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Experiment and Analyse Material Removal Rate in Plasma arc cutting of SS410 for various parameters using ANOVA

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ABSTRACT:
The plasma arc cutting process is used for the different type of metal cutting. Stainless Steel is most widely used in industries throughout the world. The material is stainless steel 410 was used in the experimental work. The quality of the cut has been monitored by measuring the Material Removal Rate (MRR), Kerf width and Bevel angle. This work aims at evaluating processing parameters, such as the Pressure, Current and Stand-off Distance. Design of Experiment (DOE) like FULL FACTORIAL method will be used to find the number of experiment runs to perform on the Plasma arc cutting machines.
Keywords: Design of Experiment, SS410, Plasma arc cutting.

I.INTRODUCTION

Plasma cutting was developed at the end of the 1950 for cutting high-alloy stainless steels and aluminium. It was designed to be used on all material which due to their chemical composition, could not be subjected to oxy-fuel cutting to its extremely high cutting speeds especially with thin materials and narrow heat-affected zone. The technique is also used now a day for cutting non-alloy steels and low-alloy steels [6].Today metal cutting was characterized by higher quality demands and increased cost pressures. The edges of cut part should not require any further processing and are expected to express maximum dimensional accuracy. So plasma arc cutting is in direct cooperation with other techniques such as oxy-fuel cutting, laser cutting and water jet cutting. The mechanical processing techniques such as punching and drilling, it can also be an alternative.

Plasma Arc Cutting (PAC) is a material removal process in which the material is removed by directing a high velocity jet of high temperature ionized gas on the work piece. The relatively narrow plasma jet melts the work piece material in its path.

Because of the high temperature involved, the process can be used on almost all materials including those which are resistance to oxy-fuel gas cutting. Plasma is mixture of free electrons, positively charged and neutral atoms. It can be obtained by heating a gas to a very high temperature so that is partially ionized. The plasma torch confines the plasma forming gas in an arc chamber, and the arc supplies a large input of electrical energy. The central zone of the plasma reaches a temperature of 15000 °C and is completely ionized. Much of the heating of the gas takes place in constricted region of the nozzle duct, resulting in high velocity gas exit [7].

Design of experiments (DOE) is a family of structured, organized techniques used to empirically understand the impact of process parameters the process performance and assist in identifying the optimum variables values. The main advantage of these techniques is ability to provide results with only a fraction of all the possible experimental combinations. Taguchi and Response surface are engineering methods for product design that focuses on minimizing variation and or sensitivity to noise. In robust parameter de-sign the primary goal is to find factors setting that minimize the response variation, while keeping the process on target. After determine which factors affect about variation, the fine settings for controllable factors will be possible to achieve. Analysis of variance (ANOVA) is a statistical model which can be used for find out effect of independent parameter on single dependent parameter. It is used to check the sufficiency of the second order model which includes test for significance of regression model, model coefficients and test for lack of fit. In modern day optimization process, these methods are either

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used single handedly or coupled with other statistical or heurestical optimization methods for parametric optimization [1].

II. LITERATURE REVIEW

K. Salonitis and S. Vatousianos [2] have investigating experimentally in the present paper for assessing the quality of the cut. The quality of the cut has been monitored by measured the kerf taper angle (conicity), the edge roughness and the size of the heat affected zone (HAZ). This work aims at evaluate processing parameters, such as the cutting power, scanning speed, cutting height and plasma gas pressure. A statistical analysis of the results was performed in order for the effect of each parameter on the cutting quality to be determined. The regression analysis was used for the development of empirical models able to describe the effect of the Process parameters on the quality of the cutting.

R. Bini et al [3] was conducted experiment on 15mm thick mild steel sheets metals using process parameters like arc voltage and cutting speed, plasma gas flowrate, shield gas flowrate and shield gas composition are to influence effect on kerf position and shape are evaluated. They revealed that cutting speed and arc voltage affect the kerf formation mechanism and their interaction is also important in defining the inclination of the cut.

Subbarao Chamarthi et al [4] were worked on plasma arc cutting (PAC) that makes use of a constricted jet of high-temperature plasma gas to melt and separate (cut) metal. They had used 12mm plate thickness Hardox-400 which was cut by high tolerance voltage, cutting speed and plasma gas flow rate included as process parameters in the analysis and their effect on unevenness of cut surface is evaluated. Despite the value selected for rate included as process parameters, the analysis shows that Hardox-400 plates can have different profiles, depending on the specific side considered.

