

Experimental Investigation and Optimization of Process Parameters for Plasma Arc Cutting of Diverse Steel Alloys

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ABSTRACT

This study optimizes plasma arc cutting parameters to maximize the material removal rate (MRR) for 1.2 mm thick sheets of mild steel, galvanized steel, and AISI 304 stainless steel. The parameters current, voltage, torch distance and pulsing time were optimized using Taguchi L9 orthogonal array. The effects of parameters were analyzed by S/N ratio and ANOVA. The optimum conditions for mild steel, galvanized steel and stainless steel were 85A-120V-3.5mm-1s, 65A-100V-4mm-1s and 65A-100V-4mm-1s.

The corresponding MRRs were 2244.4, 1559.4, and 3153.2 mm³/min, respectively. The results show a strong material dependence of the PAC performance and the optimum parameter combinations. The proposed approach offers a practical framework for enhancing cutting productivity and process efficiency.

Key words: Material Removal Rate, Taguchi Method, Process Parameters, ANOVA, S/N Ratio

INTRODUCTION

Overview

The plasma arc cutting (PAC) is a unconventional machining process vividly use in contemporary manufacturing industries owing to its ability to cut various conductive materials such as aluminium, titanium, different alloys, stainless steels etc. As a result of their higher strength-to – weight, robustness and oxidation resistance, and lower creep resistance and modulus of elasticity, the materials can not undergo precision cutting with the usage of conventional process such as oxy – fuel cutting owing to severe heat generation results into trouble – shooting in machine [1].

PAC is encapsulated as the heat energy originated cutting process employing ionized gas stream i.e. plasma, associated with intense energy and velocity. In the process of cutting, the plasma jet penetrates enormously into the designated workpiece, resulting into the material being melted and evaporated [2].

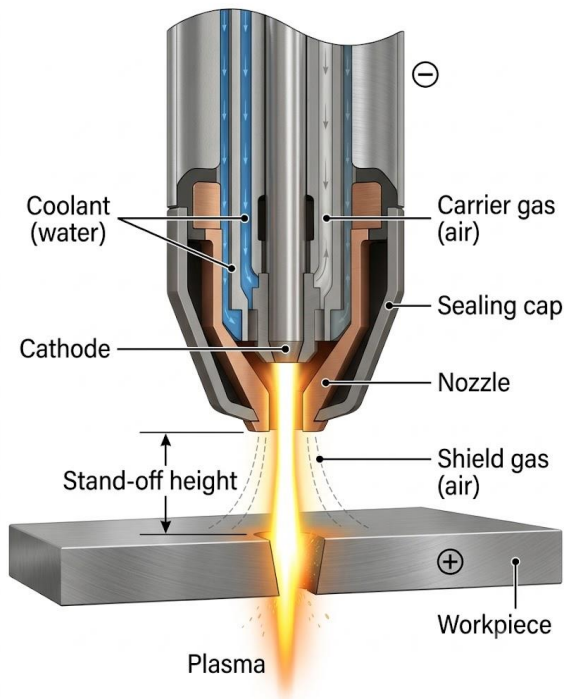


Fig.1 Plasma Arc Cutting [3]

During the cutting process, the high speed inert gas is passed through the nozzle which results into the formation of electric arc from nozzle to surface. The result is a high-velocity jet of plasma that melts the material and blows it away from the cut area [4]. The schematic diagram of PAC is shown in Fig 1.

The factors that need to be considered for efficient cutting quality, specifically the material removal rate (MRR) are plasma arc current, voltage, torch distance or geometry, pulsing time, flow rate and cutting speed [1]. MRR is the most important performance indicator in PAC since it directly stands for the rate of material removal from the workpiece, i.e., the productivity of the cutting process. The MRR is a quantitative measure of the efficiency of material removal that is traditionally calculated as the loss in the mass of the workpiece for a period of cutting. In PAC, the process parameters such as arc current, arc voltage, torch-to-workpiece distance and pulse-on time significantly impact the MRR. These parameters control the thermal energy delivered to the workpiece and the subsequent melting and ejection of material. Although these parameters can be easily adjusted in practical cutting operations, their interactive effects on MRR are often difficult to predict and control simultaneously for the shop-floor operators. Therefore, a systematic optimization of the parameters controllable by the operator is necessary to provide an optimum balance between material removal efficiency, energy consumption, productivity and cut quality.

The novelty of the present work is the development of a operator-oriented, material-specific parameter optimization framework for plasma arc cutting (PAC) where the effects of current, voltage, torch distance and pulsing time are combined to achieve maximum material removal rate (MRR). This study, unlike traditional approaches that mainly evaluate individual process parameters, considers the combined effects of the individual parameters systematically and optimizes the operating conditions for three different steel materials-mild steel, galvanized steel and AISI 304 stainless steel. The comparative optimization reveals the material-dependent behavior of PAC and shows that one parameter combination can not be optimal for all materials in terms of MRR.

