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EXPERIMENTAL INVESTIGATION OF PLASMA ARC CUTTING FOR STAINLESS STEEL SHEET

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ABSTRACT

The Plasma arc machining process is the non conventional thermal process which is applicable to perform various operations such as cutting, welding, coating etc. In recent years, considerable experimental investigations have been carried out aiming at improving plasma cutting process performance. In this work, plasma cutting parameters on stainless steel 316L width 2 mm thickness were studied. The cut quality depends on appropriate selection process parameters and it was investigated. The parameters considered include plasma arc current, cutting speed and stand of distance. The effect of cutting parameter on the cut quality was further investigated by monitoring top kerf width, bottom kerf width and kerf taper using full factorial design and finally to find best optimum cutting parameters.

KEYWORDS: Plasma Cutting, Stainless Steel 316L, Kerf Width, DOE & ANOVA

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Original Article

1. INTRODUCTION

Plasma cutting process mostly used in wide range of fabrication industries, in this work to cutting of stainless steel sheet (316 L) for plasma arc cutting machine and Stainless steel sheet exceptionally hard to slice to generation of complex shapes and many-sided profiles with stringent outline necessities. Plasma cutting is to thermal based process to melt and vaporize the base material [1]. There are some researchers to conclude the different speed to produce the same effect on cutting quality [2]. Plasma Current, Cutting speed and Stand of distance are very important significant factors to affect the plasma cutting process [3]. The stainless steel sheet cutting of complex shape by using plasma cutting process is very important to maintain the cut edge quality. Ketul Patel and Pallavi Agarwal [4] studied the effect of process parameters on cutting speed, arc ampere, torch standoff distance and pierce height on bevel angle. J. Kechagias et.al [5] analyzed stainless steel material cutting using plasma arc cutting by using DOE approach and concluded that roughness can be reduced by minimum the cutting speed. S.V.Srinivasa Raju et.al [6] discussed hybridation of response surface methodology and grey relational analysis and evaluation on the effect of machining parameters current, cutting speed and torch height on the kerf width deviation.

2. MATERIAL AND METHODS

2.1. Experimental Equipment

The experiments were conducted in micro step plasma arc cutting machine as shown in figure 1 and specification of plasma arc cutting machine are following table 1.

Table 1: Specification of Machine

Power Input	
Voltage	148 V
Phase	Single Phase
Frequency	50 Hz
Current	40 Amps
Power Output	
Duty Cycle/Rated Output	100% @ 30 Amps
	60% @ 40 Amps
	35% @ 55 Amps
Output Control	Adjustable 20 - 55 Amps
Torch Cable Length	5000 mm
Ground Cable Length	5000 mm
Power Input Cord	2500 mm
Dimensions	
Height	2mm
Width	**50mm**
Depth	**50mm**

Figure 1: Plasma Cutting Machine

2.2. Material

In this present work to analyze the cutting edge quality of stainless steel 316 L Grade 2mm thickness sheet are used .

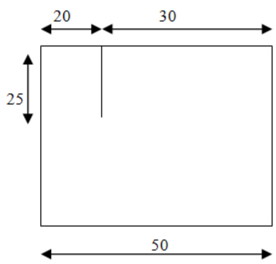

Figure 2: Cutting Profile

2.3. Measurement of Output Responses

This is to measure the responses for Top kerf width and Bottom kerf width by using direct measurement of Tool makers' microscope [9-10].

2.4. Experimental Methods

The experimental plans have used the work Response surface methodology for Box-Behenken design [11]. For three levels, three factors are considered. All the details are tabulated as below:

