Review on Shielding Gas Supply Methodologies in Fusion Welding

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Abstract

The main function of shielding gases used in welding processes, such as hydrogen (H2), oxygen (O2), carbon dioxide (CO2), nitrogen (N2), helium (He), argon (Ar) and their mixtures, is protection of the weld pool against harmful contamination that could generate defects. In addition to this primary function, shielding gases significantly affect the shape of the weld, weld geometry, seam appearance, metallurgical and mechanical properties, welding speed, metal transfer, arc stability or beam and fume emissions. The shielding gas is thus a key factor in determining weld joint properties and welding process efficiency. In view of constantly increasing prices and shortfalls in helium supply, there is a need to optimize the use of shielding gas. Consequently, an ability to closely monitor the shielding gas blend and reduce waste can provide valuable cost savings. This paper examines the various methods of supplying shielding gases in to the weld pool to optimize its usage.

Keywords: Shielding gases, GMAW, GTAW and Weld properties

1. Introduction

Due to its abundant benefits, fusion welding enjoys a major credit among welding processes. Shielding is the process of replacing a reactive environment or ambient air with an inert gas. For proper functioning of GTAW use of shielding gas is unavoidable. As the shielding gas exits the nozzle, it has a different velocity than that of the atmospheric gases surrounding it. The different velocity and density between these gases can cause currents to form, which can potentially turn the shielding gas column from a laminar flow to a turbulent flow. Usually turbulent flow of shielding gases no desirable for good quality welded joints. As the flow becomes turbulent, atmospheric gases can be pulled into the shielding gas column, leading to contamination of the weld and resulted in poor weld quality.

Shielding gases have a distinct effect on the formation and the structure of the arc plasma. This plasma, composed of ionized gas, melted metals, slags, vapors and gaseous atoms and molecules, can be controlled by application of appropriate shielding gas [1, 2]. The application of different shielding gases can result in different penetration and weld bead profiles. Porosity in the weld is one of the most common welding defects related to the shielding atmosphere. Pores can be the initiation point for crack propagation in the welded joint and can considerably decrease the life cycle of joints under dynamic loads [3, 4].

The shielding gas plays a significant role in controlling the weld bead geometry, porosity, weld microstructure, and mechanical properties of welded components. Also, it provides a suitable medium for the steady functioning of a sustained low-voltage arc as well as air contamination shielding. Shielding gases like hydrogen (H_2), oxygen (O_2), carbon dioxide (CO_2), nitrogen (N_2), helium (He), argon (Ar) and their blends are normally used in fusion welding. The shielding gases, as with TIG welding, are the inert gases argon and helium or combinations of these two. Other, active, gases such as oxygen or nitrogen even in small amounts will give porosity and smutting problems.

The most commonly used gas is argon which is used for both manual and some automatic welding. It is substantially cheaper than helium and produces a smooth, quiet and stable arc, giving a wide, smooth weld bead with a finger-like penetration to give a mushroom-shaped weld cross-section. Argon, however, gives the lowest heat input and therefore the slowest welding speeds. There is therefore a risk of lack of fusion defects and porosity on thick sections. The study includes consideration of shielding gases used for welding of both ferrous metals and non-ferrous metals.

The shielding gas for aluminum and aluminum alloys is usually argon, possibly with the addition of helium. Helium improves heat transfer, and is used when welding thicker sections. The welding current is normally AC or, at low current levels, it may be DC with the electrode connected to the positive. It was noticed that argon provides a smooth, stable, and quiet arc compared to nitrogen and oxygen [5]. However, the arc interacts with the environment in the GMAW process, resulting in weld defects such as lack of penetration, burn through, and porosity. As a result, in-process monitoring and control are required to ensure quality through defect-free welds [6].

Because the arc and droplet parameters directly controlled the weld pool behavior, the quality and stability of the GMAW process were heavily dependent on their behavior [7]. It was pointed out that argon enhances oxide breakdown and weld quality by improving arc stability. Helium promotes an increase in welding rate, penetration, and weld puddle fluidity by providing higher heat input to the base metal [8].

From all the studies, it was found that the analysis of the behavior of the shielding gas as it exits the nozzle of the torch was limited. However, it was shown that it is possible to view and record the flow and turbulence of the shielding gas. Despite the type of shielding gases used having a remarkable effect on the mechanical properties of welded joints, there are few comprehensive scientific resources dealing with this issue. The aim of this paper is to provide concise and inclusive information about the various methods of supplying shielding gases to weld pool and compare their effects on process performance and thus provide a foundation for better control and decreased shielding gas losses. Following the introduction, the second section presents and compares shielding gas properties. Various methods of supplying shielding gases are reviewed in the third section. Finally comparative evaluation of shielding gases and shielding gas supplying methods is presented and the key findings are summarized.

