Simulation of Plasma Arc Welding Process and Influence of its Parameters on Weld Pool Quality

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Abstract- *Plasma arc welding is a widely used industrial process for welding of different types of metals in several operating conditions. PAW is considered as a challenging technology compared to its main competitors: TIG and MIG in particular to weld parts from micro level upto 10mm. The work focuses on weld quality of Spot PTAW process in manufacturing of GLOW PLUG. The paper describes the process parameters of the PAW process. The simulation studies carried out to determine the influence of process parameters like Plasma gas, Shielding gas, Electrode life, Current, Welding cycle time and voltage in spot PTAW. The modelling is carried out with dimensions taken from a Plasma torch (MIG-O-MAT spot PTAW system) in 1:1 scale for simulations and study of change in parametric values that influence the outcome of the welding quality. Conclusions are drawn based on the Simulation results.*

Keywords- PAW, PTAW, Micro-welding, MIG-O-MAT, Spot, Plasma Gas, Shielding Gas, Electrode, Shear Stress, Heat Flux and Velocity.

NOMENCLATURE

PAW	Plasma Arc Welding
PTAW	Plasma Transferred Arc Welding
DCEN	Direct Current Electrode Negative
OMA	Optical Multichannel Analyzer

I. INTRODUCTION

In the work carried out we use Transferred arc type of Plasma arc welding (PTAW) i.e the circuit is formed between the electrode (-) and the work piece (+). In PAW Process the electrode (Tungsten) is positioned within the body of the torch and a plasma arc is formed and separated from the Shielding gas which envelopes the weld pool. The plasma formed is forced through a copper nozzle which constricts the arc resulting in high velocity plasma, increased energy density, reduced cross section and temperature of arc close to 25000 °C [10]. These variations of arc due to its parametric values is simulated using ANSYS WORKBENCH CFX model and results are concluded. In this work we concentrate to study the effect of various parameters of PAW, influencing the weld quality. The parameters considered in the study are Plasma Gas, Shielding Gas, and Electrode. 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 [6]. Argon is suitable as the orifice and shielding gas for welding all metals [6], hence the pure argon gas at 0 °C and its properties is used for simulating a CFX model. The schematic representation of PAW with important components is shown in figure 1.

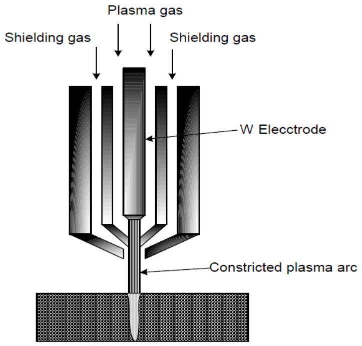


Figure 1: Schematic of PAW system showing important components

In this study a constant current type power source with DCEN polarity has been considered. The DCEN used as the tungsten electrode has a good electron emitting capability and is therefore made cathode and workpiece as anode to complete the circuit. Further, DCEN polarity causes less thermal damage to the electrode during welding as about one third of total heat is generated at the cathode and balance two-third of arc heat is generated at the anode side i.e. work-piece. At a micro level PAW, due to variation in system setup and parameters used, there is a probability of the weld pool generation at an angle which results in cross welding of the part and also the weld surface has a dimple (concave surface) at the axis of the weld pool recorded in real time manufacturing. Therefore simulation studies are carried out w.r.t electrode behaviour, flow analysis of plasma gas to understand the gas flow causing the defects.

II. SIMULATION STUDY

A computer simulation is an attempt to model the real-life or hypothetical situation on a computer which helps to study how the system works under the changing variables and hence the behaviour of the system can be predicted. It is a tool to virtually investigate the behaviour of the system under study [11]. Figure 2 shows the behaviour of tungsten electrode failure / detoriation pattern during production. The simulation studies in the present study aim at simulating the rate of heat transfer in an Electrode and also flow analysis of the plasma gas in the torch.