Table 2: Experimental Plan

SI. No	Plasma Current (Amp)	Cutting Speed (mm/min)	Stand of Distance (mm)	Top Kerf width (mm)	Bottom kerf width (mm)
1	65	3000	2	0.9741	0.8739
2	65	3000	4	0.8651	0.7652
3	65	4000	3	0.9321	0.8324
4	90	4000	2	0.9791	0.8792
5	40	5000	3	0.8932	0.7933
6	65	5000	4	0.8633	0.7632
7	40	3000	3	0.8689	0.7691
8	65	4000	3	0.9543	0.8544
9	90	5000	3	0.9534	0.8533
10	65	4000	3	0.9321	0.8322
11	65	4000	3	0.9401	0.8403
12	90	4000	4	0.8941	0.8942
13	90	3000	3	0.9731	0.8734
14	65	4000	3	0.9291	0.8293
15	65	5000	2	0.8834	0.7832
16	40	4000	2	0.8931	0.7932
17	40	4000	4	0.8732	0.7733

3. RESULTS AND DISCUSSIONS

Response surface methodology is one of the most useful techniques to solve the engineering problems. In this work box-behenken, experimental design was used and the details are shown the table 2. The present work responses are Top kerf width and bottom kerf width and variables are Current, cutting speed and stand off distance. The response surface model for interactions between these variables, was assumed [12].

$$R = b_0 + \sum_{i=1}^{2} b_i X_i + \sum_{i=1}^{2} b_{ii} X_{ii}^{2} + \sum_{i=1}^{2} \sum_{j=1,(i<j)}^{2} b_{ij} X_i X_j + \varepsilon \tag{1}$$

3.1 Analysis of Variance (ANOVA)

ANOVA is a statistical technique the difference between input variable data set [13]. The independent variables are called as factors. From the table 3, it is found that the factors arc current and stand off distance are significant factors to affect the top kerf width. Also, the combination of cutting speed and stand off distance is significantly affecting the top kerf width.

Table 3: ANOVA for Top Kerf Width

Source	Sum of Squares	DF	Mean Square	F Value	p-value
Model	0.02462	9	0.00273	9.1949	0.0040
A-Arc current	0.00920	1	0.00920	30.919	0.0009
B-CS	0.00096	1	0.00096	3.245	0.1146
C-S distance	0.00684	1	0.00684	23.002	0.0020
AB	$4.8E^{-3}$	1	$4.6E^{-4}$	1.6265	0.2429

Table 3: Contd.,					
AC	$1.05E^{-3}$	1	$1.05E^{-3}$	3.5606	0.1011
BC	$1.97E^{-3}$	1	$1.97E^{-3}$	6.6400	0.0366
A^2	$4.16E^{-6}$	1	$4.16E^{-6}$	0.01400	0.9091
B^2	$8.7E^{-4}$	1	$8.7E^{-4}$	2.9321	0.1306
C^2	$2.9E^{-3}$	1	$2.99E^{-3}$	10.0649	0.0157
Resi	$2.08E^{-3}$	7	$2.9E^{-4}$		
LOF	$1.66E^{-3}$	3	$5.5E^{-4}$	5.3127	0.0702
Pure Error	$4.1E^{-4}$	4	$1.0E^{-4}$		
Cor Total	0.0267	16			

Table 4: ANOVA for Top kerf Width

Source	Sum of Squares	DF	Mean Square	F Value	p-value
Model	0.02768	9	0.003076	5.7750	0.0153
A-Arc current	0.01722	1	0.0172237	32.336	0.0007
B-CS	9.8E-4	1	$9.8E^{-4}$	1.8422	0.2168
C-S distance	$2.2E^{-3}$	1	2.2E-3	4.1887	0.0079
AB	$4.9E^{-4}$	1	$4.9E^{-4}$	0.9211	0.3692
AC	$3.04E^{-4}$	1	$3.04E^{-4}$	0.5716	0.4743
BC	$1.9E^{-3}$	1	$1.9E^{-3}$	3.6927	0.0096
A^2	$5.6E^{-4}$	1	$5.6E^{-4}$	1.0595	0.3376
B^2	$3.07E^{-3}$	1	$3.07E^{-3}$	5.7723	0.0473
C^2	$8.6E^{-4}$	1	$8.6E^{-4}$	1.6215	0.2435
Resi	$3.7E^{-3}$	7	$5.3E^{-4}$		
LOF	$3.3E^{-3}$	3	$1.1E^{-3}$	10.658	0.0223
Pure Error	$4.1E^{-4}$	4	$1.03E^{-3}$		
Cor Total	0.0314	16			