2. Properties of the shielding gases used in welding

The various shielding gases used in welding have specified properties and functions. Shielding gases are standardized in European standard EN ISO 14175 Welding consumables - Gases and gas mixtures for fusion welding and allied processes. This standard covers six named gases, i.e. helium (He), hydrogen (H_2), carbon dioxide (CO_2), oxygen (O_2) and argon (Ar). In fusion welding, the plasma consists of ionized gas, molten metals, slags, vapours and gaseous atoms and molecules. The formation and structure of the arc plasma are dependent on the properties of the shielding gas used. Therefore, it becomes relevant to study the properties of gases used as shielding gas and further to understand their function in different welding processes. Table 1 presents basic chemical and physical properties of gases commonly used in fusion welding.

Table 1 Chemical and physical properties of gases commonly used in fusion welding

Type of gas	Content in air (vol%)	Density at 15°C, 1 bar (kg m-3)	Dissociation energy eV/molecule	First ionization energy eV/molecule	Chemical activity
Hydrogen (H_2)	0.5×10−6	0.085	4.5	13.6	Reducing
Argon (Ar)	0.934	1.669	0	15.8	Inert
Helium (He)	5.2×10−6	0.167	0	24.6	Inert
Nitrogen (N_2)	78.05	1.170	9.8	14.5	Reducing
Carbon dioxide (CO_2)	0.033	1.849	4.3	14.4	Oxidizing
Oxygen (O_2)	20.946	1.337	5.1	13.6	Oxidizing

Ionization potential is a measure of the energy required to ionize the gas and enable the gas to conduct current. The lower the ionization potential, the easier it is to initiate the arc and maintain arc stability. Thermal conductivity of a gas is its ability to transfer thermal energy. This ability affects, for example, the metal transfer mode, the weld geometry and temperature distribution. The chemical activity of a gas is a classification of whether the gas reacts chemically with the weld puddle and electrodes and the type of chemical reaction.

3. Methods of supplying shielding gases

Shielding gases taken individually have different characteristics and act in different ways on the metals for which they are intended to provide protection during welding. This behavioral difference is due to not only the type of shielding gases but also the method of supplying shielding gases to the weld pool. Hence it is essential to take into account not only the shielding gases involved in the weld but also the way by which it reaches the weld pool.

3.1. Pre mixed shielding gas supply

Instead of the conventional approach of premixed shielding gas, two different shielding gases (Argon and CO_2) are provided independently at the weld zone [9]. Its goal is to provide a better approach to shield the molten weld pool, resulting in increased weld quality and efficiency [10]. Regarding non-ferrous applications, the shielding gas is usually argon or a combination of argon and helium. However, a variety of gas combinations containing argon, helium, CO_2, and O_2 are utilized in various industries for steel welding [11].

Table 2 Investigation and Findings on premixed shielding gas supply

Researcher	Year	Methodology	Aspects reviewed
Pires et al.[12]	2007	influence of seven gas mixtures (Ar + 2%CO2, Ar + 8%CO2, Ar + 18%CO2, Ar + 5%O2, Ar + 8%O2, Ar + 3%CO2 + 1%O2 and Ar + 5%CO2 + 4%O2) on the features of GMAW process was performed	Repelled transfer occurs due to the reactive behavior of the mixture and the decrease of the conduction zone, caused by the increase of the thermal conductivity of the mixture
Fujii et al [13]	2008	mixed shielding gas He - O_2 and He - CO_2 on TIG welding process for the welding of SUS304 stainless steel	Addition of oxygen through the shielding gas in the molten pool controls the marangoni convention because oxygen is a surface active element for stainless steel.
He et al [14]	2009	He - Ar mixture is used as shielding gas in tungsten inert gas welding of SiCp/6061 Al composites	50 % volume helium in shielding gas improves the arc stability and quality of seams
Pakpoom et al [15]	2013	In GMAW shielding gases were pure argon, 75%Ar + 25%He, 50%Ar + 50%He, 25%Ar + 75%He and pure helium.	Higher helium content in shielding gases required higher arc voltage at identical arc length to ionize the gas in order to provide enough ionized gases to sustain the arc.
Kolarik et. al [16]	2013	GMA welding experiments for Al alloys using different shielding gases, Ar+CO2 , Ar, Ar+He mixtures	Mechanical properties were improved

3.2. Pulsed shielding gas supply

Automatic shielding gas regulators apply an adaptable pulsating flow principle to control of shielding gas flow into the weld pool zone. The shielding gas flow is synchronized with the welding power source, allowing flow only at pulsed welding current time. An example is the use of a solenoid valve to control the gas supply. Gas flow through an orifice is shut off or allowed by the movement of the core when the solenoid is energized or de-energized. The gas flow rate is adjusted with change of the magnitude of the current.

