IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X
PP. 75-80
www.iosrjournals.org

Experimental Analysis of Plasma Arc Cutting Process for SS 316l Plates

S. S. Pawar, K. H. Inamdar
(Department of Mechanical Engineering, Walchnd College of Engineering, Sangli, India)

Abstract: *In this paper quality characteristics of plasma cutting process for stainless steel 316l plates with different thickness are analyzed through experiments. The quality of the cut has been monitored by measuring kerf width and taper. Plate with thickness 4 mm, 8 mm and 12 mm are cut with different combination of input parameters as per the DoE. Input parameters used for experimental work are cutting speed, arc voltage and gas pressure. Effect of each process parameter on quality characteristic of cut is determined by using ANOVA. It is found that arc voltage was the major influencing parameter which affects kerf followed by cutting speed, and gas pressure. Whereas taper, influenced by cutting speed followed by arc voltage, and gas pressure. These two quality characteristics were optimized by using Grey Relational Analysis.*
Keywords: *ANOVA, design of experiments, kerf, plasma cutting, taper*

I. Introduction

There are number of thermal cutting techniques like plasma arc, laser, oxyacetylene flame etc. out of which plasma arc cutting is highly efficient cutting method for medium thick plates. Plasma arc cutting process offers massive advantage in terms of cutting speed and initial cost when compared to oxy-fuel cutting and water jet cutting. Laser cutting process is advantageous over plasma cutting process of being more precise and consumes less energy when cutting sheet metal. However, most of the industrial lasers are incapable to cut through the thick metal plates that plasma arc can [1].

The basic plasma cutting system composed of a power supply, an arc starting circuit and a torch. Torch comprises of nozzle and electrode assembly with shielding cap [2]. Cutting system can be operated on transferred arc and non-transferred arc mode. In transferred arc mode arc is formed between the electrode and the nozzle known as pilot arc which is transferred to the work piece for cutting, where as in non-transferred mode the arc is formed between electrode and nozzle, which is used for cutting [3]. Quality of cut produced by using this process can be accessed by measuring kerf width, taper (conicity), heat affected zone, surface finish, material removal rate etc. They were influenced by arc voltage, current, cutting speed, gas pressure, stand off distance etc. [4-6].

The challenge for researcher in PAC process is to study occurrence of phenomenon like double arcing and magnetic arc blow. Double arcing will result in melting of consumables like nozzle and electrode. On the other hand magnetic arc blow will result in deflection of arc which result poor quality characteristics of cut [7-9]. Efforts are taken by the researchers in order to increase flux density i.e. amount of heat per unit area generated by the system. This will results in better quality of cut while cutting plates with higher thickness [10-12].The objective of this paper is to analyse plasma arc cutting process and determine most influencing parameters that affects the quality of cut produced by air plasma cutting. Air as a cutting gas is available at no cost against other cutting gases. This reduces operating cost significantly. For this reason, it is widely used in industrial practices for cutting mild steel and stainless steel materials. But air is an active gas which results in decreased quality of cut. Statistical analysis of the results obtained with different operating conditions is done to identify the effect of each input parameter to quality characteristics of cut and to optimise cut quality.

II. Experimental Plan

In this study Taguchi Grey Relational Analysis (TGRA) is used to optimize multiple responses. The experiments were performed as per Taguchi design of experiments.Stainless Steel 316L used as workpiece material. The chemical composition of the plate material is given in the Table 1.

Table 1 stainless steel 316l composition

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

Experimental work is carried out with CNC Plasma cutting system (Hypertherm Powermax 1650). Compressed air is used as cutting as well as assist gas. Electrode used is of hafnium tip with copper holder. In the existing setup the distance between the nozzle and the work piece has been controlled with pilot arc circuit. Plasma torch is provided swirl element at the top which produces swirling flow of cutting gas. This enables arc to concentrate over one edge of the cut work piece. Because of this taper produced on one edge of the cut was smaller than other one.

