A Literature Review on Plasma Arc Welding (PAW)

Savitharoja P[1], Dr.K.T.Thilagam[2]
[1]PG Scholar Department of Metallurgical Engineering, Government college of Engineering Salem.11
[2]Assistant professor Department of Metallurgical Engineering, Government college of Engineering Salem.11

***Abstract*-Plasma arc welding is a non-conventional form of welding which can be applied to almost any existing metals. The various process parameters in plasma arc welding such as plasma gas flow rate, torch height, front weld width, back weld width etc. play an important role in the prediction of the weld geometry and quality. Several heat transfer models have been developed predict the Weld Geometry. The plasma arc welds showcase excellent mechanical properties. The wide range of applications of the plasma arc welding ranges from electronics to aerospace industries. This paper is literature review of various theoretical and experimental studies by different researchers over the years. A Section of the paper also deals with the comparative review of plasma arc welding with respect to other existing forms of welding processes, based on existing literature content.**

Keywords: Plasma Arc Welding, Arc efficiency, Weld Bead, Weld quality, Weld Geometry, Arc Efficiency, Process Parameters.

1.INTRODUCTION

Plasma arc welding (PAW) is an arc welding process similar to gas tungsten arc welding (GTAW). The electric arc is formed between an electrode (which is usually but not always made of sintered tungsten) and the workpiece. The key difference from GTAW is that in PAW, the electrode is positioned within the body of the torch, so the plasma arc is separated from the shielding gas envelope. The plasma is then forced through a fine-bore copper nozzle which constricts the arc and the plasma exits the orifice at high velocities (approaching the speed of sound) and a temperature approaching 28,000 °C (50,000 °F) or higher. Arc plasma is a temporary state of a gas. The gas gets ionized by electric current passing through it and it becomes a conductor of electricity. In ionized state, atoms are broken into electrons (−) and cations (+) and the system contains a mixture of ions, electrons and highly excited atoms. The degree of ionization may be between 1% and greater than 100% (possible with double and triple degrees of ionization). Such states exist as more electrons are pulled from their orbits. The energy of the plasma jet and thus the temperature depends upon the electrical power employed to create arc plasma. A typical value of temperature obtained in a plasma jet torch is on the order of 28000 °C (50000 °F), compared to about 5500 °C (10000 °F) in ordinary electric welding arc. All welding arcs are (partially ionized) plasmas, but the one in plasma arc welding is a constricted arc plasma. Just as oxy-fuel torches can be used for either welding or cutting, so too can plasma torches.

2.WORKING PRINCIPLE

Plasma Arc Welding (PAW) is a liquid state welding process in which the metal-to-metal joint forms in a molten state with the help of hot ionized gases known as Plasma. These hot ionized gases are used to heat the work plates, and the joint is created due to fusion. The plasma arc welding is method wherever a coalescence is generated with the temperature which is developed from a special setup between a tungsten alloy electrode and the water-cooled nozzle (Non transferred ARC) or between a tungsten alloy electrode and the job (transferred ARC). In this type of winding, there are three types of gas supplies being utilized namely plasma gas, shielding gas, and a back-purge gas. Plasma gas supplies throughout the nozzle turn into ionized. The shielding gas supplies throughout the external nozzle & protects the join from the environment. Back-Purge gas is mainly used when particular materials are being used.

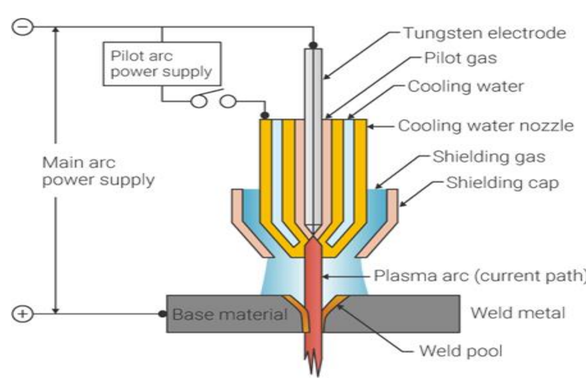

Fig 2.1 Schematic diagram of Plasma Arc Welding

3.MODES OF OPERATION

Three operating modes can be produced by varying bore diameter and plasma gas flow rate:

