

Analysis of Heat Affected Zone in Plasma Arc Cutting of SS 316l Plates

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ABSTRACT: In this paper, experimental work is carried out by using air plasma arc cutting process on SS 316l plates having thickness 4 mm and 12 mm. Voltage, cutting speed and gas pressure are considered as input parameters for experimentation. DoE is done to determine optimum number of experiments with combination of these input parameters and heat affected zone (HAZ) is considered as response parameter. Parameters viz. current and gas flow rate kept at constant level for each plate. ANOVA is used to determine influence of each input parameter on HAZ. It is found that voltage and cutting speed are significant parameters which effects HAZ. Relation between process parameters and response parameter is found through S/N ratio analysis. It is found that HAZ increases with increase in voltage and gas pressure, whereas decreases with increase in cutting speed.

KEYWORDS: Plasma cutting, Heat affected zone, ANOVA, Design of experiment, Stainless steel 316l.

I. INTRODUCTION

Thermal cutting processes is an essential part of manufacturing processes of steel component. The main advantage of thermal cutting technique is their versatility and high production rate that can be achieved with the use of them. However, they also have some disadvantages, since they produce heat affected zone due to high temperature needed achieve cutting of metals. HAZ produced can significantly reduce their service life [1]. Plasma arc cutting process is widely used in industries to cut different materials under several operating conditions. In which cutting action takes place because of transferred electric arc which is established between a negative electrode(cathode) and a positive electrode (anode) that is the metallic work-piece to be cut [2].

The aim of this paper is to analyse the effect of process parameters like arc voltage, cutting speed and gas pressure on the heat affected zone produced. Experimental work is carried out as per the design of experiment. S/N ratio analysis is used to identify relation among the process parameter and the response variable. And to determine optimal combination of process parameters which will give minimum value of HAZ. HAZ can be identified with help of hardness value as well as with the help of structural variation. In this paper measurement is carried out on the basis of structural variation.

II. RELATED WORK

Heat input depends on parameters like current, voltage and cutting speed. HAZ increases with increase in heat input. Heat input is directly proportional to voltage and current whereas inversely proportional to cutting speed [3]. Optimal combination of these parameters is required to be determined in order to minimise HAZ. As the amount of HAZ significantly reduces service life of components [4]. Other parameters like current and gas flow are kept at constant level depending on the nozzle configuration. Effect of these process parameter is catastrophic, higher value of current and lower value of gas pressure for corresponding nozzle bore diameter and length may result in double arcing which will results in melting of consumables i.e. nozzle and electrode [5-6].

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Akkurt et.al carried out cutting of aluminium alloy with different thermal and abrasive waterjet machining. It is found that plasma cutting is better than oxyfuel cutting process which produces higher reduction in hardness value, whereas waterjet machining produces no microstructural changes and harness reduction [7]. Tingaev et.al carried out evaluation of quality of cut edge by plasma and oxyfuel cutting of alloy steels with the help of chemical composition at cut area, microstructure, and hardness value. It was found that lower values of depth of HAZ and hardness were obtained with the help of plasma cutting as compared with oxyfuel cutting process [8].

III. EXPERIMENTAL PLAN

In this study, Taguchi method is used to optimise response parameter i.e. heat affected zone. The experiments were performed as per the Taguchi design of experiment. ANOVA is also done to determine influence of each process parameter over heat affected zone.

2.1 Material and Experimental Setup

Stainless steel 316l material is used as workpiece material for experimentation. It is known as marine grade steel as it is having higher resistance to corrosion in aqueous solution. It is also used in many structural applications because of its resistance to localised type of corrosion i.e. crevice and pitting [8-9]. Experiments were performed over plate having thickness 4 mm and 12 mm. The chemical composition of plate material is as given in the below Table 1.

Table 1 Stainless steel 316l composition

Contents	Fe	Cr	Ni	Mo	Mn	Si	P	S	C
	66.025	17.598	9.413	1.863	1.419	0.369	0.031	0.030	0.024
% Limit	-	-	-	-	-	-	-	-	-
	67.078	18.137	10.341	2.102	1.563	0.483	0.032	0.031	0.026

Experimental work is performed on CNC Plasma cutting system i.e. HyperthermPowermax 1650. The operating specifications of the machine setup are given in the below Table 2. Compressed air is used as cutting as well as assist gas. In order to increase operating life of electrode, electrode tip is made up of hafnium material with copper holder. Stand-off distance i.e. the distance between nozzle and the workpiece is controlled by using pilot arc circuit.

