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PULSED METAL INERT GAS WELDING - AN OVERVIEW

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ABSTRACT

Pulsed inert gas welding process for metals is a popular state-of-art joining process being used for different engineering applications due to the associated benefit of lesser heat input and controlled rate of metal transfer in the form of pulsed-spray to the weld cavity in comparison to the conventional metal inert gas welding where heat input was in higher side with unrestrained spray transfer of weld metal. This review paper throws light on the process methodology, process parameters and variables along with applications and consolidation efforts undertaken by different researchers. Considering important process parameters; materials, modelling and simulation studies undertaken by authors based on numerical methods, Artificial Neural Network and Finite Element Method are reviewed and illustrated. With similar approach, selected experimentation studies are also reviewed and presented along with application on different material vis-a-vis process variables. The process is automated easily for least manual intervention to achieve consistent quality of products.

Keywords: *Pulsed-Metal Inert Gas Welding (P-MIGW), Gas-Metal Arc Welding (GMAW), Artificial Neural Network (ANN), Finite Element Analysis (FEA). Heat affected Zone (HAZ), Welding Procedure Specification (WPS).*

INTRODUCTION

In conventional MIGW process, weld metal transfer takes place under constant current and voltage i.e. higher heat input in the four type of metal transfer modes viz. Globular, Short-Circuiting, cold metal transfer and Spray type metal transfer. Conventional MIGW process is having some inherent dis-advantages like spattered bead, high heat input to the parent metal and associated losses. Pulsed Metal Inert Gas welding, a variant of the regular Metal Inert Gas weldment procedure in which the amplitude of the current is fluctuated for managing the rate of metal transfer at low average current levels by applying small duration high current which produces smooth and unspattered welding at currents of 50A to150A normally, which would otherwise be too low for all except dip transfer with its irregular transfer and associated spatter. The cycle consists of applying the repeated pulse current over a constant background current to achieve desired metal transfer i.e. size of droplet and detachment rate for smooth weld bead. Choice of pulsing factors for a specified wire feed rate is an intricate action. Pulsation amplitude and duration are functions of feed wire composition, dia and to a lesser extent, shielding gas consist.

Pulsed-MIG welding process is a time tested method of welding and a lot of work is already done by researchers in the simulation, modelling and experimentation of Pulsed-MIGW to establish the process parameters, their variables and effectiveness on different materials. This paper is an effort to consolidate the work done in the past on the process parameter and other variables of Pulsed MIG welding.

METHODOLOGY OF P-MIGW

In Pulsed Metal Inert Gas welding, fluctuation of current was introduced originally for controlling metal transfer at comparatively low average current levels by introducing small duration high current in between the cyclic process. The cycle consists of applying the repeated pulse current over a constant background current. In Metal Inert Gas Welding process, the molten weld metal is forced by the arc from the electrode end to the puddle in bulb like shape, spray type or short-circuiting type depending on the variables like welding current, used shielding gas and electrode chemistry.

The main parameters of MIG welding are related to pulsation of current based on the requirements of input variables like puddle size and shape, wire thickness, rate of metal deposition and speed of welding. The important advancement of pulsating process is that the higher current is supplied for a smaller period in which the wire material is melted and separated in globular form. Subsequently, a smaller current is supplied to propel the globular metal to the weld cavity.

In the FIG.1 shown above, the mechanism of the spray transfer of metal from the wire electrode in the droplet form to the weld cavity is represented. FIG.2 indicates the amplitude of current in the Current vs Time plot and correspondingly position of droplet detachment and propelling from the electrode in a pulsed MIGW process. The main features of this process is summarized as under;

a. Scattered metal transfer at lower average current level and reduced bulbous metal deposition.

b. Improved spray transfer process.

c. Pulsation decreases overall heat input and at the same time adequate metal transfer.

d. Better bead appearance by eliminating spattering.

e. Directional control as the weld metal cools in between pulsation and solidify quickly which reduces risk of unsmooth or an excessive curved bead.

PPARAMETRIC SSTUDY OF P-MIGW

Presently, use of an extended range of pulsating amplitudes, durations and wave shapes at frequencies from a unit to few hundred Hertz. Pulsating magnitude and timing are optimally combined to melt and move each droplet of the similar or slightly smaller size as compared to electrode wire. The square shape pulsating current Vs. Time plot is represented in FIG.3. Different variables of current and time associated with the PMIGW process to be fixed up for specific requirement of product.