- Microplasma: 0.1 to 15A. The microplasma arc can be operated at very low welding currents. The columnar arc is stable even when arc length is varied up to 20mm.
- Medium current: 15 to 200A. At higher currents, from 15 to 200A, the process characteristics of the plasma arc are similar to the TIG arc, but because the plasma is constricted, the arc is stiffer. Although the plasma gas flow rate can be increased to improve weld pool penetration, there is a risk of air and shielding gas entrainment through excessive turbulence in the gas shield.
- Keyhole plasma: over 100A. By increasing welding current and plasma gas flow, a very powerful plasma beam is created which can achieve full penetration in a material, as in laser or electron beam welding. During welding, the hole progressively cuts through the metal with the molten weld pool flowing behind to form the weld bead under surface tension forces. This process can be used to weld thicker material (up to 10mm of stainless steel) in a single pass.

4.PLASMA ARC WELDING TYPES

Plasma arc welding is classified into two types such as,

1. Transferred PAW
2. Non-transferred PAW

1) Transferred *PAW*

The transferred PAW method uses direct polarity DC current. And in this method, the tungsten electrode can be allied to the –ve terminal and the metal can be allied to the +ve terminal. The arc produces among tungsten electrode as well as work portion. In this kind of method, both arc and plasma moved toward the work portion, which will enhance the heating capacity of the method. This type of PAW can be used to join solid sheets.

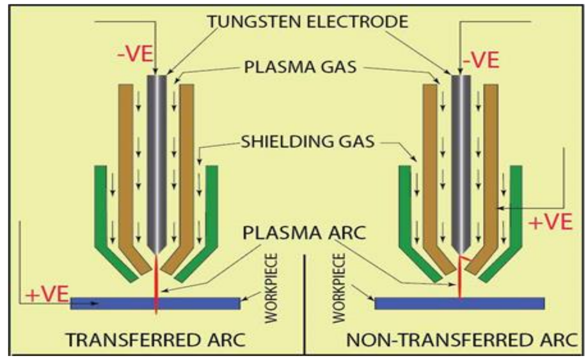

Fig 4.1 Diagram of types of Plasma Arc Welding

2) Non-transferred *PAW*

The Non-transferred PAW method used direct polarity DC current. And in this method the tungsten electrode can be connected to the –ve and the nozzle can be connected to the +ve pole. The arc generates among the nozzle as well as tungsten electrode within the torch, which will enhance the ionization of the gas within the torch. And the torch will transfer the ionized gas for further procedure. This type of PAW can be used to join thin sheets.

5.APPLICATIONS

- Microplasma welding

Microplasma was traditionally used for welding thin sheets (down to 0.1 mm thickness), and wire and mesh sections. The needle-like stiff arc minimises arc wander and distortion. Although the equivalent TIG arc is more diffuse, the newer transistorised (TIG) power sources can produce a very stable arc at low current levels.

- Medium current welding

When used in the melt mode this is an alternative to conventional TIG. The advantages are deeper penetration (from higher plasma gas flow), and greater tolerance to surface contamination including coatings (the electrode is within the body of the torch). The major disadvantage lies in the bulkiness of the torch, making manual welding more difficult. In mechanised welding, greater attention must be paid to maintenance of the torch to ensure consistent performance.

- Keyhole welding

This has several advantages which can be exploited: deep penetration and high welding speeds. Compared with the TIG arc, it can penetrate plate thicknesses up to l0mm, but when welding using a single pass technique, it is more usual to limit the thickness to 6mm. The normal methods is to use the keyhole mode with filler to ensure smooth weld bead profile (with no undercut). For thicknesses up to 15mm, a vee joint preparation is used with a 6mm root face. A two-pass technique is employed and here, the first pass is autogenous with the second pass being made in melt mode with filler wire addition.

