ISSN: 2633-4828 Vol. 5 No. S6, (Oct - Dec 2023)

International Journal of Applied Engineering & Technology

EXPERIMENTAL INVESTIGATION AND PARAMETRIC ANALYSIS OF PLASMA ARC MACHINING: A COMPREHENSIVE REVIEW

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ABSTRACT

This comprehensive review paper investigates recent advancements in the field of Plasma Arc Machining, with a specific focus on the innovative application. The paper provides a detailed analysis of the Plasma Arc Machining. Notably, the review underscores the cost-effectiveness and ease of use associated with these methods. Plasma arc Machining process is frequently used to cut stainless steel, alloy steel, aluminum and other materials. The experiment will be performed to investigate the effect of different process parameters on the different responses while using Plasma Arc Machining. It will explore the applicability of Plasma Arc Machining process for machining of Industrial Materials. Mathematical models will be developed using the experimental data for Responses. Effect of different components with respect to design aspect & Cost Analysis will be investigated.

Index Terms- Plasma Arc Machining, Optimization, Mathematical Models, Cost Effectiveness

INTRODUCTION

When a flowing gas is heated to a sufficiently high temperature to become partially ionized, it is known as ‘plasma’. This is virtually a mixture of free electrons, positively charged ions and neutral atoms.Plasma arc machining is a metal removal process in which the metal is removed by focusing a high-velocity jet of high temperature (11,000°C to 30,000°C) ionized gas on the work piece. PAM is one thermal energy based advanced machining process. Mechanism of material removal in PAM is a combination of (i) vaporization & (ii) blowing away in molten state. A jet of hot plasma is used to supply heat for material removal. Material removal takes place in fused and vapor form. PAM process is associated with excessive thermal damage of the work piece.It is almost equally effective on any metal, regardless of its hardness or refractory nature. There is no contact between the tool and work piece, only a simply supported work piece structure is enough. This is chiefly used to cut stainless steel and aluminum alloys. Profile cutting of metals and alloys has been the common commercial application of PAM. [1]

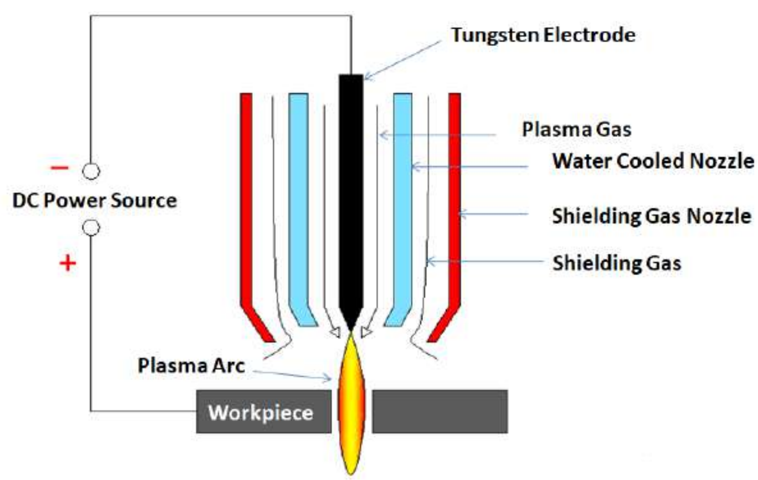


Figure 1: Plasma Arc Machining Schematic [1]

LITERATURE SURVEY

Influence of technological factors on roughness parameters Ra of the steel surface ISO Fe510 have been evaluated using planned experiments. Using factor experiment 24, the significance of the four process factors: plasma burner feed speed, plasma gas pressure, nozzle diameter, distance between nozzle mouth and material have been observed. Regression models obtained by multiple linear regression indicates the quality level as observed factors function.[2-3]