Fig 2: Electrode failure

III. ELECTRODE BEHAVIOUR

The plasma arc is formed from a sheath region as described by Michael Schnick [8]as shown in figure 3. The arc column can be described by Local Thermaldynamic Equilibrium (LTE); this allows describing all thermodynamic and transporting properties of the fluid as functions of temperature and pressure. J. F. KEY, et al., [5] have conducted experiments on electrode tip geometry by scan patterns. The arc was positioned on the slits as shown in Fig 4. The optical multichannel analyzer (OMA) scans a given slit in a sequential series of tracks and the profile of the arc is recorded as shown in the figure 4. Therefore in arc welding, the arc does not start from the tip of the electrode but it starts from the sheath region and also the rate of plasma gas flow and current used determines its arc pool characteristics.Hence, the modelling of the electrode in this study is carried out with the above data being divided into two parts, one electrode tip from where the actual arc is generated and two, the electrode trunk which is the remaining portion of the electrode.

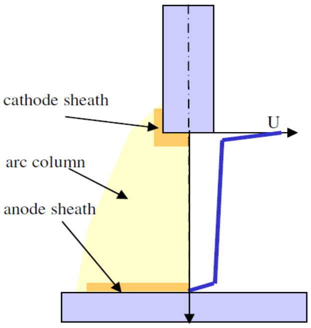


Fig 3: Discharge region [20]

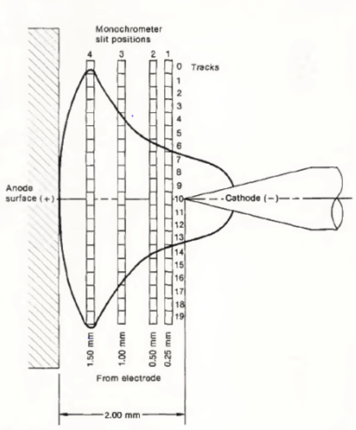


Fig 4: Arc Scanning Matrix

3.1 Modelling of the electrode

The electrode consists of the electrode truncated part as in fig 5 and the electrode tip as in Fig 6. This kind of construction is needed, as the welding arc is formed in the sheath region and the plasma temperature is subjected only at the electrode tip as it forms from the cathode sheath region.

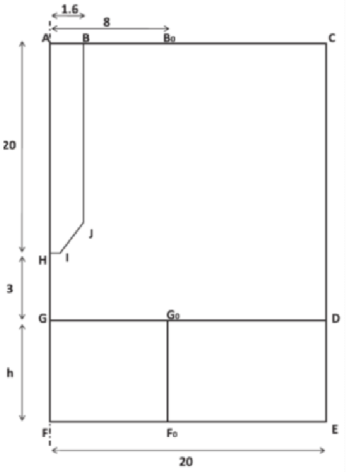


Fig 5: Electrode Trunk construction

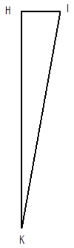


Fig 6: Electrode tip (sheath region)

In the figure 5 the radius (diameter = 2*radius) of the electrode is 1.6mm represented by AB, length of the electrode 20mm by AH, the region till Bo represents the Plasma Gas flow area, the boundary till CD represents the Shielding Gas flow and the area GDEF’ represent the area of the work piece (Anode). The area HIK is the electrode tip which comes in the cathode sheath region of the plasma arc welding process. The length of the tip HK is 3mm with an angle <IKH = 10^0. The Electrode model is constructed in the ANSYS WORKBENCH software and Meshed as shown in figures 7 & 8.