The proposed method converts the experimentally accessible PAC parameters into ready-to-use practical operating conditions for the machine operators. The paper forms a practical bridge between laboratory scale parameter optimization and actual shop-floor decision making by defining optimum parameter combinations specific to the material and comparing their effect on MRR. This framework can help operators select cutting conditions with reference to workpiece material, which can improve cutting productivity and reduce unnecessary

energy and material loss, thus contributing to more economical, efficient, and sustainable plasma arc machining.

Literature Survey

A review of previous studies indicates that PAC performance is highly dependent on electrical, thermal and geometrical process parameters. Cutting current, arc voltage, cutting speed, plasma gas pressure, torch to work piece distance and composition of gasses influencing the MRR, kerf characteristics, surface roughness, bevel angle, heat affected zone (HAZ) and overall quality of cut have been studied extensively by researchers. Different experimental and statistical methods such as Taguchi methods, response surface methodology (RSM), ANOVA, gray relational analysis and artificial neural networks (ANN) have been used for modeling and optimization of PAC performance. Based on the reviewed studies, it appears that there is no single process parameter that governs the cutting performance but the interaction among operating parameters plays an important role. However, relatively few studies have been conducted to develop a practical optimization approach using easily adjustable parameters for shop-floor operators, especially for improving MRR while ensuring acceptable cutting performance. Table 1 gives the major findings of the relevant studies. Hence, the motivation of the present study is to establish a systematic relationship between operator-controllable plasma arc cutting parameters and MRR, aiming to find an optimum operating window rather than evaluating the isolated effect of individual parameters. This approach may offer a direct link between experimental optimization and practical shop-floor operation, possibly resulting in higher productivity while maintaining acceptable cutting quality and process stability.

MATERIALS AND METHODS

Experimental Setup

In an effort to ensure high precision, repeatability and process stability, the PAC experiments were conducted in a CNC-controlled cutting platform (Fig 2.1). The primary cutting unit was a Hypertherm Powermax85 XP CNC plasma system (Fig 2.2). The system architecture includes a power source, compressed-gas supply unit, CNC motion controller, and a high-precision plasma torch with optimized consumable assemblies (electrode, swirl ring and nozzle). Automated CNC guidance reduced errors in positioning and removed human variations in operations. The operational mechanism relies on establishing an electric arc between the internal electrode and the workpiece, which ionizes a high-pressure gas flow into a constricted, high-temperature plasma jet. This jet transfers focused thermal energy to melt the target material, while the concurrent high-velocity gas stream mechanically ejects the molten mass from the cut zone. The overall MRR and kerf quality is controlled by the interaction of input thermal energy, gas dynamics and substrate thermal properties.

The main technical parameters of the experimental setup are as follows: Output Current Range: 25 – 85 A, Maximum Open-Circuit DC Voltage: 145 V, Maximum Piercing/Cutting Capacity (Mild Steel): approx 16 mm, Operating Gasses: Compressed air, nitrogen or argon-hydrogen gas mixtures.



Fig 2.1 A CNC mechanized plasma cutting machine



Fig 2.2 Power max 45XP, CNC plasma cutter

Experimental procedure

Before the experimental trials the workpiece surfaces were cleaned mechanically and chemically to remove scale, rust, oils and surface contaminants. The samples were rigidly clamped on the CNC cutting bed to avoid thermal deformation during execution. The key controllable parameters, namely cutting current, arc voltage, gas pressure, cutting speed and stand-off distance were systematically varied to assess their parametric effects on the process efficiency and cut characteristics. Dimensional and metallurgical inspection were performed on the samples after each cut, allowing them to reach ambient temperature. In plasma cutting, MRR is calculated based on the volume of material removed per unit time. For this study, MRR was determined using the weight difference method, converted to volume using the material's density (Equation 1)

$$\text{MRR} \left(\frac{\text{m}^3}{\text{min}} \right) = \frac{\text{Weight loss (g)}}{\text{Density} \left(\frac{\text{g}}{\text{m}^3} \right)} \times \frac{60}{\text{Pulsing time (s)}} \times 1000 \quad (\text{Equation 1})$$

Selection of Workpiece Material

Three industrial alloys—galvanized steel, Grade 304 stainless steel, and low-carbon mild steel—were selected to evaluate PAC performance across distinct chemical, thermal, and mechanical regimes. Galvanized Steel: Comprises a low-carbon steel core with a hot-dipped zinc protective layer. The outer zinc layer has a melting point of 420 °C, whereas the steel substrate melts between 1425 – 1500 °C. This temperature disparity induces unique phase-change dynamics and initial fluid behavior during plasma interaction. Stainless Steel (AISI 304): An austenitic alloy containing 18 – 20 % Cr and 8 – 10.5 % Ni. Its low thermal conductivity causes localized thermal dissipation, elevating thermal gradients within the kerf region. Mild Steel: Serves as a baseline benchmark material due to its widespread structural application, uniform low-carbon microstructure (0.05 – 0.25 %), and predictable thermal response. A summary table for the physico – thermal and mechanical properties of the alloys are represented in Table 2.