Synthesis of silicon carbide has been carried out using thermal plasma processing technique using SiO_2 as the solid feed and CH_4 as the gaseous reducing agent. Thermochemical calculations have been performed varying the molar ratio of silicon dioxide and methane to determine the feasibility of the reaction. Experiments using a molar ratio of SiO_2:CH_4 equal to 1:2 produced maximum yield of SiC of about 65 mol % at a solid feed rate of 5 g/min. mostly spherical morphology with some nanorods has been observed. The presence of Si had been observed and was quantified using XRD, HRTEM, Raman spectroscopy and X-ray photoelectron microscopy (XPS). Si acts as a nucleating agent for SiC nan rods to grow. [4-5]

The temperature of the plasma arc melts the metal and pierces through the work piece while the high velocity gas flow removes the molten material from the bottom of the cut. PAC of mild steel thin plates of 10 mm through a KALI-100 Plasma Arc Cutting Machine is operating in the range 25-120 A. The air is used as plasma gas as well as secondary gas. [6-7]

Automated plasma cutting is an effective process for building complex two-dimensional metallic parts in a short period of time. Because the plasma cutting machine has several factors or input variables to control (e.g., current, cutting speed, torch height) and a variety of part quality characteristics or response variables to satisfy (e.g., flatness, clean cut, bevel angle), it is very difficult to find an overall optimum machine setting. In this research, response surface methodology and desirability functions are used to simultaneously optimize 18 part quality characteristics. Final results identify an optimal machine configuration that facilitates the fabrication of parts with close-to-perfect quality for all responses considered. [8-9]

Transferred arc plasma torches are widely used in industrial processes for cutting of metallic materials because of their ability to cut a wide range of metals with very high productivity. The process is characterized by a transferred electric arc established between an electrode inside the torch (the cathode) and another electrode, the metallic work piece to be cut (the anode). In order to obtain a high-quality cut and a high productivity, the plasma jet must be as collimated as possible and must have the higher achievable power density. Plasma modelling and numerical simulation can be very useful tools for the designing and optimizing these devices, but research is still in the making for finding a link between simulation of the plasma arc and a consistent prevision of cut quality. Numerical modelling of the behavior of different types of transferred arc dual gas plasma torches can give an insight on the physical reasons for the industrial success of various design and process solutions that have appeared over the last years. Diagnostics based on high speed imaging and Schifrin photography can play an important role for investigating piercing, dross generation, pilot arcing and anode attachment location. Also, the behavior of hafnium cathodes at high current levels at the beginning of their service life can been experimentally investigated, with the final aim of understanding the phenomena that take place during those initial piercing and cutting phases and optimizing the initial shape of the surface of the emissive insert exposed to plasma atmosphere. [10-12]Unevenness can be obtained as a result of an experimental investigation aimed at selecting the proper values of process parameters of PAC system. Results of this screening step are analyzed by means of the Analysis of Variance (ANOVA) technique with use of design expert 8.0.7.1 software in order to clearly identify the main parameters, which define the unevenness quality attribute. The operating conditions have been carefully optimized through parameters adjustment like cutting speed, plasma gas and arc voltage in order to obtain good surface quality for all the sides of Hardox-400 plate. [13-14]

Air as a plasma-forming cutting gas is a natural mixture for molecular gases (78% nitrogen and 21% oxygen) and together with the obvious economic advantages it is also characterized by high thermophysical parameters. The possibility of application of APC is predetermined by the development of thermochemical cathodes, resistant in a corrosive oxidation medium. The operating mechanism of the thermochemical cathodes is determined by the formation during interaction of zirconium (hafnium) with air in the processes of combustion of the arc of a refractory film of zirconium nitride and zirconium dioxide (hafnium) at the end of the active insert, pressed into the copper holder. The film, formed at the end of the insert, is characterized by high emission properties and, consequently, high values of melting and boiling point and this ensures stable existence of the air plasma arc on the cathode support spot. [15-17]