Table 4 the p-Value 0.0007 for arc current and p-Value 0.0079 of stand of distance both are significant factors to affect the bottom kerf width. And also combination of cutting speed and stand of distance are significant factors to affect the bottom kerf width. The response surface equations are developed by using response surface methodology, developed second order polynomial regression equation to predict the top and bottom kerf width. The developed regression equations are 2&3.

$$Top \ \ker f = +0.529 + 5.2e^{-3} \times A + 6.6e^{-5} \times B + 0.084 \times C - 4.4e^{-7} \times A \times B - 6.5e^{-4} A \times B + 2.22e^{-5} B \times C - 1.59e^{-6} A^2 - 1.439 e^{-8} B^2 - 0.0266 \ C^2 \quad (2)$$

$$Bottom \ \ker f = +0.5476 + 1.72e^{-4} \times A + 1.6e^{-4} \times B - 0.04215 \times C - 4.4e^{-7} \times A \times B + 3.4e^{-4} A \times B + 2.21e^{-5} B \times C - 1.85e^{-5} A^2 - 2.70e^{-8} B^2 - 0.0143 \ C^2 \quad (3)$$

3.2. Performance Evaluation of Developed Models

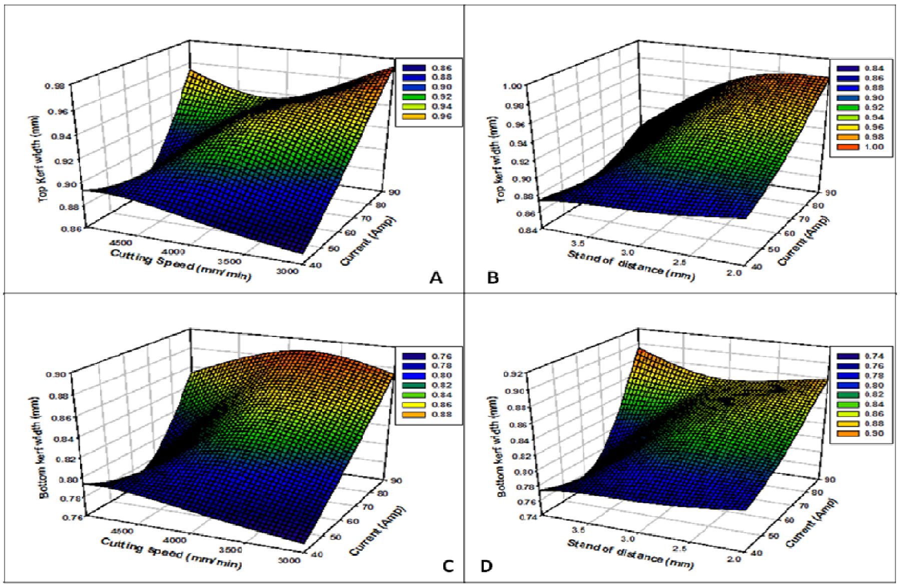

Figure 3: Response Surface Graph

Low cutting speed and current have to achieve minimum kerf width. For corresponding increase in the current, top kerf width also increases. From Fig 3 B low current high level position of stand off distance to achieve minimum kerf width. And high current, low level of stand of distance the top kerf width value is high. Initially fig 3 C cutting speed is 3000 mm/min and current 40 Amps the bottom kerf width value is very less range (0.760 -0.780 mm). Maximum cutting speed 5000 mm/min and current 90 amps the bottom kerf width is high value is 0.8940 mm. fig 3 D shows current ranges are increases the bottom kerf width also increases at all level of stand of distance.

The figure 4 and 5 developed mathematical models values are satisfied with corresponding experimental values. So that developed mathematical model are used to further optimization process.