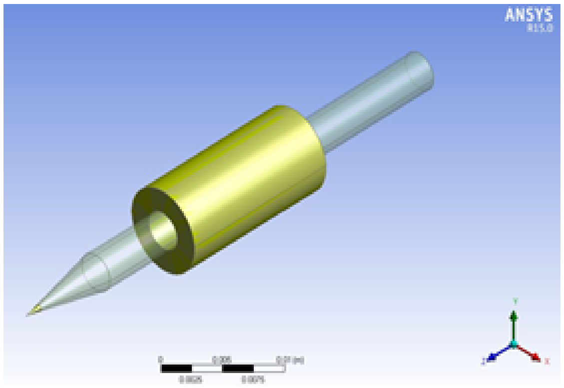


Fig 7: shows the isometric view of the electrode

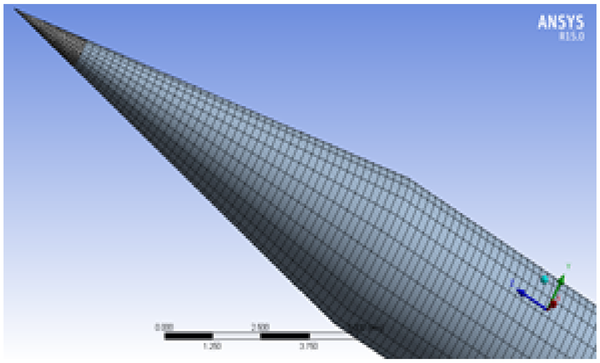


Fig 8: Electrode Mesh

3.2 Temperature Analysis

Anthony B. MURPHY [2] applied dynamic modelling techniques to simulate arc welding. The study results in a temperature of 17000K by using pure argon gas and 2000K at the work piece end with an arc gap of 5mm. Takuya Shimokura [3] simulated the temperature distribution of plasma arc welding and found the working temperature of plasma 20000k and 6000K at the work piece with an arc gap of 3mm. S. S. GLICKSTEIN [4] conducted experiments on Temperature Measurements in a Free Burning Arc and found that the temperature was 11,000 K near the cathode and approximately 8,000 K toward the anode. The maximum temperature at the tip of the electrode in the analysis is considered to be 15000K after interpolation as a lower current is used compared to the above work as the welding in present case is micro level plasma welding. The temperature of plasma arc is 15000K but the accurate temperature at the tip of electrode surface is in little excess of 3000°K after conduction. The temperature of PAW in different zones is represented in figure (9).

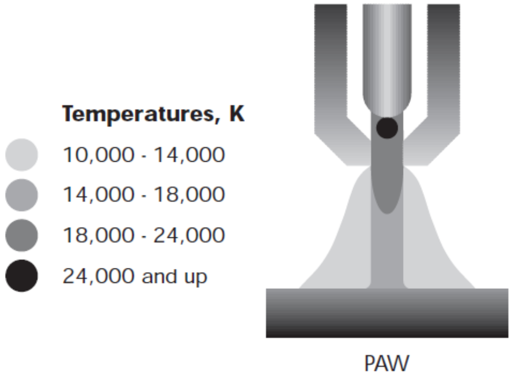


Fig 9: The temperature of PAW in different zones

The electrode in this case is setup by subjecting it to a temperature of 3000K at the electrode tip, the electrode trunk is under convection coefficient because of the plasma gas flowing at a temperature of 0^0C and the ceramic tube which is used for cooling is maintained at different temperatures 18^0C, 11^0C and 5^0C (Coolant temperature) respectively. The convection coefficient is calculated to be 1.0334W/m^2 ^{0}C with heat transfer coefficient (h) calculated from the Nusselt Number equal to 42.83 for argon gas at 0^0C. The total heat flux at 11^0C is represented in the figures 10.

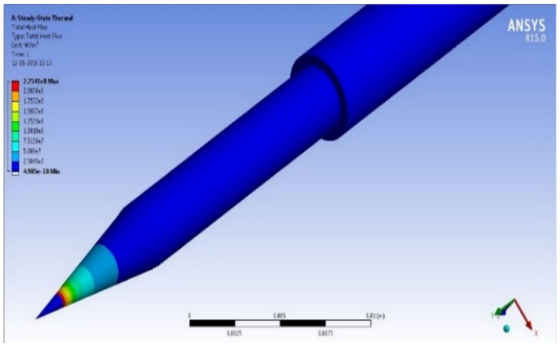


Fig 10: total heat flux with coolant at 11^0C

3.3 Results and Discussions

The simulation result of the total heat flux is shown in the figure 10. The amount of heat flux removed per square area (in mm^2) increases by increasing the refrigeration or decreasing the coolant temperature. The amount of heat removed directly depends on the refrigeration and it can be seen in the simulations. Thus by decreasing the coolant temperature and maintaining it at right temperatures continuously during the working conditions will help prevent the electrode failure from shocks, burr formation and decolourization. Therefore concluding the total heat flux removed from the electrode strongly influence electrode life in production [2].

V. SIMULATION OF PLASMA GAS FLOW

The observations during the system study has given to an understanding that the plasma gas influences directly the shape of the profile and the depth of penetration.

High Plasma Gas Volume = High Pressure on the Welding = Deep Penetration

Hence the simulations were carried out in Ansys CFX to understand the flow pattern of the plasma gas through the torch.

4.1 Modelling And Boundary Setup of Plasma Torch

The Plasma torch is constructed with special grid for modelling a PAW process with the aim to evaluate the plasma gas flow. Areas that are relevant for the gas flow have to be very fine [1] and are considered as shown in the fig 11.