2.1 Selection of Process Parameters and Levels

Arc voltage, cutting speed and gas pressure were considered as input parameters for experimentation. Thickness of the plate has been varied during experimentation. Plates having thickness 4 mm, 8 mm and 12 mm were used for experimentation. Different levels of above input parameter were chosen in order to obtain through cut, which are given in the Table 2. Other parameters like current, and gas pressure were kept constant for each plate thickness their level is listed in the Table 3.

Table 2 process parameters and their corresponding levels for different thicknesses of plate

Process Parameters	4 mm plate levels			8 mm plate levels			12 mm plate levels		
	1	2	3	1	2	3	1	2	3
Voltage (volt)	135	140	145	145	150	155	155	160	165
Cutting Speed (mm/min)	3000	3500	4000	1500	1800	2100	700	900	1100
Gas Pressure (psi)	55	60	65	65	70	75	75	80	85

Table 3 level of constant parameter for each plate thickness

Constant Parameters	For 4 mm plate	For 8 mm plate	For 12 mm plate
Gas Flow rate (lit/min):	210	230	250
Current (amp):	60	80	100

2.2 Design of Experiments (DoE)

With help of design of experiment the minimum number of experiments which are required to be performed are determined. It uses orthogonal array in order to express the relationship among the factors under investigation. The selection of suitable orthogonal array depends on the total degrees of freedom (DOF) of the problem under consideration. In our case there were 3 process parameters with their 3 different levels. The degree of freedom comes to be equal to 8, hence selecting L9 orthogonal array as the number of experiments to be conducted must be equal to or greater than the degrees of freedom [13].

III. Experimentation and Analysis

Linear cuts of length 150 mm were cut over each plate as per the design of experiment. Fig.1 shows image of cuts obtained over the plates. Measurement of kerf and taper was done USB 2.0 Interfacing Camera which has been provided with DinoCapture software interface to capture live image to measure dimensions. Fig.2 shows images of kerf and taper measurement.