As the welding parameters, plasma gas flow rate and filler wire addition (into the keyhole) must be carefully balanced to maintain the keyhole and weld pool stability, this technique is only suitable for mechanised welding. Although it can be used for positional welding, usually with current pulsing, it is normally applied in high speed welding of thicker sheet material (over 3 mm) in the flat position. When pipe welding, the slope-out of current and plasma gas flow must be carefully controlled to close the keyhole without leaving a hole.

6.LITERATURE SURVEY

[1] D. M. Evans, D. Huang et al (1998), conducted an experimental examination to identify the parameters on which the arc efficiency depended upon. A theoretical model was formulated to compare the results with the experimental answers in order compare the results, and understand how the welding current and voltage affected the heat transfer mechanism thus affecting the arc efficiency. The arc efficiency was measured from the PAW welds made on 6061 Aluminium plate. The arc efficiency was found to vary from 0.48 to 0.66. The arc efficiency was found to decrease with increase with voltage. The efficiency increased with the voltage due the increase in convection caused by the shielding gas used. The arc temperature did not vary with the welding voltage.

[2] Y. F. Hsiao, Y. S. Tang et al (2007), conducted an experiment to optimised processes parameter by applying the Taguchi method along with the Grey relational analysis. Whole the experiment carried out on 4mm thick SUS316 stainless steel plate. Optimal welding parameter is identified base on the undercut, root penetration and the welding groove width. The experimental result conclude that the welding current, welding speed, and plasma gas flow rate are primary factors that affect the welding quality of PAW, while torch stand-off is considered a secondary factor to improve welding quality and utilization of the optimal welding parameter combination enhances a significant improvement of the grey relation.

[3] Kondapalli Siva Prasada et al (2014), in the present study Austenitic stainless-steel sheets (AISI 304L, AISI 316L, AISI 316Ti, AISI 321) of 100 x 150 x 0.25 mm are welded autogenously with square butt joint without edge preparation. From the analysis of the weld quality characteristics, it is revealed that for the same thickness and same welding parameters, AISI 304L has achieved sound weld bead geometry, highest tensile strength and hardness. However, it is noticed that AISI 316L has attained lowest tensile strength, AISI 321 has lowest hardness and grain size. It means to get desired weld quality for different grade of steel plate we have to set different process parameter. There is no any particular formula to identify desired process parameter for different material have a different dimension. It is identify based on experimental study.

[4] Yajuan Jin, Ruifeng Li et al (2016), did similar study on process parameter to weld AISI 304L Stainless Steel and Galvanized Steel Plates. They study the effect of parameters on weld surface appearance, interfacial microstructure, and composition distribution in the joint. The results indicated that good appearance, bead shape, and sufficient metallurgical bonding could be obtained when the process was performed with a wire feeding speed of 0.8 m/min, plasma gas flow rate of 3.0 l/min, welding current of 100 A, and welding speed of 27 cm/min.

[5] Ramesh Kumar, Sandeep S et al (2018), investigated welding of dissimilar metal of austenitic-ferritic stainless steels. PAW has various process parameters in which three major parameter such as welding current, gas flow rate and welding speed is important to predict weld quality.

[6] Siva Prasad, Srinivasa Rao (2010) et al conducted an experimental investigation to understand the effect of various process parameters like welding current, torch height and welding speed on front melting width, back melting width and weld reinforcement of Plasma Arc Welding on Aluminium alloy is investigated by using standard statistical tool called the Response Surface Method. By experimental and theoretical investigations, it was concluded that, when the Torch height and welding speed were kept constant and when the welding current was increased, Front melting

width, Back melting width and weld reinforcement decreased Similarly when the welding current and welding speed were kept constant and the Torch height was increased, Front melting width and Back melting width increased, while weld reinforcement decreased. In another scenario where the welding current and torch height were kept constant and the welding speed was increased, then Front melting width and back melting width decreased whereas the weld reinforcement increased.