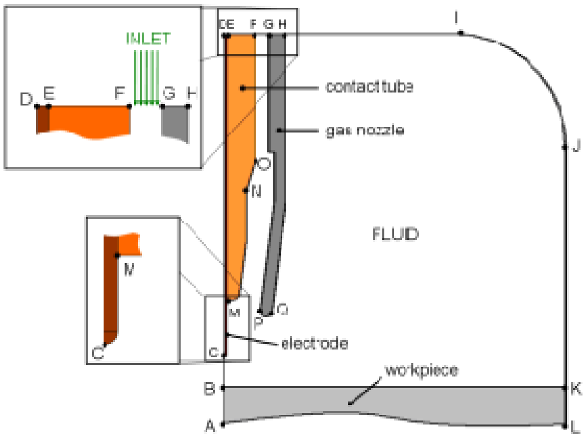


Fig 11: Model of a PAW torch [1]

In the figure 11, area between the points F and G is the inlet area of plasma gas. The plasma torch is modelled with dimensions measured directly from the actual working torch with 1:1 ratio. The plasma torch model is constructed in the Ansys Work Bench software considering the areas that are relevant to the flow of plasma gas. The 3D view of the torch is shown in figure 12. The boundary setup with K-epsilon (k-ε) turbulence mode; Continuous fluid flow and Non buoyant model with reference pressure 3.5 bar as in fig 13.

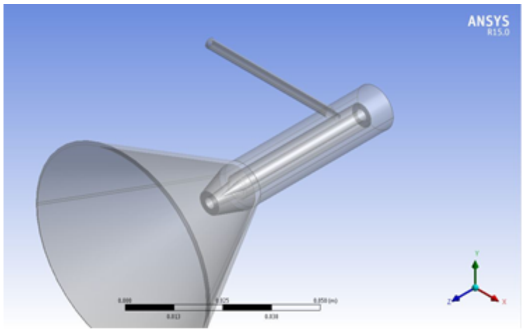


Fig 12: Plasma torch model

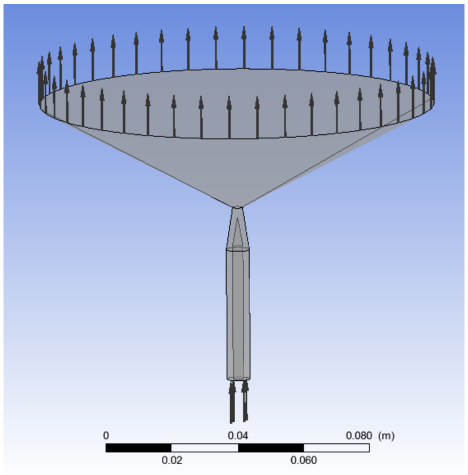


Fig 13: Boundary conditions

4.2 Simulations of Plasma Gas Flow with Different Electrode Angles

After setting up the boundary conditions, the influence of Electrode angle on the discharge of the plasma gas is simulated with different angles 20^0, 22^0, 25^0, 27^0, 30^0, 32^0, 45^0, 60^0. The simulations results with variations are tabulated in table 1.

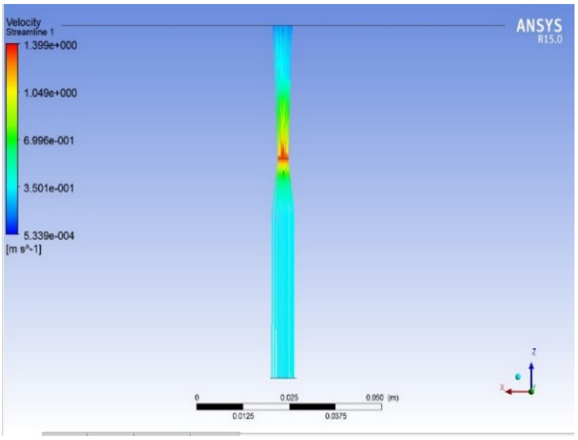
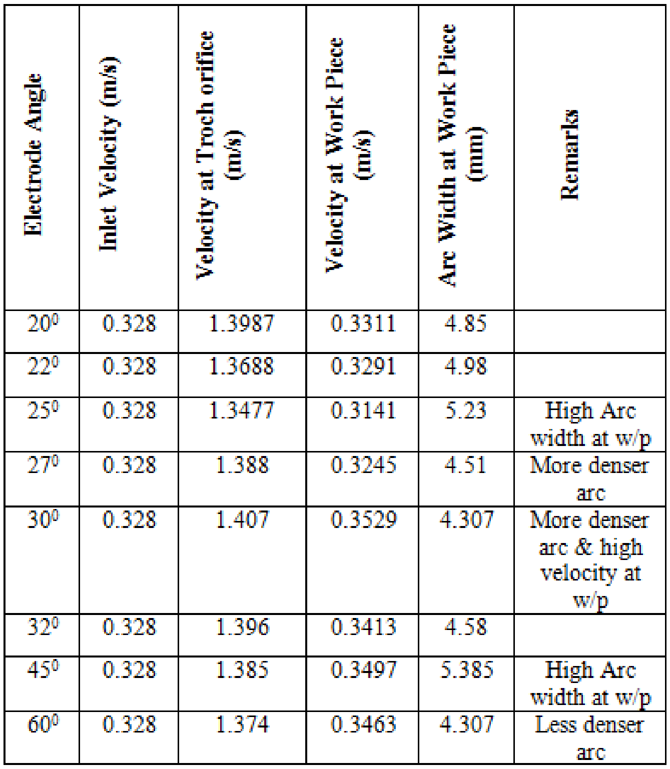