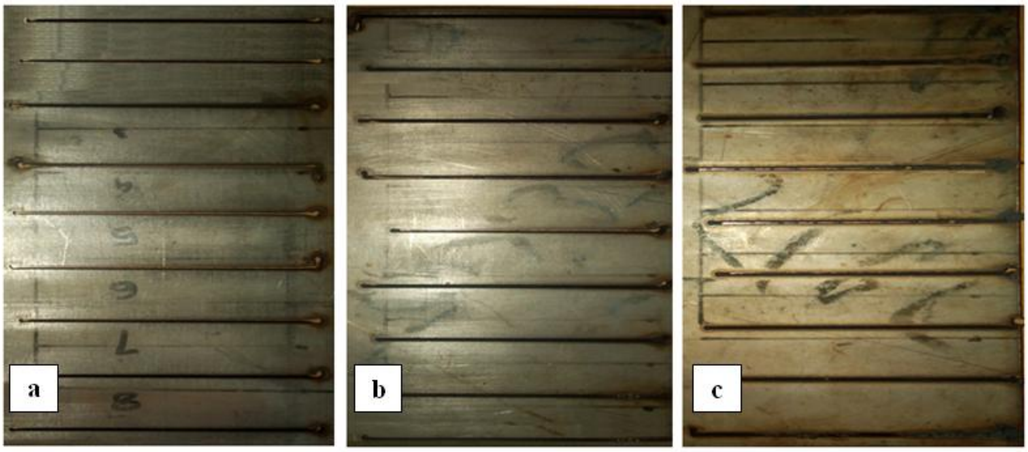

Figure 1 cuts obtained over (a) 4 mm, (b) 8 mm and (c) 12 mm plate

 DOI: 10.9790/1684-17010057580

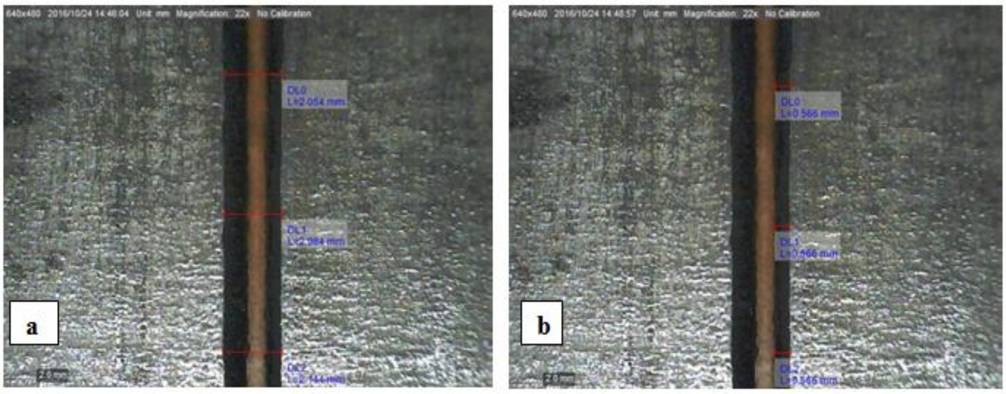

Figure 2 measurement of (a) kerf width and (b) taper with dinocapture usb 2.0 software

Results obtained by measurement of kerf and taper for each of the plate thickness along with the design of experiment are listed in the below Table 4.

Table 4 design of experiments and response values

Sr. No.	Thickness of plate (mm)	Voltage (volt)	Cutting speed (mm/min)	Gas pressure (psi)	Kerf width (mm)	Taper (mm)
1	4	135	4000	65	1.905	0.695
2		135	3500	60	2.036	0.663
3		135	3000	55	2.153	0.623
4		140	3000	60	2.203	0.423
5		140	3500	65	2.131	0.589
6		140	4000	55	2.058	0.673
7		145	3000	65	2.245	0.435
8		145	3500	55	2.238	0.512
9		145	4000	60	2.163	0.631
10	8	145	1200	65	2.912	0.898
11		145	1500	70	2.425	1.023
12		145	1800	75	2.032	1.112
13		150	1200	70	3.151	0.843
14		150	1500	75	2.475	0.912
15		150	1800	65	2.435	1.089
16		155	1200	75	3.275	0.705
17		155	1500	65	3.259	0.803
18		155	1800	70	2.892	0.923
19	12	155	700	75	2.697	1.141
20		155	900	80	2.583	1.204
21		155	1100	85	2.439	1.174
22		160	700	80	3.125	0.992
23		160	900	85	2.835	1.035
24		160	1100	75	2.589	1.189
25		165	700	85	3.415	0.898
26		165	900	75	2.945	1.105
27		165	1100	80	2.839	1.145

3.1 Analysis of Variance (ANOVA)

ANOVA technique widely used to provide a measure of confidence. Contribution of each parameter can also be determined. This is done with the help of Minitab 17 software. Results obtained by ANOVA for kerf and taper of 4 mm plate thickness are shown in Table 5 and Table6.

DOI: 10.9790/1684-17010057580

Table 5 ANOVA results of 4 mm plate for kerf

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Voltage (volt)	2	0.049892	51.79%	0.049892	0.024946	25.90	0.032
Cutting speed (mm/min)	2	0.037487	38.91%	0.037487	0.018744	20.60	0.045
Gas pressure (psi)	2	0.005008	5.20%	0.005008	0.002504	2.06	0.327
Error	2	0.003935	4.85%	0.003935	0.001968		
Total	8	0.096322	100.00%				

Table 6 ANOVA results of 4 mm plate for taper

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Voltage (volt)	2	0.055353	37.37%	0.055353	0.027676	104.79	0.009
Cutting speed (mm/min)	2	0.064138	43.30%	0.064138	0.032069	112.46	0.008
Gas pressure (psi)	2	0.019084	12.89%	0.019084	0.009542	36.13	0.027
Error	2	0.009528	6.43%	0.009528	0.004764		
Total	8	0.148103	100.00%				

Results obtained from ANOVA it is found that arc voltage is contributing more to kerf width followed by cutting speed and gas pressure, and for taper cutting speed contributing more followed arc voltage and gas pressure. Arc voltage and cutting speed found significant for kerf width as the p value is below 0.05 (95% confidence level is considered), and for taper all three parameters are found significant in case of 4 mm plate thickness.