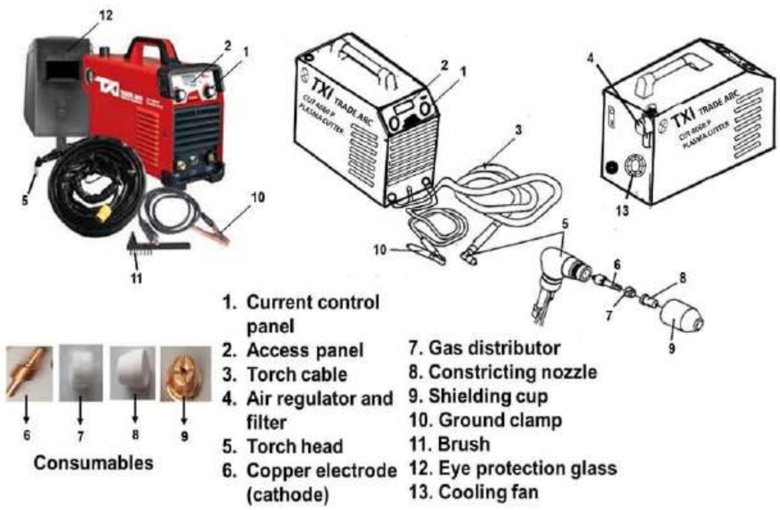


Figure 2: Plasma Torch& Power Supply [2]

The cutting method in CNC plasma machines is a thermal processing method that uses plasma (an ionized and electrical transmitter gas transfer media) transferring electrical energy from the power supply to the material to be processed, as directed by the torch and under the shielding of substitute gases. This method was developed as a branch of Tungsten arc welding in 1957 (Gas Tungsten Arc Welding (GTAW)) and has reached until today owing to improvements made in time related to the cutting quality, system safety, and consumption of consumables. This method allows materials with different thicknesses to be cut at different speeds, amperes, and arc voltages. The cutting quality and equipment efficiency depend on the plasma torch. The task of the torch is to generate a constant and geometric plasma ray and to transmit the ray to the piece. The torch is located to the end of the hose package and is controlled with the current generator. An electrode, a shield, a nozzle, a gas ring, a swirl ring, and a shield cup are the consumables on the axis of a torch. [18-20]

The experiments are conducted by using Taguchi L9 orthogonal array method and analysis was done by Minitab 17 software. Taguchi method, Signal to Noise (S/N) ratio between the input parameters and output responses are also predicted in this paper. Optimization results have been determined with the help of main effect plot and ANOVA table. ANOVA results presented that the pressure of gases and speed of nozzle are significant parameters for minimizing Kerf as well as for maximizing Penetration.[21-23]

Comparison of Input Parameters used by Researchers

Input Parameter	No. of times studied by Researchers
Arc Current	[1][2][3][5][7][9][10][12][13][14][17][20][21][23][25][30][31][33][34][35][36][37][46]
Cutting Speed	[1][2][3][4][5][6][11][12][13][15][18][20][21][23][25][26][31][32][35][36][37][38][39][40][42][48][49][50][51]
Gas Pressure	[2][3][4][5][6][10][12][14][15][19][20][26][35][39][50]
Stand Off Distance	[3][7][13][14][17][21][23][30][33][45]
Arc Voltage	[16][17][19][28][32][42][43][47]
Thickness of Material	[24][41]
Plasma Gas Mass Flow	[43][49]
Shield Gas Mass Flow	[7]
Molar Ratio	[18]
Reverse Current Polarity	[22]
Mixed Gas Supply	[22]

Comparison of Response Parameters used by Researchers

Response Parameter	No. of times studied by Researchers
Material Removal Rate	[1][3][5][6][11][12][13][15][18][20][21][26][31][32][35][36][37][38][39][40][48][49][50][51]
Surface Roughness	[1][3][5][6][10][11][14][16][18][20][21][26][27][28][31][32][35][36][37][38][39][40][42][48][49][50][51]
Heat Affected Zone	[4][6][10][11][14][16][18][26][27][28][31][35][36][42][48]
Time of Cut	[4][33]
Kerf Width	[7][8][9][11][14][20][21][24][27][41]
Kerf Taper	[10][12][16][24][34][38][45]
Temperature of HAZ	[2][23]
Expenditure	[22]
Hardness Properties	[25][43]

