2.

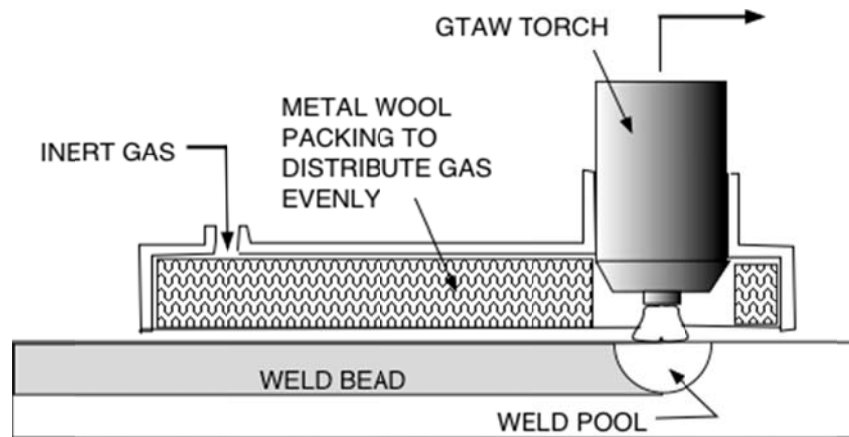


Fig. 2. A trailing shield. For the flat welding position the shield gas should be heavier than air, for example argon.

Shield Gas Arc Effects

In the GTAW process the arc is produced within the shield gas and the characteristics of the shield gas determine the characteristics of the arc, for example its intensity and stability. The sustained electrical discharge that comprises the arc is generated by collisions of electrons with gas atoms or molecules. The gas in this conducting condition is called a “plasma.” The collisions must knock out enough new free electrons to balance the electrons absorbed by the ionized atoms for equilibrium to be maintained. The electrons get their collision energy from the electric field, the voltage gradient within the discharge, which accelerates the electrons between collisions. The amount of energy accumulated between collisions is determined by the structure of the gas atoms/molecules.

The gases commonly used in the GTAW process are helium and argon. The smaller tighter outer arrangement of electrons in helium atoms and the larger looser outer arrangement of electrons in argon atoms result in different ionization potentials (i.e. the energy required to detach an outer electron). The ionization potential of helium is about 24.5 volts and argon is about 15.8 volts. That is, to initiate an arc during the interval between collisions the electron must be accelerated across a potential of approximately 24.5 volts for helium and 15.8 volts for argon. Once the arc is initiated, the collisions heat up the atoms/molecules of the gas and the kinetic energy of the atoms/molecules contributes to the ionization process, reducing the requirement of the electric field.

In SMAW an arc is initiated by bringing the electrode very close to the workpiece to allow a sufficient voltage drop across the small “mean free path” distance of a free electron. This may be initiated by the liberation of a stray photon and the subsequent collision. Once the arc is started, it can be extended to a controllable length, which may be only a few millimeters.

It has been noted that reduced gas pressure increases the mean free path of an electron and allows the electrons to accumulate more energy between collisions. For example, unwanted (and dangerous) arcs are a potential hazard in space activities, both

welding and non-welding. These unwanted arcs can cause safety concerns as well as inadvertent damage to hardware or workpiece.

In GTAW an arc is typically initiated at a distance from the workpiece surface, where the tungsten is not in danger of being contaminated by a surface interaction. A high frequency generator in series with the arc circuit can generate free electrons in the gas and initiate the arc.

Helium requires greater power from the weld generator and delivers more heat to the workpiece surface than argon because of its higher ionization potential and tendency to lose more heat due to its higher thermal conductivity properties. Thus, Helium is less stable and is more prone to cause fluctuations of the arc than Argon.

Unreactive but not necessarily inert gases, such as hydrogen, nitrogen, or carbon dioxide, can also be used as shield gases under appropriate conditions. The shielding emissions from carbon electrodes or electrode coatings fall into this category. Molecular, as opposed to monatomic inert gases, can dissociate in the arc and recombine at the workpiece to give off heat and produce a hotter effective arc.

Arcs are not symmetrical. In Direct Current Electrode Negative (DCEN) operational mode the main current carriers in the arc, the small fast-moving electrons, are emitted at the cathodic electrode. Here, they absorb heat and are conducted to the anodic workpiece where they give up heat. DCEN, often referred to as “straight polarity”, is many times the preferred mode of operation because more heat is delivered to the workpiece, where it is wanted, rather than the electrode where it is not desired.