Table 2 Operating specifications of machine setup

Sr. No.	Parameter	Powermax1650
1	Maximum cutting speed (mm/min)	7000
2	Maximum Gas flow rate (lit/min)	260
3	Gas pressure (psi)	40-90
4	Current (amp)	30-100
5	Voltage (volt)	100-200
6	Duty cycle (min)	8
7	Recommended capacity (mm)	12

2.2 Design of Experiment

During this study arc voltage, cutting speed and gas pressure are considered as process parameter. Whereas gas pressure and arc current kept constant their level is selected based thickness of work material. Process parameters and their levels considered for experimentation is given in the below Table 3. Level of constant parameter for each plate thickness is given in Table 4. Selection of these level is done for respective plate thickness in order to obtain through cuts.

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Table 3 Different process parameters with their corresponding levels for each plate thickness

Process Parameter	4 mm plate levels			12 mm plate level		
	1	2	3	1	2	3
Voltage (volt)	135	140	145	155	160	165
Cutting Speed (mm/min)	3000	3500	4000	700	900	1100
Gas Pressure (psi)	55	60	65	75	80	85

Table 4 Level of constant parameter for each plate thickness

Constant Parameter	4 mm plate	12 mm plate
Gas Flow rate (lit/min)	210	250
Current (amp)	60	100

There are three process parameters with their three levels considered for experimentation. For three parameters and three levels degrees of freedom comes to be equal to 8. The minimum no of experiments which are required to be performed must be equal to or greater than degrees of freedom hence L9 orthogonal array is selected [10]. Minitab 17 software is used to carry to determine optimal combination of process parameters and their levels given in Table 5.

Table 5 Experimental layout as per DoE for each plate thickness

Sr. No.	4 mm plate thickness			12 mm plate thickness		
	Voltage (volt)	Cutting Speed (mm/min)	Gas Pressure (psi)	Voltage (volt)	Cutting Speed (mm/min)	Gas Pressure (psi)
1	135	4000	65	155	700	75
2	135	3500	60	155	900	80
3	135	3000	55	155	1100	85
4	140	3000	60	160	700	80
5	140	3500	65	160	900	85
6	140	4000	55	160	1100	75
7	145	3000	65	165	700	85
8	145	3500	55	165	900	75
9	145	4000	60	165	1100	80

2.3 Experimental Work

Cuts of length 200 mm were obtained over each plate thickness as per the design of experiment. Fig.1 shows cuts obtained over plate with thickness 4 mm and 12 mm.



Fig.1 Experimental cuts obtained over (a) 4 mm plate and (b) 12 mm plate thickness

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To measure heat affected zone small workpiece is prepared. It is prepared from right side of the cutting direction of length 15 mm. Polishing is done with help of polish paper of 400, 800, and 1200. In order to explore microstructure etching is done of polished specimen Aqua Regia is used as etchant. Work sample is observed with 100x and 200x magnification under microscope. USB interface is provided with microscope and Dixel imaging software. With help of which measurement of HAZ is done. Fig.2 shows measurement carried out over plate of 4 mm thickness (a) and 12 mm plate thickness (b).