Comparison of Materials used by Researchers

Materials	No. of times used by Researchers
Stainless Steel	[1][2][3][4][5][6][11][12][14][20][21][23][25][27][30][31][32][35][36][37][39][41][42][44][45][47][49][51]
Mild Steel	[7][8][13][15][19][24][26][28][29][33][34][38][40][43][46][50]
Aluminum & Nickel Based Alloys	[9][10][16][17][18][22]
Composite Material	[48]

Various Materials used for Experimentation by Researchers

Ferrous Materials

Mild Steel
- Hardox-400 metal plate
- S235 material
- AISI 1017 Steel
- EN31 Material
- EN8 (AISI 1040)
- EN-45A
- IS 2062 E250 BR

Mild Steel
- EN 8 Steel Plates
- E250 Mild Steel plate
- AISI 1018
- AISI 1043
- ST37 plates
- S235JR
- St-52 Structural steel

Stainless Steel
- SS 316L
- AISI 304
- St 52 carbon steel
- SS321
- SS410 Material Plates
- AISI 206
- SS316L
- EN 10025
- SS410

Non Ferrous Materials

Aluminum & Nickel Based Alloys
- AA6061-T6
- AA5754
- Aluminum5083
- Aluminium Alloy 6082 plates
- Monel 400™ super alloy (Nickel-based)

Various Methodology adopted by Researchers

Methodology	No. of times used by Researchers
Box Behenken Design	[1]
Taguchi Method	[2][4][7][8][11][13][14][20][21][23][24][28][31][32][35][36][37][38][43][47][49][51]
Response Surface Methodology	[9][12][15][17][19][25][27][29][34][39][40][41][44][46][48]
Full Factorial Design	[3][26]
Genetic Algorithm	[5][30][33]
Grey Taguchi Based RSM	[6][42][45]
Other Methods	[10][16][18][22]

Behaviorof Parameters for Different Ferrous Materials

Material	Response Parameter	Input Parameters & its Significance								
		Arc Current	Cutting Speed	Stand Off Dist.	Gas Pressure	Arc Voltage	Thickness of Material	Plasma Gas Flow Rate	Shield Gas Flow Rate	Gas Mixture
Hardox-400 metal plate	Surface Roughness		√			√				
S235	Surface Roughness			√						
S235	HAZ	√								
EN31	Surface Roughness				√					
EN8 (AISI 1040)	MRR		√	√	√			√		