In the Direct Current Electrode Positive (DCEP) or “reverse polarity” mode the electrons are emitted at the cathodic workpiece and conducted to the anodic electrode. In this mode a curious effect is observed on the workpiece surface. A high-speed movie of an aluminum workpiece surface reveals an array of tiny flashes speckling the surface near the arc reminiscent of a movie of a landscape subject to a bombing raid. The flashes may be interpreted as local dielectric breakdowns of a thin layer of surface oxide charged by the settlement of positive ions from the arc onto the oxide surface. This blasting away of surface oxide is the origin of the well-known reverse polarity cleaning effect. Sometimes with metals that accumulate a tenacious oxide layer the optimal heating of the DCEN mode is sacrificed for the cleaning effect of the DCEP mode.

It is possible to mix optimal heating mode and cleaning mode by using an oscillating current waveform. Alternating Current (AC) mode is a simple mixing scheme. More complex square-wave forms are also available.

Gas Metal Arc Welding (GMAW).

Filler metal is often added to a GTAW pool in the form of a wire, which may be hand-held or fed automatically. If a consumable wire electrode replaces the non-consumable GTAW electrode itself, the GTAW process becomes the Gas Metal Arc Welding (GMAW) process. In the GMAW process, the effect of shield gas on metal transfer from the electrode to weld pool must also be considered. Whereas the GTAW filler wire can be simply immersed in the weld pool, if there is to be a GMAW arc, the end of the consumable wire electrode must be separated from the weld pool. The metal may transfer in large drops (globular transfer) or a fine spray (spray transfer).

Globular transfer of metal may form occasional metal bridges between the electrode and weld pool. The short circuiting bridges heat rapidly and explode with an

abundance of metal spatter. Other mechanisms cause spatter are electromagnetic forces, trapped thermal energy in surface indentations of bubbles, and pool impacts from larger drops causing splash of molten drops.

Variable Polarity Plasma Arc Welding (VPPAW).

Shielding does not address every form of contamination. It doesn't remove surface oxide or other surface contamination already present on the weld metal surfaces such as residual oils. Oily matter tends to decompose in the arc yielding hydrogen. More hydrogen can dissolve in molten aluminum than in solid aluminum, thus an aluminum alloy weld pool that has sufficient dissolved hydrogen contamination precipitates bubbles of hydrogen on the solidifying surface at its back.

Porosity may be addressed through surface preparation: by a solvent wipe, white glove handling, and surface scraping. Even so, a certain amount of porosity may have to be ground out and re-welded. Additionally, the weld process could be designed to allow for easy escape of porosity. It is often easier to avoid working welds overhead and favor the flat welding position if possible.

Porosity can also be flushed from the weld. The Plasma Arc Welding (PAW) process has flushing capability. In 1955 Robert M. Gage of the Linde Division of Union Carbide Corp. filed for the patent of an "Arc Torch and Process," issued in 1957 as US Patent Number 2,806,124. This is usually regarded as the birth of PAW although non-welding plasma arc torches already existed.

The arc or plasma torch emits a jet of plasma similar to the flame of a gas welding torch, except much hotter. An arc is initiated between a tungsten electrode and a water-cooled constricting nozzle surrounding the electrode. As the gas heats up, it expands, and jets out of the constricting nozzle as a plasma with enough force to press into the molten metal pool where the jet impinges on the workpiece. If conditions are suitable, the jet will penetrate all the way through the workpiece and emerge out of the back of the workpiece. This mode of operation is called "keyholing." In keyholing the plasma jet entrains and flushes out gas impurities that might cause porosity. Meanwhile, the extremely hot molten metal surrounding the plasma jet is flooded with shield gas emitted from a secondary nozzle surrounding the PAW plasma-constricting nozzle just as the GTAW shield gas nozzle surrounds the tungsten electrode. The PAW torch nozzle is shown in Figure 3.

The PAW process as described is adequate for welding steels, but aluminum alloys are covered with a thin tenacious oxide layer. In the PAW keyholing mode the molten metal on the forward surface of the keyhole tends to migrate and merge into a unified pool behind the keyhole. The backflow occurs because the surface tension of the molten metal increases as the metal cools and pulls the molten metal with it. As the plasma jet advances and melts more metal at the keyhole surface, the surface tension gradient driven lateral flows remove it and feed it to the weld pool at the back of the keyhole. In aluminum alloys the tenacious oxide layer can be imagined as plastic film wrap covering the molten metal surface; it disturbs the backflow from the melting surface and prevents consolidation of the two lateral streams. Instead of a uniform quality weld, a rough and "blobby" structure will emerge in the wake of the plasma jet.