Design of Experiments

In the present investigation, MRR was selected as the primary response for evaluating the cutting performance. Four controllable process parameters, namely cutting current, arc voltage, torch stand-off distance, and pulsing time, were considered as the principal factors influencing the cutting process. The cutting current and arc voltage directly influence the electrical energy supplied to the plasma arc and, consequently, the thermal energy transferred to the workpiece. Torch stand-off distance affects the interaction between the plasma jet and the workpiece by altering the effective energy density and arc characteristics at the cutting zone. Pulsing time influences the duration and temporal characteristics of energy delivery to the workpiece and may consequently affect melting, material ejection, and overall cutting efficiency. The combined effects of these parameters were therefore investigated experimentally to determine their influence on MRR. Minitab was employed to design the experiment, generate the orthogonal array, and analyze the results.

The four factors considered in the experimental investigation were cutting current (I), arc voltage (V), torch stand-off distance (d), and pulsing time (t_p). Their respective levels are presented in Table 3. The selected parameter ranges were established based on the practical operating conditions used for plasma cutting of thin steel sheets with thicknesses approximately 1.2 mm. Mild steel, galvanized steel, and AISI 304 stainless steel were considered in the experimental investigation. The identical factor levels were maintained for all three materials to ensure consistency of the experimental design and to enable direct comparison of their responses under equivalent process conditions. A Taguchi (L9) orthogonal array was employed to design the experimental trials. Four process parameters were investigated at three levels each, resulting in nine experimental combinations. The orthogonal-array approach enables the effects of the selected factors to be evaluated systematically while substantially reducing the number of experimental trials compared with a full-factorial design. The same parameter-level combinations were applied to each selected workpiece material (mild steel – Table 5, galvanized steel – Table 6, Stainless steel – Table 7) to facilitate a consistent comparison of material-dependent cutting behaviour.

Experimental Consistency

To minimize experimental variability, the same procedure, equipment configuration, workpiece thickness, and parameter levels were maintained for all material systems wherever applicable. Prior to each trial, the workpiece was cleaned and securely clamped to the CNC cutting bed. The plasma torch was positioned at the prescribed stand-off distance, and the required current, voltage, and pulsing conditions were established before initiating the cutting operation. Following each cut, the specimen was allowed to cool to ambient conditions before its final mass was determined. This standardized procedure was adopted to minimize errors associated with thermal effects, specimen movement, and variations in measurement conditions. The resulting experimental dataset formed the basis for subsequent Signal to noise ratio (S/N ratio), ANOVA and optimization analyses.

RESULTS AND DISCUSSION

Signal to Noise Ratio

The Taguchi method was employed to optimize the plasma cutting parameters, current, voltage, torch distance and pulsing time for maximizing the MRR of mild steel, galvanized steel and stainless steel. The “larger-is-better” criterion was used as higher MRR is desirable. The S/N ratio is calculated as (Equation 2)

$$\frac{S}{N} \text{ ratio}, \eta = -10 \log_{10} \left[\frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2} \right] \quad (\text{Equation 2})$$

Where, y_i is the observed MRR and n is the number of observations.

Through the Delta value, which is the difference between the maximum and the minimum mean S/N ratios, the relative importance of each parameter is evaluated. The factors were ordered by the Delta value, the larger the Delta value, the more influential on MRR. For mild steel, the most influential parameters were current (20.02) and voltage (16.80). For galvanized steel, pulsing time (494.3) and voltage (290.7) had the largest impact. The dominant parameters were current and pulsing time equal to 12.79 and 8.44 respectively for stainless steel. The results indicate that the relative importance of plasma-cutting parameters is a function of the work-piece material.

Parametric effects on MRR

Mild Steel

MRR rises as cutting current and arc voltage increase, according to the main-effect plot for means and S/N ratio (Fig 3.1 and Fig 3.2). The represented graphs illustrate the effect of current, voltage, torch distance and pulsing time on the measured response. According to it, the response has a non-linear dependence on all four process parameters. For current, the response first reduces at 65 A and then increases sharply at 85 A showing a significant effect at higher current. Similar trend is observed for voltage where the response increases significantly at 120 V. Response overall increases with increasing torch distance from 3.0 to 4.0. For the pulsing time, the maximum response is at 1 s, and then a big decrease at 2 s and a small recovery at 5 s. In general, the plots show that the response is strongly affected by the current and pulsing time, while the effects of voltage and torch distance are parameter dependent. The observed non-linear trends indicate the presence of interactions and optimum operating regions and should be further evaluated using ANOVA and response-surface analysis.