3.2 Grey Relational Analysis

In our case, there are two quality characteristics which are to be minimized. Therefore, the problem is required to be converted into single objective optimization problem i.e. grey relational grade using grey relational analysis. Following are the steps followed to carry GRA [14]:

A) Normalization of S/N ratio for each response

In this step data is preprocessed to transform original sequence to a comparable sequence. For this purpose, the experimental data of S/N ratio is normalized in the range of zero to one. As both the responses kerf width and taper were to be kept minimum in order to increase quality of cut. Hence using smaller the better characteristic of signal to noise ratio which is given by eq. (1),

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

Where, Y is the value of the response for j^{th} and i^{th} experimental condition, with i=1, 2, 3…n and j = 1, 2…k.

There are three approaches to carry normalization. These approaches depends on whether we require smaller is better, higher is better, or nominal the best. As both the quality characteristics are required to be minimized smaller is better approach is used. Normalized as by using eq. (2):

$$Xi = \frac{\max Xi(k) - Xi(k)}{\max Xi(k) - \min Xi(k)} \quad \text{..... (2)}$$

Where, max Xi(k) denotes maximum value of S/N ratio whereas, min Xi(k) denotes minimum value of S/N ratio for response under consideration. Xi (k) is the reference value of S/N ratio. Calculated values of S/N ratio and normalized S/N ratio are listed in Table 7.

B) Computation of deviation sequence

After normalization difference between reference sequence and comparability sequence gives deviation sequence. Deviation sequence is given by eq. (3),

$$\Delta_{0i}(k) = \left| Xo(k) - Xi(k) \right| \quad \text{..... (3)}$$

Where, Xo(k) is the reference sequence and Xi(k) is the comparability sequence.

C) Determine grey relational coefficient (GRC)

Relation between the ideally normalized and actually normalized S/N ratio is given by GRC. If the two sequences match then their grey relational coefficient is 1. The grey relational coefficient is given by eq. (4),

$$\gamma(Xo(k), Xi(k)) = \frac{\Delta\min + \zeta\,\Delta max}{\Delta oi(k) + \zeta\,\Delta max} \quad \text{..... (4)}$$

Where, Δmin denotes minimum and Δmax value denotes maximum deviation sequence. Δ_{0i}(k) is the reference deviation sequence and ζ is the distinguishing coefficient. Its value can be adjusted in the range of 0 to 1. It is taken equal to 0.5.

D) Determine grey relational grade (GRG)

The overall evaluation of multiple responses is done with the help of grey relational grade. It is the average sum of grey relational coefficients of each response which is given as by eq. (5):

$$\gamma(Xo, Xi) = \frac{1}{m}\sum_{i=1}^{m}\gamma(Xo(k), Xi(k)) \quad \text{...... (5)}$$

Where, $\gamma(Xo,Xi)$ is the grey relational grade for the jth experiment and m the number of quality characteristics. Calculated values of GRG are listed in Table 7. GRG is required to be higher in order to get optimum setting of process parameters.