Factors affecting choice of parameters of PMIGW has been studied by P.K. Palani et al. [1] and found that the Pulsed-MIGW is a method of spray transfer of metal in a controlled way. In this process the arc current is kept at a higher magnitude to expedite transfer of weld metal for long enough to initialize disconnection of molten metal in drop from wire electrode. When the drop shape weld metal is detached from the wire, the current is minimised to a comparatively lower magnitude to keep up the arc from propelling the droplet to the puddle. Variables of current pulses have a definite effect on the features of weldment like, constancy of the arc, weld excellence, bead look and bead profile. Achieving combination of parameters without a logical support is a matter of lower prospect because the complexity and correlation of the pulsed variables in the process. In a similar review consequence of study of pulsed variables on Weld Quality, Kamal Pal et al. [2] presented that the quality of weld evaluated by bead profile, micro-structure and other properties of the weld. In conventional MIGW produces coarse-grain microstructure, higher HAZ, and reduced depth of weld along with high underpinning reduces service life of weldment. Pulsed-MIGW is an improved method executed in a superior way to overcome the quality issues. In the process more peak current is applied to detach melted droplet during each pulse and a low remaining current to keep regularising the arc stability. As a result, current pulsating refines the grains in weld fusion zone and increased penetration of arc fluctuation. Best quality weld joint can be produced by optimising pulsing parameters.

EXPERIMENTAL STUDY OF P-MIGW

Wang et al. [4] in his study of metal transfer developed an un-isothermal numerical model for simulating transfer of metal in this process. Results with high-speed photography, laser based imaging and metallographic analysis is broadly in line with the practical process. Further they found that the taper formation on the electrode end at higher welding current is closely associated with heat energy input on the non melted part of the electrode and also the bulbous–spray changeover is because of the higher current, electro-magnetic squeeze force and the taper creation. Considered droplet shape consolidated for a peculiar detachment process in bulbous and spray modes are shown in the FIG.7 and FIG.8 respectively.

Spectroscopic study and analysis of PMIGW process by M E Rouffet et al. [5] presented that metal vapours are impacting effectiveness. He established that Iron is composed in the central part of plasma and the iron level increases quickly at the starting of the high-current pulse and reduces slowly when the central part widens. The minimum temperature profile becomes 8000 K to 13.000 K approximately in central and remaining areas. High percentage of iron and high radiation explain the shape of the obtained temperature profile. Gregor G¨ott et al. [11] shown that the light generated from the arc and analysed with spectroscopy and high-speed camera imaging for comparison. A conclusive remark about plasma arc and the droplet development is logical. Desired control on the power input may be kept in association with the spectral and local information about the plasma, accordingly, a spectral control unit is initiated.

Yangyang Zhao et al. [7] worked on the impact of pulsating variables on dynamic and heat transfer characteristics of drop by a numerical method subjected to the magneto hydrodynamic co-relations within the ambit of phase-field method. Pulses having more current but smaller timing resulted in increased elongation of drop shape pendent, previous disconnection, and increased velocity of the detached drop. However, more peak current only leads to a small increase in mean temperature of the disconnected drop dissimilar to drop velocity. The cause for this small increase is that value of joule heating enhances with the higher current only, whereas sheath heat and arc heating is being controlled by the mean current and remains nearly constant having difference in pulsating variables. Simulation results and elevated speed photographs exhibited conformity. S. KIM et al. [13] shown that the static force balancing modelling can forecast the drop dimension in transfer zone but deviates significantly in the spray transfer range. The reason behind this deviation may be the change in the geometry of the electrode as taper formation. M.St. Wêglowski et al. [14] investigated that the wire input rate and current has a noticeable influence on droplet dia, speed and rate of transfer. Sensitivity of this newly adopted procedure as per narrow band filter for scanning is very high for the changes in welding parameters and advised to be used as a tool. Kamal Pal et al. [12] presented the recorded arc sounds with current and voltage in time horizon and frequency horizon to compare with different process variables and modes of metal transfer. The most important difference of secondary arc sound frequency peak was found as a result of pulse shape change as seen in the outcome of frequency horizon study. Author also used arc sound to find out defects in welding.