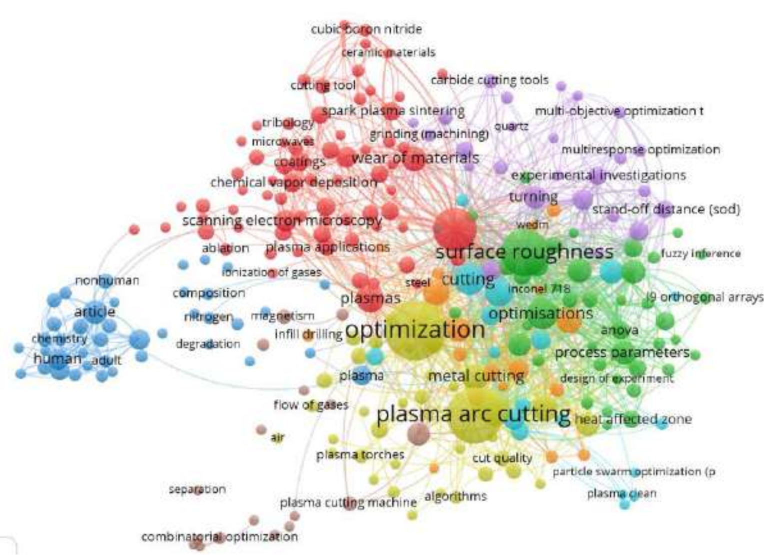
Material	Response Parameter	Input Parameters & its Significance								
		Arc Current	Cutting Speed	Stand Off Dist.	Gas Pressure	Arc Voltage	Thickness of Material	Plasma Gas Flow Rate	Shield Gas Flow Rate	Gas Mixture
EN-45A	MRR	√	√		√					
IS 2062 E250 BR	MRR	√	√		√					
Hot Rolled Mild Steel	Surface Roughness		√			√				
ST37 plates	Bevel Angle	√								
S235JR	Surface Roughness		√							
S235JR	MRR	√								
St-52 Structural steel	Surface Roughness				√					
EN 8 Steel Plates	MRR				√					
EN 8 Steel Plates	Surface Roughness				√					
E250 Mild Steel plate	Hardness Properties	√	√	√	√		√			
E250 Mild Steel plate	Surface Roughness			√	√					
E250 Mild Steel plate	Machining Time	√	√	√	√					
AISI 1018 Material	HAZ	√								
SS 316L	Kerf Width					√				
SS 316L	Kerf Taper		√							
AISI 304	MRR		√				√			
St 52 carbon steel	MRR						√			
Stainless steel SS321	Surface Roughness	√	√	√	√					
Stainless steel SS321	HAZ		√		√					
SS410 Material Plates	Surface Roughness	√				√				

Material	Response Parameter	Input Parameters & its Significance								
		Arc Current	Cutting Speed	Stand Off Dist.	Gas Pressure	Arc Voltage	Thickness of Material	Plasma Gas Flow Rate	Shield Gas Flow Rate	Gas Mixture
Stainless steel (EN 10025)	Kerf Width	√	√				√			
Stainless steel (EN 10025)	Bevel Angle	√					√			
Stainless steel SS 420	Surface Roughness		√	√						

Behavior of Parameters for Different Non-Ferrous Materials

Material	Response Parameter	Input Parameters & its Significance								
		Arc Current	Cutting Speed	Stand Off Dist.	Gas Pressure	Arc Voltage	Thickness of Material	Plasma Gas Flow Rate	Shield Gas Flow Rate	Gas Mixture
AA6061-T6	HAZ	√		√	√					
AA5754	Surface Roughness	√	√				√			
Aluminum 5083 (EN ISO 9013)	MRR		√		√					
Aluminium Alloy 6082	Kerf Width & Bevel Angle	√	√	√	√					
Monel 400™ super alloy	Surface Roughness	√		√						

Bibliometric Analysis of Plasma Arc Machining



CONCLUSION

- Although lot of work has been done in the field of plasma arc machining, mostly statistical optimization approach has been used for easy and simple optimization of process parameters. From the literature survey it is clear that there is lack of research in many other materials like aerospace alloy, Aluminum Alloy, composites etc. for enhanced quality of cutting operation through plasma and less work has been carried out. From the literature survey, it is clear that there is lack of research in Cutting force, Microstructure analysis, Nozzle Design and Dimensional accuracy achieved in plasma arc machining.
- It is observed that plasma arc machining based on latest optimization techniques is limited. Optimization of parameters by various techniques such as Genetic Algorithm, Particle Swarm Optimization, Simulated Annealing, and Data envelopment analysis approach are still in its initial stages and therefore, there is scope for further development in these areas.
- As we move forward, further research and development in this field are essential to investigate the effect of different process parameters on the different responses while using Plasma Arc Machining, To explore the applicability of Plasma Arc Machining process for machining of Industrial Materials, To develop mathematical models Using the experimental data for Responses To investigate effect of different components with respect to design aspect Cost Analysis.

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