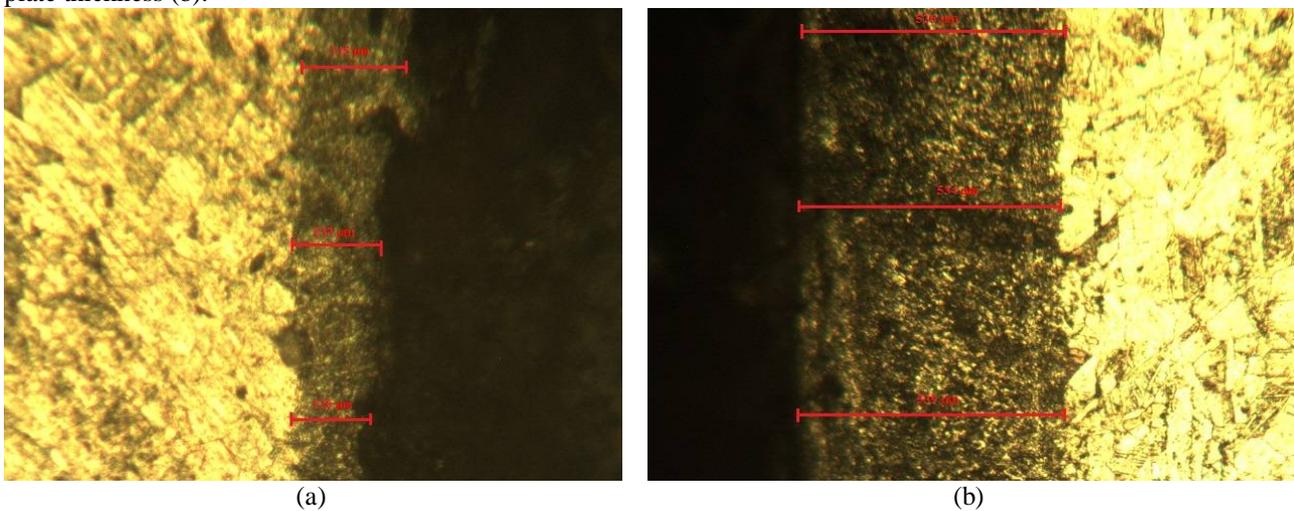


Fig. 2 Measured images of HAZ (a) for 4 mm plate and (b) for 12 mm plate thickness

Measured values of HAZ for each experiment is given in below Table 6. From the results obtained by measurement it is found that HAZ varies between 0.139-0.276 mm for 4 mm plate thickness and for 12 mm plate thickness it varies between 0.419-0.735 mm. As the response variable HAZ is required to be kept at lower side smaller the better characteristic of the S/N ratio is used for analysis. Computed values of S/N ratio are also tabulated in Table 6.

Table 6 Measured values of HAZ for each plate thickness with their S/N ratios

Sr. No.	For 4 mm plate thickness		For 12 mm plate thickness	
	HAZ (mm)	S/N ratio	HAZ (mm)	S/N ratio
1	0.139	17.139	0.521	5.663
2	0.149	16.536	0.498	6.055
3	0.183	14.751	0.419	7.555
4	0.223	13.033	0.613	4.250
5	0.203	13.850	0.551	5.176
6	0.141	17.015	0.439	7.150
7	0.276	11.181	0.735	2.674
8	0.243	12.287	0.659	3.622
9	0.198	14.066	0.538	5.384

IV. RESULTS AND DISCUSSION

In the present study effect of process parameters i.e. arc voltage, cutting speed and gas pressure on HAZ is done with the help of S/N ratio analysis. Smaller the better characteristics of the S/N ratio is used as the response is required to be kept at lower side. S/N ratio for smaller the better characteristics is given by eq. (1). Effect of each parameter at different level is calculated by using S/N ratio is shown in below Table 7. From the chosen process parameters,

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maximum S/N ratio is obtained for voltage followed by cutting speed and gas pressure. Which indicates that voltage is the most predominant factor affecting HAZ followed by cutting speed and gas pressure.

$$\frac{S}{N} = -10 \log \frac{1}{N} \sum_{i=1}^n Y^2 \quad \dots\dots\dots(1)$$

Where, Y= value of response characteristics and N= no. of replications of experiment

Table 7 Response table for S/N ratios for each plate thickness

Level	4 mm plate thickness			12 mm plate thickness		
	Voltage (volt)	Cutting Speed (mm/min)	Gas Pressure(psi)	Voltage (volt)	Cutting Speed (mm/min)	Gas Pressure(psi)
1	16.14	12.99	14.68	6.43	4.20	5.48
2	14.63	14.22	14.55	5.53	4.95	5.23
3	12.51	16.07	14.06	3.89	6.69	5.13
Delta	3.63	3.09	0.63	2.53	2.51	0.34
Rank	1	2	3	1	2	3

Figure 3 shows main effect plot of S/N ratio for response HAZ. It is seen from the plot that HAZ increases with increase in voltage, decrease in cutting speed and gas pressure, smaller value of HAZ is obtained at process parameter setting of 135 volt voltage, 4000 mm/min cutting speed, and 55 psi gas pressure for 4 mm plate thickness, and for 12 mm plate thickness at 150 volt voltage, 1100 mm/min cutting speed, and 75 psi gas pressure.