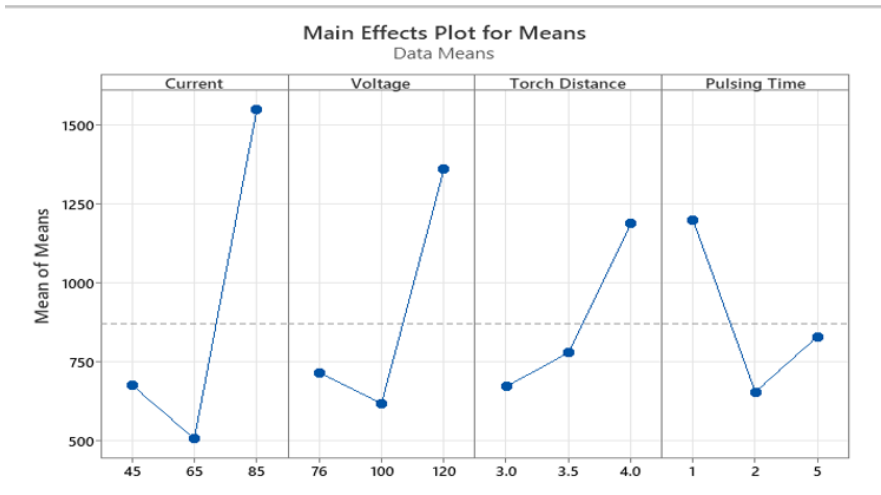


Fig 3.1 Main effects plot for means of MRR (mild steel)

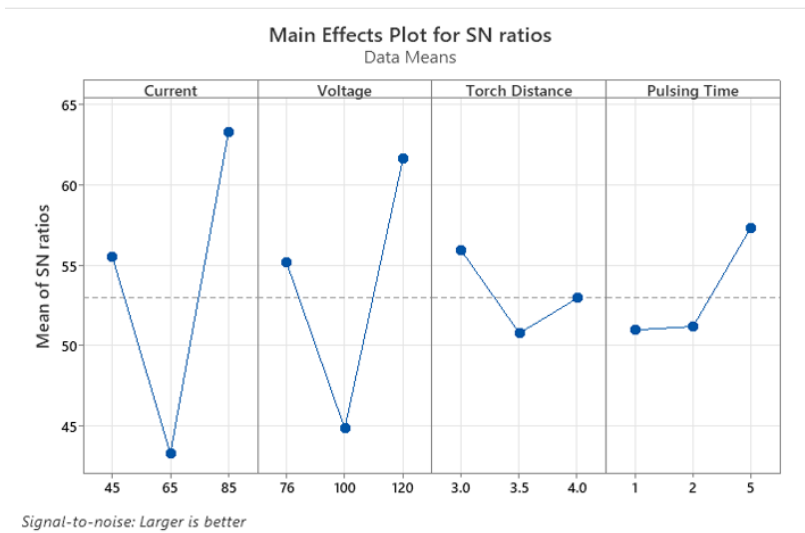


Fig 3.2 Main effects plot for S/N ratios of MRR (mild steel)

Galvanized Steel

Cutting current, arc voltage, and pulse length are the primary parameters impacting MRR, according to the interpretation of Figs. 3.3 and 3.4, which show steep gradients and significant variations in mean S/N response across their respective factor levels. The response increases as a function of current with a maximum at 85A. The voltage rises sharply from 76 to 100 V and then levels off at an almost constant 120 V. The torch distance decreases slightly at 3.5 mm and increases dramatically at 4.0 mm. The pulsing time has the most important effect, response is highest at 1 s, and response decreases significantly at 2 s and then only a slight increase at 5 s.

Higher current and voltage levels increase the electrical power input to the system, increasing the plasma arc's energy density and heat transfer rate. This enhanced energy transfer speeds up localized melting of the working material. Simultaneously, a perfect pulse length ensures constant thermal stimulation, enabling efficient molten metal ejection before excessive conductive dissipation. Secondary Factor (Torch Distance): In contrast, the torch-to-workpiece distance had the least statistical significance, with a relatively flat S/N response curve and minimal variation across levels. Stand-off height is a secondary driver in regard to primary electrical energy inputs since it has no effect on the momentum or heat focus of the plasma column within the examined range. Optimized parameters are: cutting current 65 A, arc voltage 100 V, torch distance 4 mm and pulse duration of 1 s.