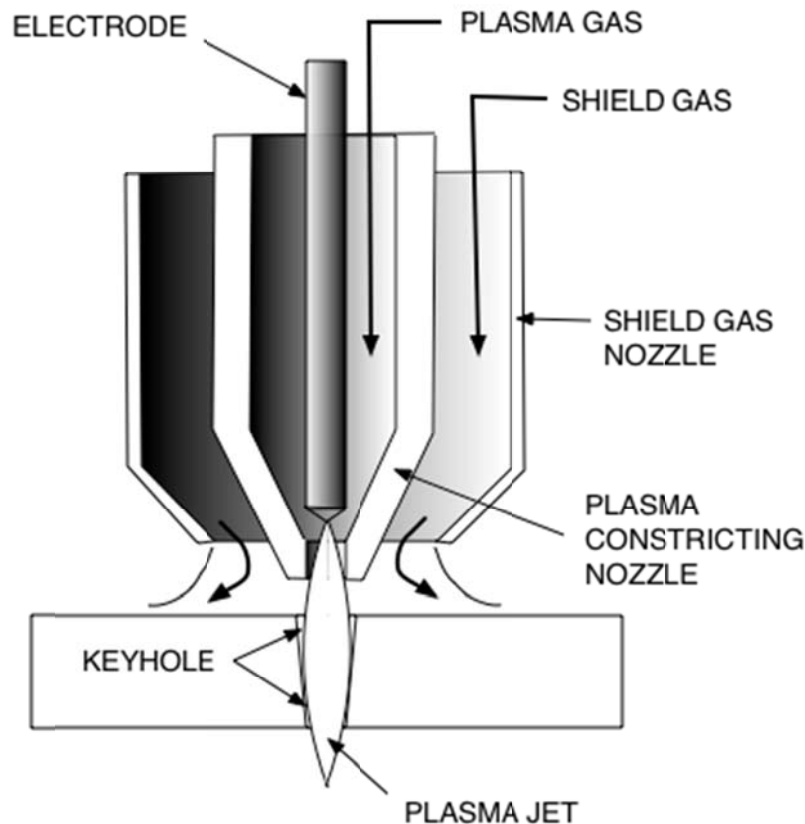


Fig. 3. Schematic of a PAW torch nozzle. The water-cooling channels of the plasma-constricting nozzle are not shown.

Similar to GTAW discussed previously, a remedy for the oxide problem is to incorporate enough reverse polarity cleaning effect into the weld process to blast away the surface oxide during the consolidation of the molten weld pool. The Variable Polarity Plasma Arc Welding (VPPAW) process incorporates a power supply that does this. The polarity reversing waveform for the current gives the process a characteristic buzzing sound.

Friction Stir Welding (FSW).

Gas shielding, plasma flushing, and reverse polarity cleaning as part of the VPPAW process has not proven adequate in preventing all forms of contamination. Newer aluminum alloys containing lithium can interact with nitrogen from the air at temperatures at approximately 360° C, well below that of welding, to form aluminum-lithium-nitride. Lithium nitride is well known as a candidate for storing large quantities of hydrogen. With such alloys one may see secondary porosity, which, unlike that due to simple supersaturation of the melt, does not appear in the first weld pass. This will instead emerge in response to heating by a second weld pass.

Even unwelded parent metal can exhibit secondary emission of gas and grain boundaries have been known to bubble when heated in the hot-stage microscope. Manufacturers have presumably eliminated this problem at this stage in the development of these alloys.

In spite of attempts to use heated titanium getters to reduce contaminants in the weld gas, it proved sufficiently difficult to produce ductile welds in a solid-state process until Friction Stir Welding was introduced.

In the FSW process a rotating pin stirs the weld seam surfaces together, while a shoulder caps the weld and prevents the weld metal from flowing up around the pin. If the shoulder were not present to prevent metal upflow, the metal upflow would leave a trench in the wake of the pin. The metal adjacent to the pin softens with the heat, but no gross melting occurs. However, in some circumstances low-melting phases present in small volume fractions may melt. The axial compression force is large and the weld metal is under considerable pressure. Welds generally comprise a single pass. Friction stir welds in aluminum-lithium alloys do not exhibit the tendency for low ductility exhibited by fusion welds in that metal. If a friction stir weld is exposed to the heat of a fusion weld pass, it may exhibit secondary porosity.

Current FSW practice does not generally employ gas shielding (like fusion welding), although the surfaces to be joined may be brushed and solvent cleaned. The large shear imposed upon the seam as it enters the deformation field around the tool expands the seam surface to expose a great deal of clean surface for welding. Although large oxide chunks or other hard particles could embrittle the surface, FSW is not especially sensitive to seam contamination. As FSW practice is extended to higher melting metals, protection of hot metal surfaces may require shielding in the form of a trailing shield and back purge or an inert atmosphere box with a sealed moving surface incorporating the tool.

Laser Beam Welding (LBW).

LBW is a high power density beam welding process like Electron Beam Welding (EBW). The power density is so high that when these fine focused beams impinge upon a metal surface, the metal vaporizes at the point of impingement. A schematic of laser beam welding can be seen in Figure 4.