Influence of protective gas on the structure of undercutting has been presented by Ran Zong et al. [8] using vision-base data aquiring systems to analyse the performance of droplet movement, arc profile and melt flow by changing used gas composition. Outcome of study shown that suppressed undercutting defect was primarily reduced backward flow-velocity of weld metal in pool because of the reduced arc force and drop impact force when CO2 composition enhanced to 100% from 10%. Dimensionless fitment procedure was followed to ascertain the correlation in weld variables and undercutting deficiencies. This study established that suitable pulsed current may arrest undercut and spatter having increased CO2 composition in used gas. Jianxiong Li et al. [9] in their work studied influence of position and angle of torch on product quality and consistency of process of welding. Results shown that shape of arc their macro and micro-structure and mechanical properties are influenced by torch position when work is at zero degree and travel angle of torch is 20°. However, when both the angles are twenty degree, the effect of torch aiming position is not significant.

MODELLING AND OPTIMISATION STUDY ON P-MIGW

Srinivasa Rao Pedapati et al. [15] experimented and analyzed using Taguchi method mathematical models to establish relation between welding process parameters with weld bead geometry. Important variables of process like, feeding speed of wire, thickness of part, pulsing frequency in Hz, current magnitude and welding speed are chosen for modelling with the help of several regression analyses. Outcome of study shown desirable accuracy and confirmation with experiments and established that such modelling can anticipate the bead geometry after checking process adequacy.

A 3D FEM model of pulsed AC type process have been presented by Kiran at al [16] to assess the shape and temperature sharing in the weld pool. The results shown desirable confidence level in modelling and experimental values of weld-width, penetration, and the heating cycles. They also observed that the temperature distribution in the region is as per Gaussian distributed heat source were in synchronization with the current waveform. Increased cooling rate in the weld pool resulted reduced bainitic phase and increased martensitic phase.

ANN model to predict joint strength has been presented by Sukhomay Pal et al. [17] using parameters like, peak and back-ground voltage, pulse duration, pulse frequency, wire feeding and welding speed. Root mean square (RMS) values of current and voltage are considered as input of the numerical model and the UTS of the work piece is taken as the output variable. The outcome of simulation shown that ANN model provided better confidence level when compared with the multiple regression analysis for welding strength. A dynamic modelling presented by LA Jones et al. [18] shown that dynamic model of drop disengagement at lower and medium current in the plasma riched with argon and similar experiments on axial magnetic forces is very low when compared with simulation results may be due to the hypothesis of internal flaws during development of droplet.

Optimisation of Parameters with a Neuro-GA Technique using genetic algorithm by minimizing objective function considering

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weld strength, bead geometry, distortion and deposition efficiency into the account for desired output quality presented by Surjya K Pal et al. [19] and observed that Neuro-GA technique is a potent tool in optimization of process in comparatively lesser experiments and variation in results was within 3% only. Taguchi orthogonal array method is used by S. R. Patil et al. [20] for optimization to improve weld strength and observed that speed of welding has high influence on weld joints strength in tensile mode. Parametric optimization by Using Factorial Design method is presented by Manoj Singla et al. [21] and found that process parameters has a bearing on the bead area to noticeable level in which welding current was most bearing variable to welds made using negative polarity electrodes with a small diameter electrode, long electrode, low voltage and low welding speed which produces large bead area.

Similar works to optimize quality parameters using grey-based Taguchi method has been presented by Surjya K. Pal et al. [22] and observed that the pulse voltage and frequency are the most significant factors who affect the weld quality whereas another factors contribution can also not be neglected. Wire feed rate for welding of Al sheets is optimized by H.J. Park et al. [23] and noticed that best quality weld is achievable with 0.5 m/min, 1.0 m/min, and 1.5 m/min welding speed.

CONCLUSIONS

In this review study, the well taken fact is that the pulsed MIG is one of the reliable and time tested methods of welding of metals. Many remarkable works have been done in different sub-domains of GMAW process and optimizations and atomization of the processes for different type of applications are done. The important conclusions drawn are:

i. Quality of welds may be optimized by proper selection and regulation of process parameters like, pulsed current and voltage, welding speed, wire feed rate and shielding gas etc. and is achievable in State-of-art Pulsed-MIG.

ii. Modelling, simulation and optimization studies are successfully done to review and redesign the process parameters to improve overall product quality using Numerical methods, ANN, FEA etc.

iii. Experimental modelling with pre-defined boundary conditions and welding parameters shown matching results with simulation modelling up to the desired confidence levels.

iv. Lower heat affected zone (HAZ), higher production rate (welding speed), instantaneous overlapping beads, easy atomization and welding on dissimilar materials are the encouraging features of the Pulsed-MIG process and is being used predominantly with materials like steel, Aluminum, tungsten and magnesium etc.

v. Automation and implementation of Robotics with least manual intervention is comparatively easier in Pulsed-MIG for achieving consistent quality level and there is noticeable scope with specific requirement of materials for research and development.