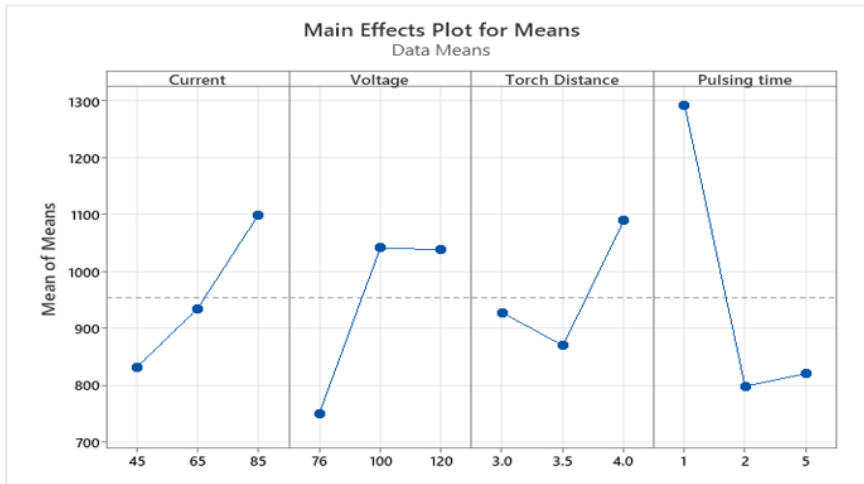


Fig 3.3 Main effects plot for means of MRR(galvanized steel)

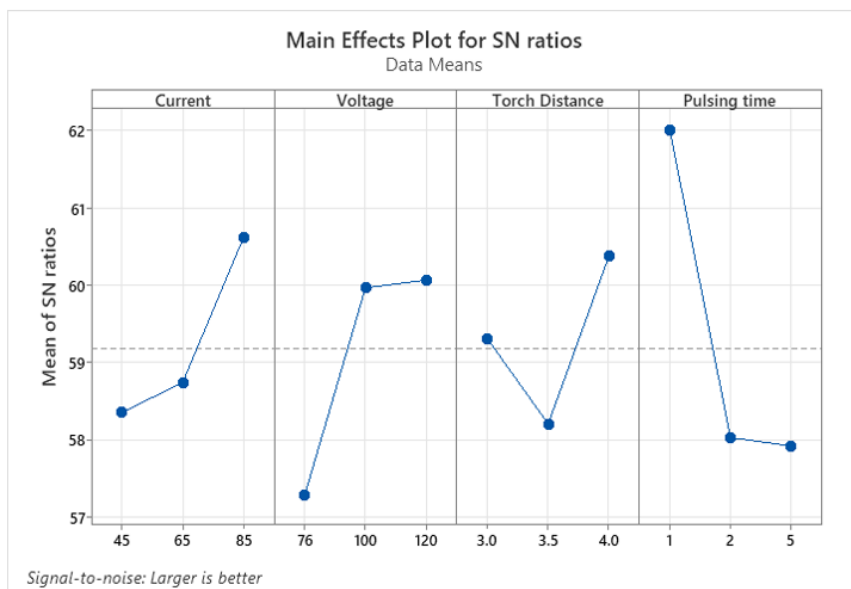


Fig 3.4 Main effects plot for S/N ratios of MRR (galvanized steel)

Stainless steel

The optimum process parameters for maximizing MRR were determined from the main effect plot (Fig. 3.5), developed using the mean Signal-to-Noise (S/N) ratios presented in Fig. 3.6. As can be seen from the greater variance in the mean S/N ratios throughout their different levels, the plot shows that current and pulsing duration have the most noticeable effects on MRR. Torch distance, on the other hand, shows the least amount of influence because the response varies very little between its levels.

When compared to the other process parameters, voltage has a moderate impact on MRR. The best combination for optimizing MRR was found to be current = 65 A, voltage = 100 V, torch distance = 4 mm, and pulse time = 1 s based on the highest mean S/N response at each parameter level. This combination serves as an appropriate foundation for further confirmation trials and indicates the parameter levels linked to the maximum experimental response within the examined range.