[7] Siva Prasad, Srinivasa Rao et al (2011), did a similar study on weld bead quality by using factorial design approach. In this study, two levels and four input process parameters were taken and experiments were conducted as per design matrix considering full factorial design. In this study the plasma gas flow rate was also include as one of the process variables. The results were similar to the previous experiment conducted. Though it was noted in the experiment that as the number of process variable increased the accuracy of the weld bead quality would also improve.

[8] Kondapalli Siva Prasad et al Prasad (2012), presented a detailed literature review on the advances in PAW, based on has survey earlier most of the works in Plasma Arc Welding and associated phenomena are towards modelling of plasma arc, temperature & heat transformation and process parameter optimization to get the desired weld quality. In most of the works welding current, arc voltage, welding speed, magnitude of ionic gas, torch stand of are considered for predicting and optimizing the weld bead geometry, many works were carried out on Stainless Steels, Aluminium, Nickel based alloys, Titanium etc.

[9] M. H. Park (2016) et al, investigated the relationship between the process parameters and the bead geometry in Plasma arc welding (PAW). The quantitative effect of process parameters on bead geometry was calculated using sensitivity analysis. Experimental result show that change of process parameters (variable parameter: welding current, welding speed and shielding gas) affects the bead width more strongly than bead height.

[10] Emel Taban, Alfred Dhooge et al (2009), conducted an experiment on 6mm thick modified stainless-steel plate weld by using PAW without filler metal and with filler metal (AISI 316L austenitic type of consumable filler wire). Photo macrography of weld bead with and without filler metal show in fig 4. It was noticed that hardness value at the HAZ is higher by using filler metal as compare to without filler metal.

[11] Birendra Kumar Barik, P. Sathiya et al (2014), investigate the mechanical and metallurgical properties of welds made AISI 410S plates of 6 mm thickness without filler metal. It was noticed that the higher tensile properties were obtained than the base metal and the impact energy value for welded joints is more than base metal at room temperature.

[12] S Mandal, S Kumar et al (2014), study investigates the role of thermal energy in deposition of thick layer of powder material by PTAW process Stainless steel plates of grade SS316 with size of length 150 mm, width 110mm and thickness 7 mm were used as substrate. Material powder of grade SS304L was used for deposition and conclude that the energy distribution between the powder and the substrate is found to be very important for continuous and thick deposition of powder materials with low dilution.

[13] Selva R Bharathi, S M Sadham et al (2014), investigate the effect of various welding process parameters on the weld ability of stainless-Steel specimens of grade 312 having dimensions 75mm× 55mm× 6 mm, by using SS316 powder form of filler metal and to optimised processes parameter by applying the L25 Taguchi method. Result conclude that by using powder form of filler metal welding defects like cracks which are eliminated to 100%, there is no lack of fusion in the welded portion and the gas holes or porosity on the weld are completely eliminated and welding penetration observed in 3mm.

[14] Shiming huang, daqian sun (2015) et al investigation carried out using powder as filler metal for coating on base metal for improving wear resistances, corrosive resistance property. The results indicate that the powder coatings have a full metallurgical bond in substrate interface.

7.CONCLUSION

Continuous experimental studies are going on the field of PAW, in order to optimize the process to extend the range of materials it can weld. It was understood from the earlier works that most of the works in plasma arc welding carried out to improve weld bead quality by changing process parameter such as welding current, welding speed, torch stand of distances etc. As from literature survey wire form of filler metal used in welding and powder form of filler metal used in coating purposed. Studies are being made in order to improve weld quality using powder as a filler metal in welding purposed and developed new technology powder plasma arc welding and characterised has mechanical and metallurgical property.

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