Table 7 calculated values of Grey Relational Grades

Sr. No.	S/N ratio kerf	S/N ratio taper	Normalized S/N ratio kerf	Normalized S/N ratio taper	Deviation sequence kerf	Deviation sequence taper	GRC kerf	GRC taper	GRG	Rank
1	-5.5979	3.1603	0.0000	1.0000	1.0000	0.0000	0.3333	1.0000	0.6667	6
2	-6.1756	3.5697	0.4050	0.9051	0.5950	0.0949	0.4566	0.8404	0.6485	7
3	-6.6609	4.1102	0.7452	0.7797	0.2548	0.2203	0.6624	0.6942	0.6783	4
4	-6.8603	7.4732	0.8850	0.0000	0.1150	1.0000	0.8130	0.3333	0.5732	9
5	-6.5717	4.5977	0.6827	0.6667	0.3173	0.3333	0.6117	0.6000	0.6059	8
6	-6.2689	3.4397	0.4704	0.9352	0.5296	0.0648	0.4856	0.8853	0.6855	3
7	-7.0243	7.2302	1.0000	0.0563	0.0000	0.9437	1.0000	0.3463	0.6732	5
8	-6.9972	5.8146	0.9810	0.3846	0.0190	0.6154	0.9634	0.4483	0.7058	1
9	-6.7011	3.9994	0.7734	0.8054	0.2266	0.1946	0.6882	0.7199	0.7040	2
10	-9.2838	0.9345	0.7539	0.5310	0.2461	0.4690	0.6701	0.5160	0.5931	7
11	-7.6942	-0.1975	0.3704	0.8169	0.6296	0.1831	0.4427	0.7320	0.5873	8
12	-6.1585	-0.9221	0.0000	1.0000	1.0000	0.0000	0.3333	1.0000	0.6667	3
13	-9.9690	1.4834	0.9191	0.3923	0.0809	0.6077	0.8608	0.4514	0.6561	5
14	-7.8715	0.8001	0.4132	0.5649	0.5868	0.4351	0.4601	0.5347	0.4974	9
15	-7.7300	-0.7406	0.3791	0.9541	0.6209	0.0459	0.4461	0.9160	0.6810	2
16	-10.3042	3.0362	1.0000	0.0000	0.0000	1.0000	1.0000	0.3333	0.6667	3
17	-10.2617	1.9057	0.9897	0.2856	0.0103	0.7144	0.9799	0.4117	0.6958	1
18	-9.2240	0.6960	0.7394	0.5912	0.2606	0.4088	0.6574	0.5502	0.6038	6
19	-8.6176	-1.1457	0.2987	0.8167	0.7013	0.1833	0.4162	0.7318	0.5740	7
20	-8.2425	-1.6125	0.1704	1.0000	0.8296	0.0000	0.3761	1.0000	0.6880	1
21	-7.7442	-1.3934	0.0000	0.9140	1.0000	0.0860	0.3333	0.8532	0.5933	5
22	-9.8970	0.0698	0.7363	0.3395	0.2637	0.6605	0.6547	0.4308	0.5428	8
23	-9.0511	-0.2988	0.4470	0.4842	0.5530	0.5158	0.4748	0.4922	0.4835	9
24	-8.2626	-1.5036	0.1773	0.9572	0.8227	0.0428	0.3780	0.9212	0.6496	3
25	-10.6678	0.9345	1.0000	0.0000	0.0000	1.0000	1.0000	0.3333	0.6667	2
26	-9.3817	-0.8672	0.5601	0.7074	0.4399	0.2926	0.5320	0.6308	0.5814	6
27	-9.0633	-1.1761	0.4512	0.8287	0.5488	0.1713	0.4767	0.7448	0.6107	4

Taguchi method is used to determine optimum value of process parameters to maximize GRG. Table 9 shows results obtained by this.

Table 8 optimal process parameter level for each plate thickness

Parameters	4 mm plate	8 mm plate	12 mm plate
Voltage (volt)	145	145	155
Cutting speed (mm/min)	4000	1800	1100
Gas pressure (psi)	55	65	80

Cuts were obtained with above optimal process parameters over each plate thickness and measurement of kerf width and taper is done results obtained by the measurement are shown in Table 10.

Table 9 results obtained by optimal process parameters

Parameters	4 mm plate	8 mm plate	12 mm plate
Kerf (mm)	2.078	2.029	2.435
Taper (mm)	0.645	1.112	1.189

IV. Conclusions

Plasma arc cutting is a very promising thermal cutting technique which gives high productivity with good quality. In this study stainless steel 316l is cut with CNC controlled plasma arc cutting process, and kerf width and taper these two quality characteristics were monitored.