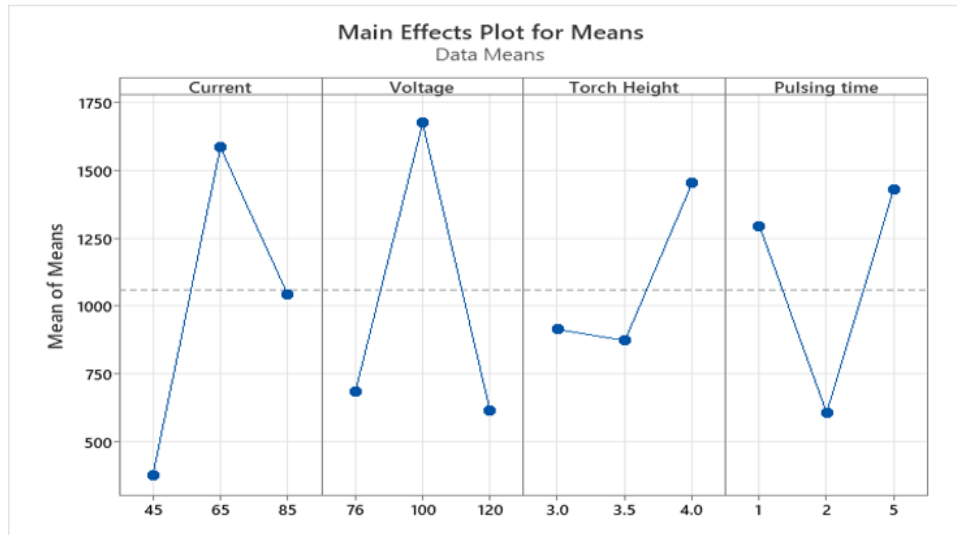


Fig 3.5 Main effects plot for means of MRR(stainless steel)

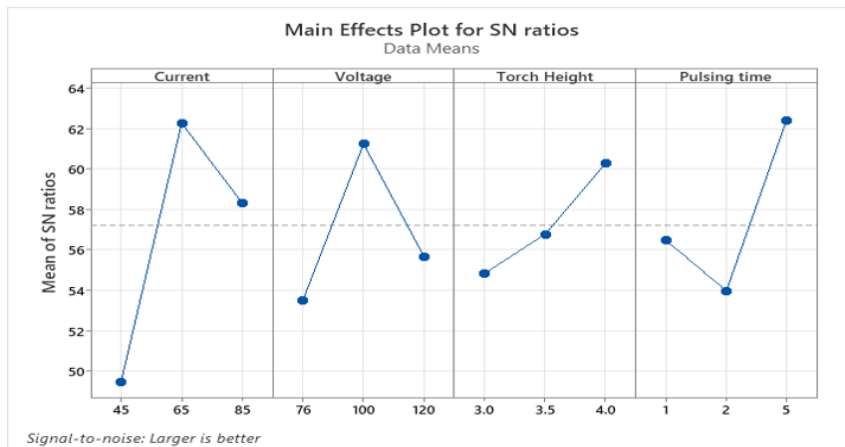


Fig 3.6 Main effects plot for S/N ratios of MRR(stainless steel)

ANOVA Results Comparative Analysis

Comparative ANOVA results for machining of mild steel, galvanized steel and stainless steel are presented in Table 8. The analysis shows that the pulsing time is the most dominant process parameter for all the three materials with F-values of 29.63, 36.80 and 34.44 respectively. The corresponding p-values of 0.0326, 0.0265 and 0.0282 are below the 0.05 significance level, indicating that the effect of pulsing time is statistically significant.

The relatively high F-values indicate a large contribution of the pulsing time to the variation of the measured response. Galvanized steel has the highest F-value (36.80) among the studied materials, followed by stainless steel (34.44) and mild steel (29.63). This demonstrates that under the investigated conditions the galvanized steel reacts relatively more sensitive to changes in the pulsing time.

The second factor which is dominant in the materials investigated is the current. The relatively high contribution of the current can be explained by its direct effect on the energy input as well as the material removal mechanism during the cutting process. The energy density of the plasma arc, and therefore melting, vaporization and expulsion of material, generally increases with increasing current. The main effects plots also indicate a strong variation of the response with the change of the current, especially at higher current levels. Thus, although pulsing time has the most significant statistical effect, current is another important control parameter which should be considered carefully during process optimization.

Furthermore, the obtained statistical models show R^2 values close to 0.99, indicating an excellent agreement between the experimental and predicted responses. The high values of coefficients of determination indicate that the models explain about 99% of the observed variability, confirming their strong predictive capability in the experimental domain. The combined ANOVA and R^2 results confirm the adequacy and reliability of the developed models from the statistical point of view. Further, they underline the criticality of pulsing time as an indicator for process optimization for all three materials.

CONCLUSIONS

This paper presents the optimization of plasma arc cutting parameters for maximizing the material removal rate (MRR) of mild steel (1.2 mm), galvanized steel (1.2 mm) and AISI 304 stainless steel (1.2 mm) using Taguchi design of experiments and analysis of variance (ANOVA). The results show that the optimal cutting parameters are highly dependent on the workpiece material and thickness.

The maximum MRR of 2671.7 mm³/min was achieved at mild steel at 85 A current, 120 V voltage, 3.5mm torch distance and 1s pulsing time. The best combination of 65 A, 100 V, 4 mm and 1 s for galvanized steel resulted in an MRR of 2559.4 mm³/min. The highest MRR of 3122 mm³/min was obtained for AISI 304 stainless steel at 65 A, 100 V, 4 mm, and 1 s. These differences in optimal conditions demonstrate the very different performance of plasma cutting depending on the properties of the material and the interaction of the process parameters.