Fig 14: Simulation of Plasma Gas through an Electrode angle 20^0

Table 1: Tabulated results of plasma flow from the simulation



Electrode Angle	Inlet Velocity (m/s)	Velocity at Troch orifice (m/s)	Velocity at Work Piece (m/s)	Arc Width at Work Piece (mm)	Remarks
20^0	0.328	1.3987	0.3311	4.85	
22^0	0.328	1.3688	0.3291	4.98	
25^0	0.328	1.3477	0.3141	5.23	High Arc width at w/p
27^0	0.328	1.388	0.3245	4.51	More denser arc
30^0	0.328	1.407	0.3529	4.307	More denser arc & high velocity at w/p
32^0	0.328	1.396	0.3413	4.58	
45^0	0.328	1.385	0.3497	5.385	High Arc width at w/p
60^0	0.328	1.374	0.3463	4.307	Less denser arc

4.2.1 Results and Discussions

From the above results, the electrode angle with 30^0 has a denser and constricted arc with higher velocity at orifice which will help in increasing the welding profile depth and the increased axial velocity has a strong influence on the arc pressure and shear stress [2]. The difference in electrode angle from 20^0 to 30^0 in a plasma torch with all other parameters constant will develop higher rates of arc velocity at orifice at 30^0 and helps to operate the process at lower discharge rates, saving the cost of the fluid (Plasma gas) used. The rate of velocity of the Plasma gas has high influence in determining the characteristics of the weld pool.

4.3 Case 2: Simulations of Plasma Gas Flow with Different Discharge Rates

After setting up the boundary conditions, the influence of Plasma gas flow rate is simulated with different discharges 0.3l/min, 0.4 l/min, 0.5 l/min, 0.6 l/min and 0.7l/min. The simulations results with variations are shown in table 2.

4.3.1 Results and Discussions

From the above results, the discharges of 0.6l/min and 0.7l/min has a denser and constricted arc with higher velocity at orifice which will help to increase the depth of the weld profile and also influence in generating a dimple (concave surface in axis). This increase in flow and pressure of the plasma gas directly influences on increase in shear stress and dimple formation. Therefore it's required to be validated by experiments and set the required flow rate to match quality.

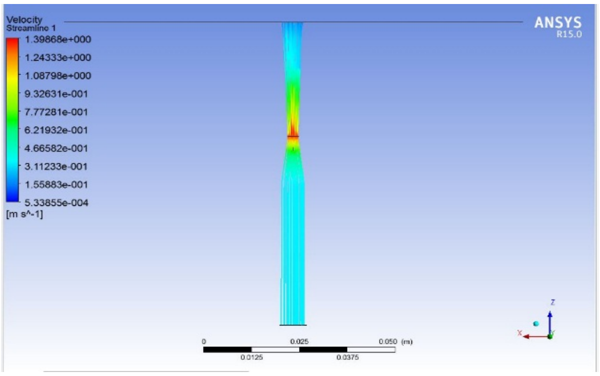
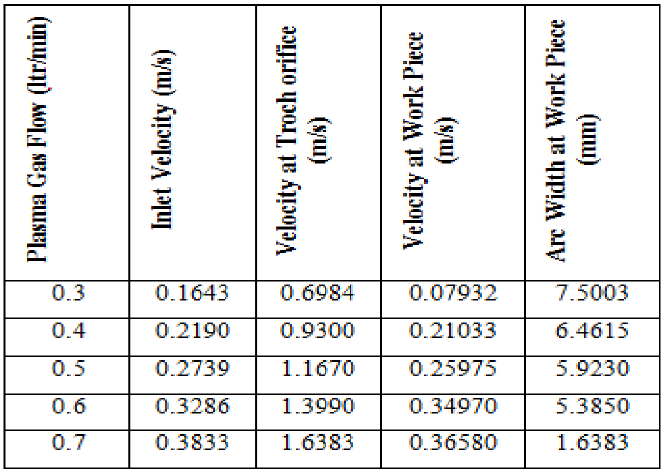