R. Bhuvenesh et al [5] were shown that manufacturing companies define the quality of thermal removing process based on the dimension and physical appearance of the cutting material surface. Therefore, the roughness of the surface area of the material cut by the plasma arc cutting machine was importantly considered. Plasma arc cutter selco Genesis 90 was used to cut standard AISI 1017 Steel of 200mm ×6mm manually based on the selected parameters setting. The material removal rate (MRR) was measured by determining the weight of the specimens before and after the cutting process. The surface roughness (SR) analysis was conducted using Mitutoyo CS-3100 to determine the average roughness value (Ra). Taguchi method was utilized to achieve optimum condition for both outputs studied. The microstructure analysis in the region of the cutting surface is performed using SEM. The results reveal that the SR values are inversely proportional to the MRR values. The quality of the surface roughness depends on the dross peak that occurred after the cutting process.

III-EXPERIMENTAL WORK

Material Selections

There are different grades and surface finishes of stainless steel to suit the environment the alloy must endure. Stainless steel is used where both the properties of steel and corrosion resistance are required. Stainless steels are the most popular and widely used alloy steels. They are high alloy steels. They have excellent corrosion and oxidation resistance. It provides adequate resistance to atmospheric corrosion, fresh water, mild acids and some other chemicals.SS 410 can be easily formed by drawing, spinning, bending and roll forming. SS 410 is providing high strength and hardness. [8]

Table 3.1: Chemical Composition of SS 410[8]

Element	Weight %
Carbon (C)	0.030 – 0.15
Manganese (Mn)	0.41 – 1.00
Silicon (Si)	0.53 – 1.00
Phosphorus (P)	0.028 – 0.040
Sulphur (S)	0.015 – 0.030
Nickel (Ni)	0.15 – 0.75
Chromium (Cr)	11.50 – 13.50

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Table 3.2: Mechanical Properties of SS 410 (Annealed properties)

Ultimate Tensile Strength	75000 PSI
Yield Strength(0.2% offset)	45000 PSI
Elongation	25%
Modulus of Elasticity (Tension)	29×10^6 PSI
Poisson's Ratio	0.24
Density	7750 KG/m^3
Melting Point	1460° C
Thermal Conductivity	25 W/m.k

Specimen Preparation
Test specimens having dimension 100mm × 100mm × 2.5mm were prepared for the experimental work. The material for test specimen was Stainless Steel 410.

Figure 3.1: Test Specimen

Equipment
With kind permission at Shree Sai Tech, this performance could be able to work on machine 'Hypertherm powermax 105' CNC Plasma Arc Cutting system.

Figure 3.2: Hypertherm powermax 105 CNC machine

Full Factorial Design of Experiment

A full factorial design contains all possible combinations of a set of factors. This is the most full proof design approach. The full factorial designer supports both continuous factors and categorical factors with up to nine levels. In full factorial designs, require to perform an experimental run at every combination of the factor levels.

The combinations of factor levels represent the conditions at which responses will be measured. Each experimental condition is a run. The entire set of runs is the design. Factorial designs with three factors have a sample size that is a power of three (specifically 3f where f is the number of factors). General full factorial design is use to find out, which variable are the most influential on the response and interaction between two or more factors that influences the response. Unfortunately, the sample size grows exponentially in the number of factors, so full factorial designs are too expensive to run for most practical purposes. In order to analyze the results, this method uses a statistical measure of performance called 'signal-to-noise' ratio, (S/N), where S is the standard deviation of the performance parameters for each array experiment and N is the total number of experiment in the orthogonal array. After performing the statistical analysis of S/N ratio, an analysis of variance (ANOVA) needs to be employed for estimating error variance and determining the relative importance of various factors. Here, full factorial design is selected and used. For a full factorial design, if the numbers of levels are same then the possible design N is

$$N = L^m$$

Where, L = number of levels for each factor
m = number of factors

Plasma Arc Cutting Parameters

Form available literature related to the plasma arc cutting it is found that there are

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numerous factors which affect on cut quality which helps to identify the factors for the experiments and also gives idea to set the appropriate parameters for better cut quality. Variable which seem to be the most influential factors on the cut quality pressure, current and stand-off distance.These parameters should be called as process parameters. These parameters cause effects on the work material, which should be analyzed in the form of response parameters such as MRR, kerf width and bevel angle. These parameters also cause effects on consumable parts.

Process Parameters

1. Current
2. Stand-off distance
3. Pressure

Response Parameters

1. Material Remove Rate (MRR)

Measurement of Cut Quality Parameters

The cut usually includes top kerf width (Kt), bottom kerf width (Kb) and bevel angle (θ). The top kerf width is identified as the distance between the two points where the beveled cut surface meets the flat top surface of the work. Similarly, the bottom kerf width is the distance between the two points where the cut surface meets the flat bottom surface. The bevel angle is the angle between line joining the top and bottom kerf width points and the line perpendicular to the bottom surface of the work at the point for bottom kerf width which represents the ideal non beveled cut.In the experiment, the cross section of kerf was digitally photographed, and then the geometrical parameters of kerf were measured in computer based on the enlarged picture of the cross section using image software tool for image processing and edge detection.

