Optimization of Process Parameters of Plasma Arc Cutting using Grey Relational Analysis Technique

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Abstract- *The research work investigates the effects and parametric optimization of process parameters for plasma arc cutting (PAC) of SS304 steel using grey relational analysis (GRA). Four process parameters are selected for experimentation, Viz., torch height, arc voltage, arc current and cutting speed. Response variables selected for experimentation are material removal rate and surface roughness. Experimentation is carried out on the basis of L18 orthogonal array. Process parameters viz,. Material Removal Rate (MRR) and Surface Roughness (SR) of machined surface are measured for every experimental run. For maximum material removal rate and minimum surface roughness process parameters are optimized based on Taguchi method coupled with Grey relational analysis.*

Keywords- Arc Voltage (AV), Arc Current (AC), Cutting Speed (CS), Torch Height (TH), Grey Relational Analysis (GRA), Material Removal Rate (MRR), Plasma Arc Cutting (PAC), Surface Roughness (SR)

I. INTRODUCTION

Plasma is the fourth state of matter which is obtained by heating a gas at elevated temperature which ionizes the gas. Ionization of gas results in formation of free electrons and positive ions among the gas atoms. When this happens, gas become electrically conductive which heats the gas at extreme level and thus state of gas changes to Plasma which is sufficient to cut any type of material. For any machining process generally two response variables are concerned- Material removal rate and surface roughness. From economic point of view material removal rate should be high and surface roughness should low because a no. of mechanical properties like fatigue, creep life etc are dependent on surface roughness.

Fig1 Experimental setup of plasma arc cutting

Literature review, modeling and analysis of plasma arc cutting process presented below

Milan Das Kumar et al. [1] investigated process parameter optimization of plasma arc cutting of EN 31 steel using weighted principal component analysis (WPCA). The machining process parameters (gas pressure, arc current and torch height) are optimized in order to maximize MRR and minimize surface roughness value. WPCA method when employed with Taguchi method gives optimum level of process parameters (7 bar, 200A, 4mm torch height) and optimum settings for roughness and material removal rate.

Miroslav RADOVANOVIC et al. [2] developed Artificial Neural Network (ANN) model for optimizing process parameters of plasma arc cutting. In ANN model three input parameters and one output parameter were considered. The ANN model was expressed in the form of mathematical equation by which contour plot of roughness were generated, by knowing these plots machining conditions for cutting can be selected with minimum surface roughness value.

K Salonities et al. [3] investigated process parameters of plasma arc cutting for assessing the quality of cut. Process parameters examined are cutting speed, cutting current, gas pressure and torch height. The quality characteristics that were assessed are surface roughness, heat affected zone (HAZ) and conicity of cut geometry. During experimentation and analysis it is found that surface roughness and conicity are mainly affected by torch height and HAZ is mainly influenced by cutting current.

Ali. Moarrefzadeh et al. [4] presented Numerical simulation of process by ANSYS software for gaining the temperature field of workpiece, the effect of parameter variation on temperature field and process optimization for different cases of plasma Arc is done.

Vinay Kumar et al. [5] explains the parametric effect on kerf and Power consumed in PAM in which parameter x4, x1, x3 and x2 (Cutting speed, Thickness, Arc voltage, Arc current) have influence on kerf and power and also the mean response and S/N curve depicts the optimum values. This work helps in tuning the PAM process for better accuracy with less kerf accordingly.

Joseph C. Chen et al. [6] used Taguchi parameter design to optimize the roundness of holes made by an aging plasma-cutting machine.

II. EXPERIMENTAL WORK

Experimentation and analysis work is carried out by following way-

a) Design and performing experiments for pilot readings

b) Decide each level of process parameters from pilot experimentation

c) Design and perform orthogonal array with the help of level of each parameters

d) After performing orthogonal array experimentation Taguchi and ANOVA analysis technique is used is used to find percentage contribution of each process parameter for respective response variables

e) Grey relational analysis is carried out for finding optimal settings for plasma arc cutting with the help of grey relational grade.