Fig 15: Simulation of Plasma Gas at 0.6ltr/min

Table 2: Tabulated results of the Plasma gas with different discharges



Plasma Gas Flow (ltr/min)	Inlet Velocity (m/s)	Velocity at Troch orifice (m/s)	Velocity at Work Piece (m/s)	Arc Width at Work Piece (mm)
0.3	0.1643	0.6984	0.07932	7.5003
0.4	0.2190	0.9300	0.21033	6.4615
0.5	0.2739	1.1670	0.25975	5.9230
0.6	0.3286	1.3990	0.34970	5.3850
0.7	0.3833	1.6383	0.36580	1.6383

V. VALIDATION OF SIMULATION RESULTS

The results obtained from the Simulations is validated on spot PTAW, MIG-O-MAT system and have concluded that the results for a plasma flow rate 0.55 l/min, shielding gas 6 l/min, welding cycle time of 500ms, current 43A and electrode angle 27^0 has resulted in a good quality weld with in a cross section of 5mm diameter without dimple and electrode life of 5000 cycles.

VI. RESULTS AND DISCUSION

The change in the shape of the electrode has an effect on the heat distribution and current density with respect to the workpiece i.e. the change in cross section of the electrode tip directly influences on the heat distribution and the current density decreases with increase in included angle, a narrower arc is generated. The change in electrode angle also influence strongly on the arc pressure and shear stress i.e. by change in electrode angle the velocity of the plasma gas changes and from simulations it is been found that the maximum velocity is obtained for an electrode angle 30^0. These properties will affect the shape of the weld pool and depth of penetration with boundary conditions.

The weld pool is formed based on the four important parameters at the interface of the plasma Arc and workpiece. They are Heat Flux, Current Density, Shear Stress and Arc Pressure. The depth of the weld pool depends on the amount of heat flux transferred from the arc to the weld bead. Therefore by controlling the heat flux i.e current and welding time we can control the weld pool depth. The heat flux is dependent on two factors: Electron heating and Thermal Conduction. Electron heating which is directly proportional to electron current density, which is approximately equal to the total current density. Hence it is concluded that the current density influences the weld pool depth via heat transfer. The increase in Shear stress, influences on the outward flow of the material near the weld pool axis on the surface of the weld pool which results in a shallower weld pool i.e in the thesis addressed as DIMPLE. This is controlled by controlling arc pressure. Therefore, the arc pressure should be controlled in such a way, it will result in minimum surface curvature on the weld pool. Thereby concluding the primary reason for the Dimple formation on the weld pool and by controlling the Arc Pressure and Current Density the Quality of the weld part is achieved.

VII. CONCLUSION

The Simulation results show the fluid flow analysis of Plasma Gas and the Shielding Gas with different boundary conditions, to be well constricted for a welding cross-section of 5mm diameter. The change in the welding profile and dimple formation can be addressed by controlling the axial velocity of the plasma gas and Current. The heat flux in the arc region on the surface of the electrode can be reduced by maintaining lower coolant temperature and increasing the angle of the electrode (increases the conical cross sectional area at tip) which help the electrode to perform over longer cycle without failure. Therefore it is concluded that by change in electrode angle from 20^0 to 30^0 the electrode life also increases and velocity required can be obtained at a lower discharge rate, thereby saving cost of fluid. The experiments were conducted and validated for the simulation results. The Plasma gas, Current and Welding Cycle Time are determined as the key parameters and the best combination of parameters can be obtained through experiments which help in optimizing parameters and produce a good quality.

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