Table 3 Investigation and Findings on pulsed shielding gas supply

Researcher	Year	Methodology	Aspects reviewed
Steven C. Woods [17]	2006	Gas pulsing in GMAW	Ability to give similar penetration depths as mixed gas welds with greater ratios of CO_2
Ostrovskii et. al [18]	2009	Pulsed feed of shielding gases in TIG welding	20-40% of argon was saved and the extent of splashing reduced
Tazetdinov et. al [19]	2012	Pulsed supply of dissimilar gases in arc welding	Periodic impact effect on the weld pool resulted in the formation fine-grained structure at the welded joint with a
Nakhla et. al [20]	2012	Pulsed feed of CO_2 gas in MIG welding	Reduce emissions while maintaining quality welding process
Campbell et al [21]	2012	Synchronized pulsed current to pulse the shielding gas in GMAW	Reduction in shielding gas consumption and increased productivity

3.3. Alternating shielding gas supply

In this experiment, supply of shielding gases is controlled by gas alternator. Gas alternator is an apparatus used for alternate supply of shielding gases to the welding torch, which ensures delivery of the shielding gas alternately and directly to the welding torch to avoid mixing of the gas before entering the torch. In alternator a ‘T’ joint is used to connect the hoses from two different gas cylinders and one outlet of 'T' joint is connected to the nipple provided in torch body through hose. Gas alternator consists of two solenoid valves which alternate the shielding gas supply at a frequency range of 20-120 cycles/minutes. The duration of flow for each individual gas is controlled through two timer knobs provided in the front panel of the shielding gas alternator. By using this method, two shielding gases are supplied in an alternating frequency to the weld pool which causes the stirring of weld pool thereby improving the weld properties.

Table 4 Investigation and Findings on alternating shielding gas supply

Researcher	Year	Methodology	Aspects reviewed
Yeo et. al [23]	1996	Multi level heat input using Ar and He alternatively in cladding of tubes	Reduction in weld defects, such as cracking, porosity, distortion
Nsbarabokhin et al. [24]	2000	Alternate supply of Ar and He using the AC(alternate current) GTA welding machine	Increased strength and improved ductility properties of welded joints
Nakamura et al. [25]	2002	A new welding torch that periodically controls shielding gas composition, and introduces periodically CO_2 into Ar+ 2%O_2 mixture in GMA welding	High efficient welding was achieved in terms of weld quality
Kim et. al [26]	2006	Experimental and a numerical research to find an interrelationship between alternate supply of shielding gas and weld quality in a GTA welding process	Effect of alternate supply of shielding gas used to narrow gap welding process
Kang et al [27]	2006	compared conventional gas supply with alternate supply of shielding gases in GMAW of aluminum alloys supplied	Alternate supply yields the low degree of weld porosity, deeper and broader weld penetration profile
Kang et al [28]	2009	alternate supply of pure argon and argon + 67 % helium mixture for the welding of austenitic stainless steel using GTA welding process	Alternate method with argon+ 67 % helium mixture produces the lowest degree of welding distortion and produces better quality welds
Campbell et al [29]	2012	using alternating shielding gases during GMAW joints of AA 6082T6 aluminum alloy	Resulted in increased productivity, reduced porosity, moderate strength increase and a reduction in post weld straightening
Novikov et al [30]	2012	alternating supply of two shielding gases on the geometrical parameters and mechanical properties of the welded joints	periodic increase in the pressure of the welding arc resulted in the grain refinement in the zone of the weld metal and the fusion zone
Bitharas et al [31]	2016	visualization of flow of alternating shielding gases using argon and helium during GTAW with high speed schlieren imaging	Increase in weld penetration with the alternating shielding gas, suggesting that the helium is used more efficiently.
Neelam et al [32]	2016	alternate supply of shielding gases of TIG welding and its influence on mechanical properties of austenitic stainless steel	Weld distortion is less observed in alternate supply of shielding gas sets compared with pure argon gas
Mahadevan et al [33]	2018	Alternating supply of Ar and He in GTA welded joints of AA6061 alloy	Bead profile characteristics was improved with alternate supply of shielding gases
Mariappan et al [34]	2021	Alternating shielding gases in gas metal arc welding of SA515 Gr 70 carbon steel	Alternating shielding gases showed a substantial impact on arc stability and efficiency, deposition rate, microstructure, chemical, and mechanical properties

4. Conclusion

The study investigated various methods of supplying shielding gases in fusion welding processes. Based on a review of the relevant literature and the various recommendations made therein, the following findings are of significance:

1. Pure gases show acceptable performance, but shielding gas mixtures provide optimal results. Optimum performance is achieved with mixtures of inert gases.
2. Adaptive control is possible either by alternating the type of gas injected into the weld zone or by supplying the required gas at an optimal flow rate.

3. Electric pulses, power sources with different inductivity and wire feed systems that generate mechanical pulses can be used to influence droplet transfer time. Thus, it is possible to control the metallurgy by selection of welding equipment and welding parameters.

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