Sr. No	Process parameters	Response variables
1	Torch height (mm)	MRR (gm/sec)
2	Arc voltage (V)	Surface roughness (µm)
3	Arc current (A)	
4	Cutting speed (mm/min)	

Table 1 Process parameters and response variables

Sr. No	Fixed variables
1	Material SS304
2	Sample dimensions (100x50x4) mm

Table 2 Fixed variables for experimentation

Pilot experimentation is carried out to decide the level of each process parameter and the results of same is presented below in table 3.

Sr. No	Process parameters	Level 1	Level 2	Level 3
1	Torch height (mm)	3	5	-
2	Arc voltage (V)	140	145	150
3	Arc current (A)	70	75	80
4	Cutting speed (mm/min)	1500	1600	1700

Table 3 Process parameters and their levels

A response variable gives better result for level 1 (lower) and level 2 (higher) of torch height and level 1 (lower), level 2 (medium), level 3(higher) of remaining three process parameters. On the basis of two level of one parameter and three level of next three process parameters L18 orthogonal array is generated by using a software package Mini Tab-17. Experimentation is carried out on the basis of L18 orthogonal array. Process parameters viz,. Material Removal Rate (MRR) and Surface Roughness of machined surface are measured for every experimental run.

Sr. No	TH (mm)	AV (V)	AC (A)	CS (mm/min)	SR (µm)	MRR (gm/sec)
1	3	140	70	1500	3.5	8.8
2	3	140	75	1600	3.19	9.4
3	3	140	80	1700	5.14	9.7
4	3	145	70	1500	4.1	8.7
5	3	145	75	1600	3.31	9.1
6	3	145	80	1700	6.2	10.2
7	3	150	70	1600	7.7	9.0
8	3	150	75	1700	4.1	9.7
9	3	150	80	1500	4.3	8.7
10	5	140	70	1700	4.0	10.2
11	5	140	75	1500	7.3	9.1
12	5	140	80	1600	5.6	9.4
13	5	145	70	1600	4.4	9.3
14	5	145	75	1700	3.9	10.3
15	5	145	80	1500	3.6	9.1
16	5	150	70	1700	4.3	9.8
17	5	150	75	1500	3.16	8.7
18	5	150	80	1600	5.1	9.4

Table 4 L18 orthogonal array

III. GREY RELATIONAL ANALYSIS (GRA)

Grey relational analysis is one of the most powerful tool to analyse the process parameters which is having multiple performance characteristics. To solve complex and multivariate problems of particular system GRA technique is used. GRA is carried out for solving complicated problems which have interrelationships among the designated performance characteristics. The purpose of grey relational analysis is the multi-objective problem has been converted into single objective optimization using GRA technique.GRA is alternate method for traditional statistical method which deals with small sample size and uncertainty conditions and can be applied in multiple quality characteristics. GRA is normalization based evolution technique in which the quality characteristics of the measured data are first normalized ranging from 0 to 1. Therefore one has to pre-process the data which are related to a group of sequence ,which is called "grey relational generation "data preprocessing is a process of transferring the original sequence to a comparable sequence for this purpose the experimental result are normalized in the range between zero and one[7].Procedure of grey relational analysis is describe as follows-

Flow chart of grey relational analysis

Grey relational generating (Comparability sequence)

⇩

Preparation of deviation sequence

⇩

Calculation of grey relational coefficient

⇩

Calculation of grey relational grades

Fig 2 Flow chart of grey relational analysis [8]

1] Data pre-processing [9]

Normalize the measured values of surface roughness and material removal rate from zero to one. This process is known as normalization. Normalization is carried out by mathematical equations

$$X_i^* = \frac{Max\ X_i^0(K) - X_i^0(K)}{Max\ X_i^0(K) - Min X_i^0(K)} \dots\dots\dots\dots 1$$

$$X_i^* = \frac{X_i^0(K) - Min\ X_i^0(K)}{Max\ X_i^0(K) - Min\ X_i^0(K)} \dots\dots\dots\dots 2$$

Equation 1 is used for normalization of surface roughness and equation 2 is used for normalization of material removal rate.