 DOI: 10.9790/1684-17010057580

a) Through S/N ratio analysis it is found that increase in arc voltage results in increase kerf width and decrease in taper produced. Increase in cutting speed results in decreased kerf width and increase in taper. Increase in gas pressure causes increase in kerf width and decrease in taper produced.
b) ANOVA is done in order to identify influence of process parameters on quality characteristics. It is found that arc voltage and cutting speed are significant for kerf width. Whereas all three input parameters arc voltage, cutting speed and gas pressure are found significant for taper.
c) Contribution of arc voltage is found more for kerf width followed by cutting speed and gas pressure. Cutting speed is contributing more for taper followed by arc voltage and cutting speed.
d) GRA is used to optimize both the responses kerf width and taper. GRG is found maximum for 4 mm plate at 145 volt, 3500 mm/min and 55 psi, for 8 mm plate at 155 volt, 1500 mm/min and 65 psi, for 12 mm plate at 155 volt, 900 mm/min and 80 psi.
e) Taguchi method is employed to optimize GRG it is found that GRG is maximum for 4 mm plate at 145 volt, 4000 mm/min and 55 psi, for 8 mm plate at 145 volt, 1800 mm/min and 65 psi, for 12 mm plate 155 volt, 1100 mm/min and 80 psi. Better results of quality characteristics were obtained by using these process parameters.

Acknowledgement

The authors would like to acknowledge Kirti Profiles Private Limited to support for performing the experiments required for this work.

References

[1] D. Krajcarz, Comparison Metal Water Jet Cutting with Laser and Plasma Cutting, *Procedia Engineering, 69(2),* 2014, 838-843.
[2] M. Radovanovic and M. Madic, Modeling the Plasma Arc Cutting Process Using ANN, *Nonconventional Technologies Review, 4,* 2011, 43-48.
[3] Ozek, U. Çayda, and E. Unal, A Fuzzy Model for Predicting Surface Roughness in Plasma Arc Cutting of AISI 4140 Steel, *Materials and Manufacturing Processes, 27,* 2012, 95-102.
[4] Gullu and U. Atici, Investigation of the effects of plasma arc parameters on the structure variation of AISI 304 and St 52 steels, *Materials and Design, 27,* 2006, 1157-1162.
[5] K. Salonitis and S. Vatousianos, Experimental Investigation of the Plasma Arc Cutting Process, *Procedia CIRP, 3,* 2012, 287-292.
[6] R. Bini, B.M. Colosimo, A.E. Kutlu and M. Monno, Experimental study of the features of the kerf generated by a 200A high tolerance plasma arc cutting system, *Journal of Materials Processing Technology, 96,* 2008, 345-355.
[7] L. Prevosto, H. Kelly and B. Mancinelli, On the Double Arcing Phenomenon in A Cutting Arc Torch, *Numerical Simulation of Physics and Engineering Processes, 23,* 2011, 501-524.
[8] Y. Yamaguchi, Y. Katada, T. Itou, Y. Uesugi and T. Ishijima, Experimental study of magnetic arc blow for plasma arc cutting, *Welding International, 7,* 2015, 37-41.
[9] R. P. Reis, D.Souza and A. Scotti, Models To Describe Plasma Jet, Arc Trajectory And Arc Blow Formation In Arc Welding, *Welding In the world, 55,* 2011, 24-32.
[10] Q. Zhou, H. Li, F. Liu, S. Guo, W. Guo and P. Xu, Effects of Nozzle Length and Process Parameters on Highly Constricted Oxygen Plasma Cutting Arc, *Plasma Chem Plasma Process, 28,* 2008, 729–747.
[11] L. Prevosto and H. Kelly, On the influence of the nozzle length on the arc properties in a cutting torch, *Journal of Physics: Conference Series, 166,* 2009, 1-7.
[12] R. Bini, M. Monno and Maher Boulos, Effect of Cathode Nozzle Geometry and Process Parameters on the Energy Distribution for an argon Transferred Arc Plasma, *Chemistry and Plasma Processing, 27(4),* 2007, 359-380.
[13] D. Besterfield, C. Besterfield, G. Besterfield and M. Besterfield, Total Quality Management, Taguchi's Quality Engineering, 3, 2003, 561-617.
[14] R. Pawade and S. Joshi, Multi-objective optimization of surface roughness and cutting forces in high-speed turning of Inconel 718 using Taguchi grey relational analysis (TGRA), *International Journal Advanced Manufacturing Technology, 56*, 2011, 47-62.