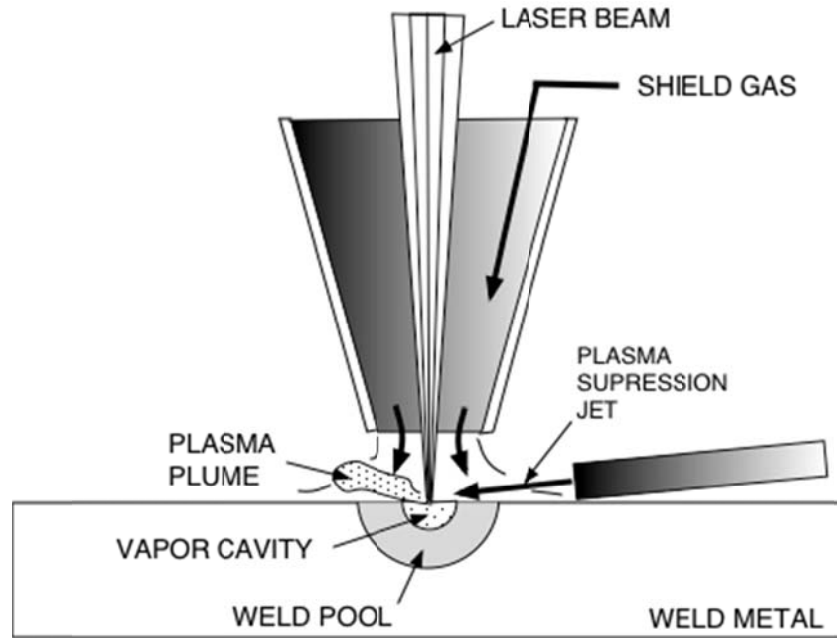


Fig. 4. Schematic of LBW operation. Many different configurations have been used to shield the weld and suppress plasma obstruction of the beam.

An electron beam yields up its power on the forward surface of a vapor cavity. The slope of the forward surface steepens to present more area for power dissipation if the beam power increases or if the weld speed is reduced, thus the cavity and the weld deepens. The molten metal on the forward surface of the cavity flows back around the beam, driven by thermo-capillary, i.e. temperature driven surface tension gradient, forces, to solidify at the back of the vapor cavity. A very narrow, deep weld can be made; this minimizes the detrimental effect of the metal regions melted and heated during the making of the weld and improves weld properties. Because electron beams (of normal voltages) do not penetrate air, EBW is performed in a vacuum chamber and the necessity for gas shielding does not arise.

LBW is similar to EBW, although the tendency of metal surface to reflect light makes the power coupling of a laser beam to a metal surface more complex than for an electron beam. The outstanding difference is that the laser beam has no trouble penetrating air and can operate in the atmosphere. A laser beam can be attached to a robotic arm to perform elaborate welding operations automatically in a production environment and recent advances have produced handheld laser welding torches.

Similar to GTAW and VPPAW processes, LBW raises the temperature of exposed metal to levels where the atmosphere would react with it detrimentally. To prevent this, shield gas nozzles emitting a flow of inert gas like the shield gas nozzles surrounding arcs and plasmas typically surround welding laser beams.

Lasers impose unique shielding gas challenges not encountered during some of the traditional welding techniques. Laser welding systems may include the previous generation systems, such as CO₂ and Nd:YAG, as well as some of the newer fiber laser systems or hybrid systems. Incorrect shielding gas or turbulent flow can cause plasma formation or secondary plumes, which can damage hardware and also make visibility difficult for the operator. Selection of the shielding gas as well as laser welding parameters is critical to clean and defect free laser welds.

Many laser systems use similar gas shielding systems to those of traditional GTAW including distribution cups and bodies, gas lenses and diffusion screens, and nozzles. These assemblies are often modified to accommodate the optics path and it is good practice to run a gas flow test. Flow tests are a simple visual tool to understand the varying flow characteristics through the shielding assembly and if turbulent flows are present that could adversely affect the weld. Backup purges or trailing shields might also be appropriate for some situations. The interaction of secondary flow or trailing shielding gas should also be investigated during a flow test prior to implementing a new gas system for laser welding.

Unlike the case for GTAW and VPPAW processes, evaporated metal from LBW may be ionized to a plasma that absorbs and attenuates the laser beam. This has been observed in handheld laser welding with Nd:YAG and fiber laser systems. The pulse frequency and peak power and interaction of shielding gas can cause plasma formation that makes it difficult for the operator to observe the weld and can also cause damage to the workpiece or hardware. A lower pulsing rate in a quasi-continuous wave operation can help minimize the plasma formation. Additionally, Helium has replaced Argon in most handheld laser welding operations, which helps to minimize plasma formation due to its higher ionization potential as discussed previously. In some instances a cross current of gas, or plasma suppression jet, is required to remove the plasma.

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