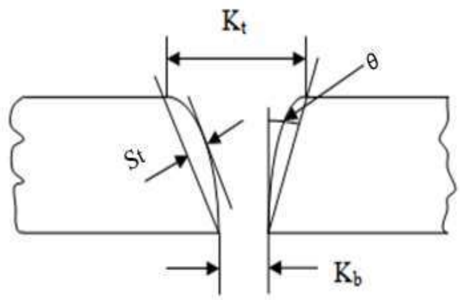


Figure 3.3:Measurement of cut quality parameters[13]

IV.RESULT & DISCUSSION

Material Removal Rate Measurement

The Material Removal Rate for all number of runs is measured using digital weight balancer equipment.

In order to obtain the amount of Material Removal Rate (MRR) the weight of the work pieces (specimens) before and after the cutting process need to be measured.

Figure 4.1: Digital Weight Balancer

The following table shows reading of MRR at each experiment.

Table 4.1: Data obtained from measurement (MRR)

Table 3.4: Range of Process Parameters

Parameters	Units	Level 1	Level 2	Level 3
Pressure	bar	4	4.5	5
Current	A	40	45	50
Stand-off Distance	mm	2	3	4

So total numbers of runs required are:

N = (No. of Levels) $^{\text{(No. of Factors)}}$,

where,

N = Total number of trials,

F = Number of factors and

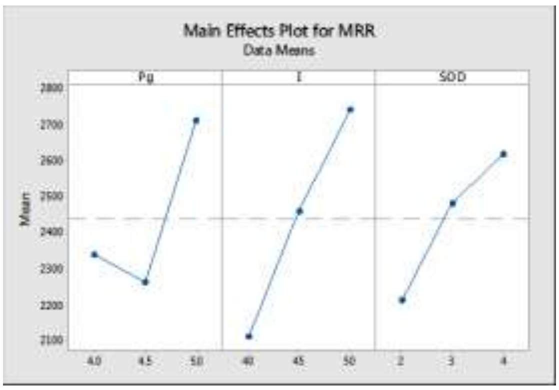
L = Number of levels. So it will be

N =3^3 = 27.

Sr. No.	Input Parameter			Response Parameter
	Pressure (Bar)	Current (A)	SOD (mm)	MRR (mm)
1	4	40	2	1756.66
2	4	40	3	2091.91
3	4	40	4	2316.66
4	4	45	2	2096.16
5	4	45	3	2645.62
6	4	45	4	2332.44
7	4	50	2	2386.44
8	4	50	3	2609.09
9	4	50	4	2828.34
10	4.5	40	2	1856.25
11	4.5	40	3	2025.22
12	4.5	40	4	2196.25
13	4.5	45	2	1947.19
14	4.5	45	3	2128.34
15	4.5	45	4	2256.64
16	4.5	50	2	2408.21
17	4.5	50	3	2674.24
18	4.5	50	4	2867.59
19	5	40	2	1921.79
20	5	40	3	2247.19
21	5	40	4	2596.25
22	5	45	2	2681.19
23	5	45	3	2980.30
24	5	45	4	3074.76
25	5	50	2	2871.62
26	5	50	3	2938.42
27	5	50	4	3095.51

Analysis Of Variance (ANOVA) For MRR

The ANOVA response graph for the main effects of the plasma arc cutting parameters on mean for the Material Removal Rate (MRR) is given in Graph 4.1.The result of ANOVA represented in response diagrams shown in Graph 4.1 suggest that the optimal combination of plasma arc cutting parameter levels, which gives the lowest value of the Material Removal Rate (MRR) is Pg1I2SOD2.



Graph 4.1: Main Effect Plot for MRR

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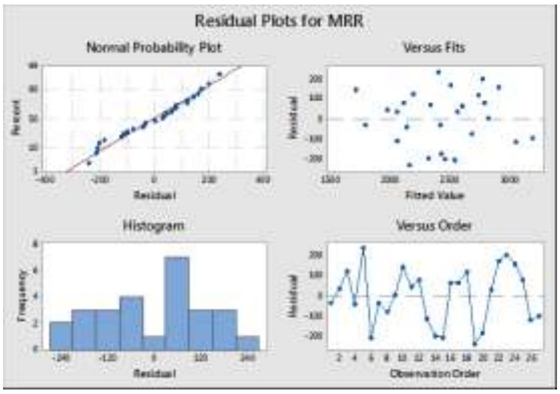

Graph 4.2: Residual plot for MRR

Residual plots are used to evaluate the data for the problems like non normality, non random variation, non constant variance, higher-order relationships, and outliers. It can be seen from Graph 4.2 that the residuals follow an approximately straight line in normal probability plot and approximate symmetric nature of histogram indicates that the residuals are normally distributed. Residuals possess constant variance as they are scattered randomly around zero in residuals versus the fitted values. Since residuals exhibit no clear pattern, there is no error due to time or data collection order.