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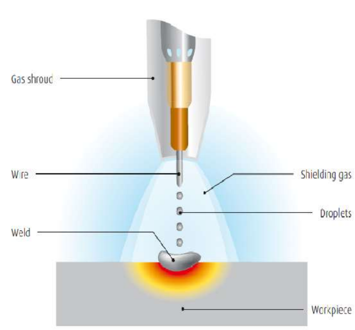

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FIG.1, *Schematic of Spray Transfer [24]*

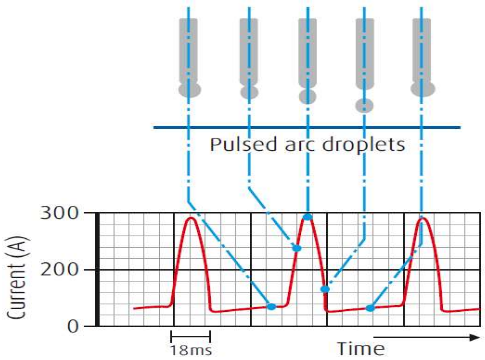

FIG.2, *Droplet Transfer System [24]*

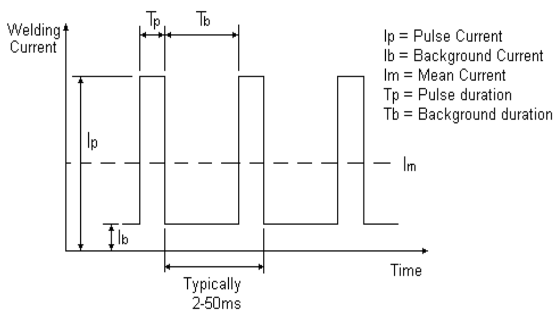

FIG.3, Pulsating Current Wave Representation

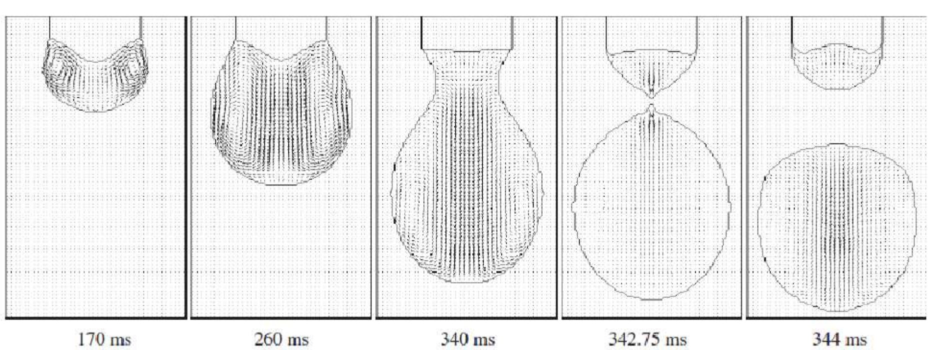

FIG.7, Predicted droplet profile, melting interface, and velocity field in globular transfer mode

(1.6mm wire, 175 A, 22V, 95 ipm or0.0402ms−1, argon) [4]

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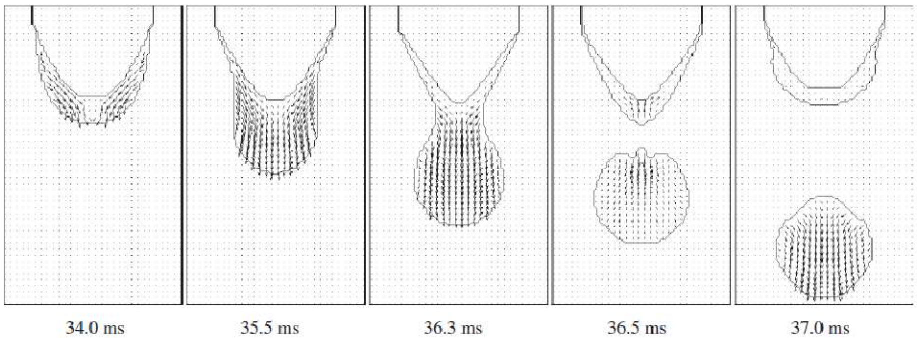

FIG.8, Predicted droplet profile, melting interface, and velocity field in spray transfer mode

(1.6mm wire, 350 A, 30.5V, 218 ipm or0.0925ms−1, argon) [4]