The results of the ANOVA analysis proved that the pulsing time was the most influential parameter for the three materials and current was the second dominant factor. The calculated F-values for pulsing time were 29.63, 36.80 and 34.44 for mild steel, galvanized steel and stainless steel respectively. The p-values were less than 0.05 hence confirming the statistical significance of the pulsing time. The developed models also showed R^2 values close to 0.99 which indicates a high correlation between the experimental and predicted MRR values and confirms the adequacy of the models.

In general, Taguchi approach was successful in obtaining suitable parameter combinations with lesser number of experiments. The results provide practical guidelines for the selection of plasma arc cutting parameters when the MRR is the principal performance criterion. Future studies should focus on process stability and industrial applicability by including cutting quality, kerf characteristics, surface roughness, torch-height control, consumable wear and confirmation experiments for further improvement.

Table 1 Literature survey

Sl. No	Workpiece / Material	Major Input Parameters	Response / Performance Characteristics	Method / Approach	Key Findings	Ref
1	Al ₂ O ₃ ceramic plates	Nozzle diameter, hydro-magnetic confinement	Kerf width, cutting speed, nozzle heat load	Experimental investigation	Hydro-magnetic confinement reduced kerf width and improved cutting speed and process stability.	Xu et al. (2002) [5]
2	Commercially pure Ti sheets	Feed rate, O ₂ /N ₂ cutting and shielding gases	Cut geometry, surface quality, HAZ, microstructure	Experimental & thermal analysis	Oxygen enabled higher feed rates and better geometric characteristics; thermal cycles strongly	Gariboldi et al. (2005) [6]

					influenced the HAZ and microstructure.	
3	AISI 304 stainless steel & St52 carbon steel	Cutting speed	Burning, dross, hardness, heat-affected region	Experimental investigation	Cutting outside the recommended speed range increased burning/dross and altered hardness; thermal effects extended into the material.	Gullu et al. (2006) [7]
4	15 mm mild steel	Arc voltage, cutting speed, plasma/shield gas flow and composition	Kerf position, kerf shape, unevenness, torch wear	Experimental investigation	Arc voltage and cutting speed significantly affected kerf formation; lower voltage reduced standoff distance but increased torch/electrode wear.	Bini et al. (2008) [8]
5	—	Cutting speed, current, plate thickness	Surface roughness (Rz)	Artificial Neural Network (ANN)	ANN successfully predicted surface roughness and can assist in selecting machining conditions for improved cut quality.	Radovanovic et al. (2011) [9]
6	SS 316L	Gas pressure, current, cutting speed, arc gap	MRR, surface roughness (Ra)	Taguchi method	Optimum parameter combinations were identified separately for maximum MRR and minimum surface roughness; confirmation tests showed acceptable error.	Singh et al. (2012) [10]
7	—	Cutting speed, current, plasma gas pressure, torch-workpiece	Surface roughness, HAZ and cut quality	Experimental investigation	Cutting speed, current, gas pressure and cutting height were identified as important PAC	Salonitis et al. (2012) [11]

		distance			parameters affecting cut quality.	
8	Hardox-400, 12 mm	Voltage, cutting speed, plasma flow rate	Cut-surface unevenness	Experimental optimization	Cutting speed, plasma flow rate and voltage strongly affected unevenness; optimum conditions minimized surface irregularity.	Chamarthi et al. (2013) [12]
9	Mild steel, 16 mm	Plasma gas type, current	Arc behaviour, cutting performance, plasma jet characteristics	Experimental investigation	Plasma gas significantly affected arc energy and jet characteristics; steam generated higher energy than the other investigated gases at the same current.	Kavka et al. (2013) [13]
10	Stainless steel X10CrNiMn-16-10-2	Current, cutting speed, material thickness	Kerf, surface roughness, bevel angle	Experimental & MATLAB analysis	Demonstrated significant relationships between process parameters and cut characteristics and provided a basis for statistical/AI modelling.	Lazarevic et al. (2014) [14]
11	EN31 steel	Gas pressure, arc current, torch height	MRR, surface roughness, chip morphology	RSM, ANOVA & Grey Relational Analysis	Gas pressure was reported as the most influential factor, followed by arc current and torch height, for the investigated responses.	Das et al. (2014) [15]
12	EN-45A steel	Cutting speed, current, stand-off distance, plasma gas pressure	MRR	Taguchi L16 & ANOVA	Cutting speed, current and plasma gas pressure were identified as major factors influencing MRR; optimum	Sharma et al. (2017) [16]

					settings were validated experimentally.	
13	Stainless steel sheet	Multiple PAC cutting parameters	Kerf width, kerf taper	Full-factorial design	Identified optimum cutting conditions for improving geometrical accuracy of stainless-steel cuts.	Parthiban et al. (2018) [17]
14	Steel alloys	Cutting power, scanning speed, plasma gas pressure, feed rate	Edge roughness, MRR, cut quality	Review study	Highlighted the importance of process parameters, particularly feed rate and edge roughness, in PAC performance and optimization.	Cinar et al. (2018) [18]
15	Metallic materials	Plasma gas pressure, scanning speed, cutting power, cutting height	Edge roughness, kerf width, HAZ	Experimental investigation	Demonstrated that process parameters significantly influence edge roughness, kerf width and HAZ, confirming the controllability of PAC quality.	Magid et al. (2021) [19]