2] Grey relational coefficient

Following to data pre-processing, grey relational coefficient and grey relational grade is calculated to express the relationship between ideal and actual experimental result. The grey relational coefficient is expressed as follows

$$\xi_i\ (k) = \frac{(\Delta min + \zeta \Delta max)}{(\Delta 0i\ (k) + \zeta \Delta \max)} \quad \dots\dots\dots\dots\dots 3$$

Where,

ξ_i (k) = Grey relational coefficient

$\Delta min = min\|x0(k) - xi(k)\| = \|1-1\| = 0$

$\Delta max = max\|x0(k) - xi(k)\| = \|1-0\| = 1$

ζ = distinguishing coefficient between [0, 1] = (0.5) selected.

Δ0i (k) = Deviation sequence

$\Delta 0i\ (k) = \|x_0^*(k) - x_i^*(k)\|$

$x_0^*(k) = 1$ ………(Maximum normalized value)

3] Grey relational grade (γ_i)

Grey relational grade is calculated by some mathematical formulations. Mathematical formulation consists terms like weightage of respective response variable and grey relational coefficient, hence grey relational grade can be defined as summation of product of weightage of respective response variable and grey relational coefficient of respective response variable.

$\gamma_i = \sum W_i\ (k) \times \xi_i\ (k)$ ……………………...4

Where,

γ_i= Grey relational grade

W_i= Weightage given to response variable

Sample calculation showing grey relational analysis (for run no 1)

1] Comparability sequence (For R_a)

$$X_i^* = \frac{Max\ X_i^0(K) - X_i^0(K)}{Max\ X_i^0(K) - Min X_i^0(K)} \dots\dots\dots\dots 1$$

Here,

Max value = 7.7μm, Min value= 3.16 and X_i^0= 3.5

X_i^*= 0.93

2] Deviation sequence

$\Delta 0i\ (k) = \|x_0^*(k) - x_i^*(k)\|$

Here,

$x_0^*(k) = 1$, $x_i^* = 0.93$

Δ0i (k) = 0.07

3] Grey relational coefficient

$$\xi_i\,(k) = \frac{(\Delta min + \zeta\,\Delta max)}{(\Delta 0i\ (k) + \zeta\,\Delta \max)}$$

Here,

Δmin=0, Δmax=1, ζ=0.5, $\Delta 0i$ (k) = 0.07

ξ_i (k)= 0.87

$\gamma_i = \sum W_i (k) \times \xi_i (k)$

Here,

w1= 0.5, w2= 0.5, ξ_i (k) (For R_a)=0.87 ξ_i (k) (For MRR),= 0.35

γ_i=0.61

4] Grey relational grade (w1=0.5, w2=0.5)

Sr. No	Normalized surface roughness	Normalized MRR	Deviation sequence of SR	Deviation sequence of MRR	Grey relational coefficient surface roughness	Grey relational coefficient MRR	Grey relational grade (w1=0.5, w2=0.5)
1	0.93	0.09	0.07	0.91	0.87	0.35	0.61
2	0.99	0.45	0.01	0.55	0.99	0.47	0.73
3	0.57	0.62	0.43	0.38	0.54	0.57	0.55
4	0.80	0.00	0.20	1.00	0.71	0.33	0.52
5	0.97	0.26	0.03	0.74	0.94	0.40	0.67
6	0.34	0.90	0.66	0.10	0.43	0.84	0.63
7	0.00	0.17	1.00	0.83	0.33	0.38	0.35
8	0.79	0.61	0.21	0.39	0.70	0.56	0.63
9	0.75	0.00	0.25	1.00	0.67	0.33	0.50
10	0.81	0.90	0.19	0.10	0.72	0.84	0.78
11	0.09	0.26	0.91	0.74	0.36	0.40	0.38
12	0.46	0.45	0.54	0.55	0.48	0.47	0.48
13	0.73	0.35	0.27	0.65	0.65	0.44	0.54
14	0.84	1.00	0.16	0.00	0.76	1.00	0.88
15	0.91	0.26	0.09	0.74	0.85	0.40	0.63
16	0.75	0.71	0.25	0.29	0.66	0.63	0.65
17	1.00	0.01	0.00	0.99	1.00	0.34	0.67
18	0.58	0.45	0.42	0.55	0.55	0.47	0.51

Table 5 Normalized response variables, deviation sequence and Grey Relational grade.