Table 4.2: ANOVA for MRR

Source	**DOF**	**Sum of square (SS)**	**Mean of square (MS)**	**F**	**P**
Pressure	2	1039043	519522	20.98	0
Current	2	1793471	896735	36.21	0
SOD	2	761912	380956	15.38	0
Error	20	495266	24763		
Total	26	4089691			
S = 157.364		**R-Sq = 87.89%**		**R-Sq (adj) = 84.26%**	

Regression Analysis for MRR

Residual plots are used to evaluate the data for the problems like non normality, non random variation, non constant variance, higher-order relationships, and outliers. It can be seen from graph 4.3 that the residuals follow an approximately straight line in normal probability plot and approximate symmetric nature of histogram indicates that the residuals are normally distributed. Residuals possess constant variance as they are scattered randomly around zero in residuals versus the fitted values. Since residuals exhibit no clear pattern, there is no error due to time or data collection order.

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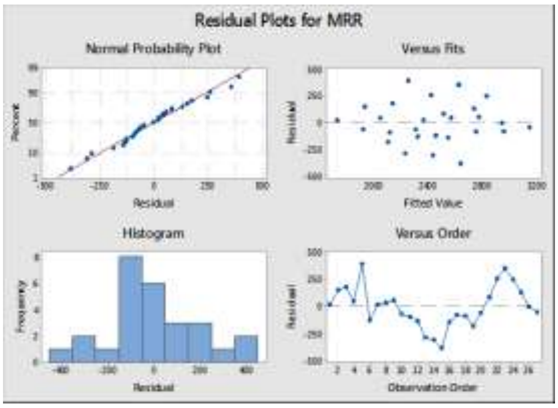

Graph 4.3: Residual plot of regression analysis for MRR

Regression Equation is

MRR = -2676 + 371.5 Pg + 63.01 I + 202.2 SOD

Table 4.3: Regression Coefficient of MRR

TERM	Coef	SE Coef	T	P
Constant	-2676	626	-4.27	0
Pressure	371.5	95.6	3.89	0.001
Current	63.01	9.56	6.59	0
SOD	202.2	47.8	4.23	0

S = 202.811 R-sq = 76.87% R-sq (adj) = 73.85%

Table 4.4: Regression analysis of ANOVA for MRR

Source	DOF	Adj (SS)	Adj (MS)	F	P
Regression	3	3143646	1047882	25.48	0
Pressure	1	621133	621133	15.1	0.001
Current	1	1786856	1786856	43.44	0
SOD	1	735656	735656	17.89	0
Error	23	946046	41132		
Total	26	4089691			

Experimental Validation

For the experimental validation work take two random levels of input parameters within the range of previous experimental level. Putt this input parameters in regression equation and obtain the response parameters. The next step is to perform experiment by taking this level of input parameters and obtain the cuts. Measure the cutting quality like MRR, kerf width and bevel angle. A compare these experimental results with mathematical results.

Table 4.5: Factors and Their Levels for Validation

Factors Designation	Factors	Level 1	Level 2
A	Pressure (Bar)	4.2	4.8
B	Current (A)	42	48
C	Stand-off Distance (mm)	2.5	3.5

The number of runs obtained for cutting stainless steel 410 plates through plasma arc cutting machine using MINITAB17 is:

Table 4.6: Comparison Table for Observation of MRR

Sr. No.	Pressure (Bar)	Current (A)	SOD (mm)	MRR Results		Deviation %
				Experimental	Mathematical	
1	4.2	42	2.5	1924.28	2036.22	5.49
2	4.2	42	3.5	2204.28	2238.42	1.52
3	4.2	48	2.5	2370.89	2415.03	1.82
4	4.2	48	3.5	2589.03	2616.48	1.04
5	4.8	42	2.5	2040.73	2259.87	9.69
6	4.8	42	3.5	2310.73	2461.32	6.11
7	4.8	48	2.5	2830.18	2637.18	6.81
8	4.8	48	3.5	2986.96	2839.38	4.94
Avg. Deviation = 4.67%						

V.CONCLUSION

1. From graphical representation and main effects plot for MRR the current and Stand-off distance are most significant parameter followed by pressure.
2.Mathematical calculation are carried out with help of ANOVA analyzer to find out percentage contribution of each cutting parameters pressure, current and stand-off distance on response parameters MRR, top kerf width, bottom kerf width and bevel angle for cutting of SS410 using CNC plasma arc cutting machine.
3. Validation of the experimental work with the help of Regression Analysis. Mathematical equation for liner order of MRR R-sq is 76.87% and average deviation is 4.67%.

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