Table 2 Physical, thermal, and mechanical properties of the selected workpiece alloys

Material Property / Parameter	Galvanized Steel	Stainless Steel (AISI 304)	Mild Steel
Density (g/cm ³)	7.85	7.80	7.85
Melting Point (°C)	Substrate: 1425 – 1500 Coating (Zn): 420	1400 – 1530	1450
Thermal Conductivity (W/m.K)	50.0	16.2	50.0
Tensile Strength (MPa)	400 – 550	515 – 700	400 – 550
Yield Strength (MPa)	250 – 400	205 – 300	250 – 400
Elongation (%)	15 – 30	40 – 60	15 – 30
Brinell Hardness (HB)	120 – 160	160 – 200	120 – 160
Modulus of Elasticity (GPa)	200	190 – 200	200

Table 3 Process factors and experimental levels used for plasma arc cutting

Factor	Symbol	Unit	Level 1	Level 2	Level 3
Cutting current	I	A	45	65	85
Arc voltage	V	V	76	100	120
Torch stand-off distance	D	mm	3.0	3.5	4.0
Pulsing time	t _p	s	1	2	5

Table 4 L9 Orthogonal array with factor levels

Run	Current (A)	Voltage (V)	Torch Distance (mm)	Pulsing Time (s)
1	45	76	3.0	1
2	45	100	3.5	2
3	45	120	4.0	5
4	65	76	3.5	5
5	65	100	4.0	1
6	65	120	3.0	2
7	85	76	4.0	2
8	85	100	3.0	5
9	85	120	3.5	1

Table 5 DOE for mild steel

Sl. No.	Current (A)	Voltage (V)	Torch Distance (mm)	Pulsing Time (s)	Initial Weight (g)	Final Weight (g)	MRR (mm ³ /min)
1	45	76	3	1	40.0212	39.9722	374.4
2	45	100	3.5	2	40.0212	39.8930	490.1
3	45	120	4	5	40.0052	39.8382	255.2
4	65	76	3.5	5	39.8885	39.1255	1166.2
5	65	100	4	1	39.9735	39.9277	350.1
6	65	120	3	2	39.9735	39.4743	1908.4
7	85	76	4	2	80.1114	79.4123	2671.7
8	85	100	3	5	79.8974	79.6918	314.2
9	85	120	3.5	1	73.0971	72.9431	1177.2

Table 6 DOE for galvanized steel

Sl. No.	Current (amp)	Voltage (volt)	Torch Distance (mm)	Pulsing Time (s)	Initial Weight (g)	Final Weight (g)	MRR (mm ³ /min)
1	45	76	3	1	104.7085	104.59	905.7
2	45	100	3.5	2	104.59	104.4052	706.2
3	45	120	4	5	104.4052	104.2897	882.8

4	65	76	3.5	5	104.2897	102.5887	519.8
5	65	100	4	1	102.5887	102.3847	1559.4
6	65	120	3	2	102.3847	101.9567	818.7
7	85	76	4	2	101.9567	101.8485	827.0
8	85	100	3	5	101.8485	101.71	1059.4
9	85	120	3.5	1	101.71	101.5252	1412.5

Table 7 DOE for stainless steel

Sl. No.	Current (A)	Voltage (V)	Torch Distance (mm)	Pulsing Time (s)	Initial Weight (g)	Final Weight (g)	MRR (mm ³ /min)
1	45	76	3	1	88.102	88.081	160.6
2	45	100	3.5	2	88.081	87.969	214.1
3	45	120	4	5	87.969	85.470	764.3
4	65	76	3.5	5	85.470	80.783	1434.0
5	65	100	4	1	80.783	80.375	3122.0
6	65	120	3	2	80.375	80.114	499.5
7	85	76	4	2	80.114	79.874	458.5
8	85	100	3	5	79.874	73.071	2081.3
9	85	120	3.5	1	73.071	72.995	582.8

Table 8 Comparative ANOVA analysis

Material	Most influential factor	F-value of dominant factor	p-value	Statistical significance
Mild steel	Pulsing time	29.63	0.0326	Significant
Galvanized steel	Pulsing time	36.80	0.0265	Significant
Stainless steel	Pulsing time	34.44	0.0282	Significant

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