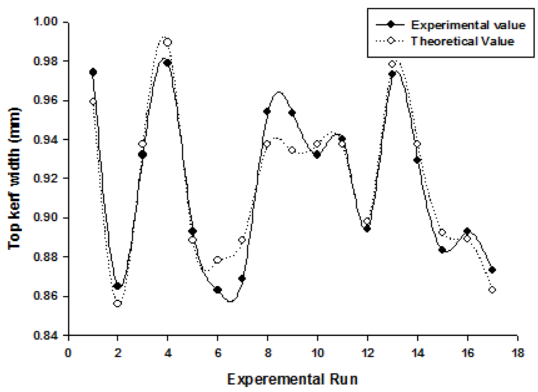

Figure 4: Experimental Value vs Mathematical Model Value for Top Kerf Width

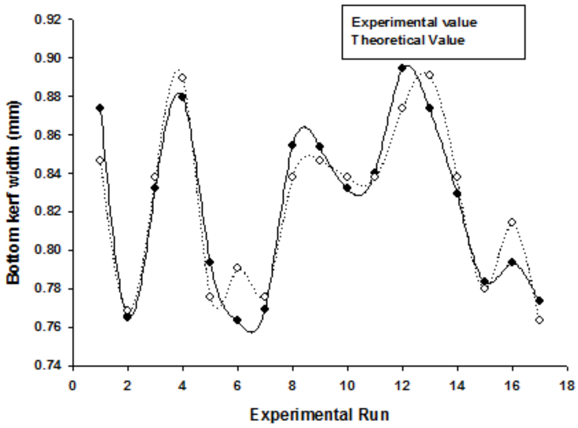

Figure 5: Experimental Value vs Mathematical Model Value for Bottom Kerf Width

4. OPTIMIZATION

Optimization is finding the minimum or maximum given function [14-15]. Optimization can be solving the all complicated engineering problems. In this work to optimization of plasma arc cutting parameter on kerf dimensions for AISI 316L stainless steel sheet for 2mm thickness. In these Work optimization techniques was used to solve the problem by using in design expert software. In these optimization techniques is to set the goal as shown in Table 4. The table 5 shows the output value for top kerf width and bottom kerf width of input variables. To predict the output value top kerf width 0.8523 mm and Bottom kerf width 0.7648 mm has been achieved.

Table 5: Ranges for Optimization

Parameters	Units	Goal	Lower Limit	Upper Limit
Arc current	Amp	minimize	40	90
Cutting Speed	mm/min	maximize	3000	5000
Stand of distance	Mm	minimize	2	4
Top kerf width	Mm	minimize	0.8633	0.9791
Bottom kerf width	Mm	minimize	0.7632	0.8942

Table 6: Optimization Result

SI. No	Plasma Current (Amp)	Cutting Speed (mm/min)	Stand of Distance (mm)	Top Kerf width (mm)	Bottom kerf width (mm)	Desirability
1	40	4999.99	2	0.8523	0.7648	0.998
2	40.19	5000	2	0.8526	0.7648	0.997
3	40	5000	2.01	0.8531	0.7651	0.996
4	40.85	5000	2	0.8537	0.7649	0.994
5	40	4982.43	2	0.8532	0.7661	0.994
6	40	4999.24	2.04	0.8551	0.766	0.991
7	40	4965.15	2	0.8541	0.7674	0.99
8	42.24	5000	2	0.856	0.7652	0.988
9	40	5000	2.07	0.8566	0.7665	0.988
10	42.43	4999.99	2	0.8563	0.7652	0.987

5. CONCLUSIONS

Response surface methodology based optimization techniques were applied in this work to improve the multi-response characteristics such as top kerf width and bottom kerf width of AISI 316L stainless steel sheet during Plasma arc cutting process. The conclusions of this work are summarized as follows:

- The ANOVA tables of the top kerf width and bottom kerf width shows the developed models are significant
- The Response surface graph used to graphically to selecting the plasma arc cutting parameters and as long as the favored top kerf width and bottom kerf width values.
- The optimal parameters combination was determined as plasma arc current at 40 Amp, cutting speed at 4999.9 mm/min and stand of distance 2mm.
- This work demonstrates the method of using Response surface methodology for optimizing the Plasma arc cutting process parameters for multiple responses are top and bottom kerf width characteristics.

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