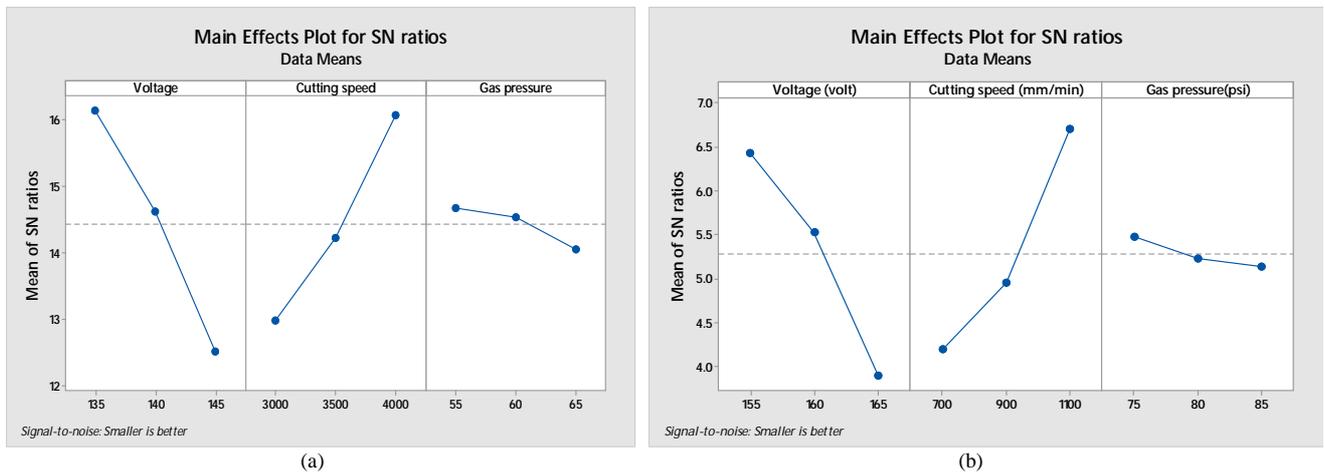


Fig.3 Effect of process parameters on HAZ (a) for plate 4 mm plate (b) for plate 12 mm plate thickness

Further effect of each process parameter on response is determined by using ANOVA (Analysis of Variance) which is a statistical technique [11]. Significance of each process parameter is determined by using F-test at confidence level of 95%. It is seen that F value for voltage and cutting speed is found greater than critical value of F found from standard table of F value at 95% confidence level with 2 degrees of freedom of error and 8 total degrees of freedom for each plate thickness i.e. equal to 19.38 [12]. Whereas F values for gas pressure are found lesser than critical values. Hence voltage and cutting speed found to have significant effect on HAZ. Results of ANOVA for each plate thickness is given in the Table 8.

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Table 8 ANOVA result table for each plate thickness

Source	DF	For 4 mm plate thickness			12 mm plate thickness		
		Seq SS	Adj MS	F-Value	Seq SS	Adj MS	F-Value
Voltage	2	0.010248	0.005124	40.35	0.042167	0.021083	35.25
Cutting speed	2	0.006986	0.003493	27.50	0.038555	0.019277	32.23
Gas Pressure	2	0.000546	0.000273	2.15	0.001270	0.000635	1.06
Error	2	0.000254	0.000127		0.001196	0.000598	
Total	8	0.018034			0.083188		

V. CONCLUSIONS

In this study plates of stainless steel 316l are cut with CNC controlled plasma arc cutting process, and HAZ quality characteristic is monitored. Following conclusions are drawn from the experimental work carried out.

- Through S/N ratio analysis it is found that voltage is the most affecting parameter followed by cutting speed and gas pressure. From S/N ratio plot it is found that increase in voltage result in increase in HAZ as it results in increase in amount of heat supplied, increase in cutting speed results in reduction in HAZ as it reduces amount of heat supplied, whereas gas pressure is required to be kept at lower level in order to minimise HAZ as increase in gas pressure results in increase in heat flux.
- ANOVA is done to determine influence of each process parameter on HAZ. It is found that voltage and cutting speed are the significant parameter which affects HAZ.
- For 4 mm, thick plate optimal combination of voltage, cutting speed, and gas pressure which will produce minimum HAZ is 135 volts, 4000 mm/min, and 55 psi and for 12 mm plate thickness it is found at 155 volt, 1100 mm/min, and 75 psi.

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