IV. RESULT AND DISCUSSION

After applying GRA technique it is observed that experiment no 14 shows higher grade, thus experiment no. 14 in table no 5 gives optimal settings for the best multi-performance characteristics of plasma arc cutting process among the 18 experiments. Main effect plot for mean of grey relational grade is as follows-

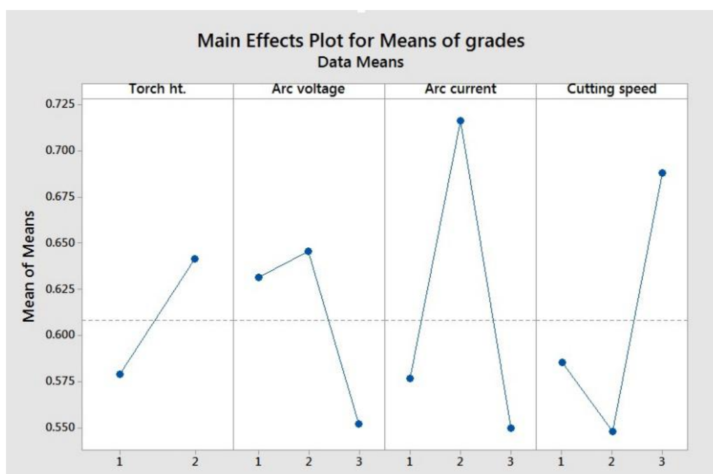

Fig 2 Main effect plot for means of grey relational grade

From fig 2 level 2 (5 mm) of torch height, level 2 (145 V) of arc voltage, level 2 (75 A) of arc current, level 3 (1700 mm/min) of cutting speed gives a greater mean values of response variables, hence optimal setting for plasma arc cutting for equal weightage of response variable is 5mm torch height, 145V arc voltage, 75A arc current, 1700mm/min cutting speed. After getting the levels of each process parameters, confirmation test is carried out. The purpose of confirmation test is to validate the conclusion drawn during the analysis phase.

Sr. No	TH (mm)	AV (V)	AC (A)	CS (mm/min)
1	0.58	0.63	0.58	0.59
2	0.64	0.65	0.72	0.55
3		0.55	0.55	0.69
Delta	0.06	0.09	0.17	0.14
Rank	4	3	1	2

Table 6 Response table for mean

From above table it can be conclude that rank of arc current is one so that arc current is most dominating parameter followed by cutting speed, arc voltage, torch height

Source	Adj SS	Adj. MS	F-Value	P-Value	Percentage contribution
TH	0.027	0.028	6.53	0.031	6.73 %
AV	0.039	0.019	4.65	0.041	12.75%
AC	0.09	0.049	11.60	0.003	40.99 %
CS	0.06	0.029	6.84	0.016	23.85 %
Error	0.04	0.004			15.68%
Total					100 %

Table 7 Response table of ANOVA for grades obtained by GRA

From table 7 it can be conclude P- Values of all process parameters are less than 0.05 that means all process parameters have influence on grey relational grade. Percentage contribution of arc current is 41 % followed by cutting speed, arc voltage, torch height.

V. CONCLUSION

The Grey relational Analysis along with Taguchi method is used to find optimum settings for plasma arc cutting of SS 304 having thickness 4 mm. The optimum setting is obtained from grey relational grade. Experimental run 14 has higher grade which gives optimum result of surface roughness and material removal rate, so the optimal settings obtained for plasma arc cutting are 5 mm torch height, 145V arc voltage, 75A arc current, 1700 mm/min. After getting optimal settings, confirmation test is carried out for the same and it is observed that confirmation test gives surface roughness 3.8µm and material removal rate 10.11 gm/sec with the error in surface roughness 2.56% and error in material removal rate is 1.88%. This error is occurred due to environmental factors and it is generally acceptable.

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