ISSN: 2456-9348
Vol (01) _Issue (04) Impact Factor: 4.520

iJETRM
International Journal of Engineering Technology Research & Management

EXPERIMENTAL MODELING OF ABREX MATERIAL USING MULTIPLE REGRESSION ANALYSIS IN PLASMA ARC CUTTING PROCESS

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ABSTRACT
Plasma arc cutting process is widely used in metal cutting industries and modern fabrication units. Precise cutting of high strength material is still a challenging task to the industries. This process involves thermal cutting phenomena. Abrex is a high strength and high abrasion resistant material which is used in manufacturing of body parts of dump truck, buckets, barges, front loaders etc. This special alloy material is identified as "hard-to-cut" type materials. Cutting of this material create a heavy challenge in order to meet the quality. Therefore, optimization and selection of optimal process parameter plays a vital role in cutting such type of material using plasma arc cutting process. This present work proposes an experimental investigation of plasma arc cutting process of abrex high strength material. Experiments were conducted based on Taguchi's L9 orthogonal array design. The cutting parameters analysed were arc current, stand-off distance and cutting speed whereas material removal rate, kerf and dross were selected as output responses. Also, a prediction model was developed to estimate the responses using multiple regression analysis. Analysis of variance (ANOVA) and analysis of means (ANOM) were used to verify the effect of each parameter on the surface quality to be assessed.

Keywords:
Abrex material, Dross, Kerf; Regression analysis.

INTRODUCTION

In 1950, plasma arc cutting machine was introduced in fabrication unit to cut the steel and aluminum materials. Modern fabrication units have greater flexibility to adopt an advance or special materials. In this era, cutting the materials with higher accuracy, reduced time and better quality product is a challenging tasks to manufacturing sectors. There is a lot of cutting process to cut the materials, but plasma arc cutting process is quietly economic process comparing to other.

Plasma is a forth state of matter. Solid, liquid, gaseous and plasma are the matters. While excess heating of gaseous medium, it acts like a plasma. It is highly energized in nature and electrically conductive medium [1].

Plasma arc cutting is a thermal cutting process which involves high energized plasma gas to cut the high strength material. While cutting process, high velocity ionized plasma gas is impinges to the workpiece through the nozzle. The arc generates between the nozzle and work material. The temperature around the arc gap reaches to 20,0000C. By this process, the workpiece gets melted and blown away by the help of pressure of high velocity plasma jet [2].

A combination of response surface methodology coupled with grey relational analysis and principal component analysis was introduced to find the optimization of plasma arc cutting process of AISI 304L stainless steel [3]. The responses were measured as material removal rate, dross, chamfer, kerf and surface roughness. Experimental modeling was established using general regression analysis and ANOVA while machining of Ti-6Al-4V titanium alloy [4]. Parametric optimization of plasma arc cutting process of stainless steel 304L obtained using grey-Taguchi based response surface methodology [5]. Taguchi's optimization technique is used to find the optimum condition of plasma arc cutting process of 1017 steel and Taguchi's L27 orthogonal array utilized to outline the design [6]. Desirability function and response surface methodology are applied to optimize automated plasma arc cutting process [7].

MATERIALS AND METHODS

Experiments have been performed in MESSER BURNY 1205 CNC plasma arc cutting machine. Abrex 400 steel material which is high abrasion resistance in nature was taken for experiment as workpiece material. This material has also good workability and better weld capacity. As compared to normal steel this abrex 400 material has three times better abrasion resistance. For better life of the products, manufactured form this material has greater advantages. Thickness having 5 mm abrex 400 steel was considered for experiment. Mostly fabrication unit used this special type of material. The application of this steel in part product manufacturing of dump truck, bulldozer, crusher and excavator. The chemical composition of abrex 400 steel is presented inTable1.

Table 1: Chemical composition of abrex 400 steel

Mat.	**C**	**P**	**Mn**	**S**	**Si**	**Ni**	**Cr**	**Mo**	**B**	**Fe**
%	0.21	0.025	2	0.01	0.70	1	1.20	0.06	0.005	Balance

In plasma arc cutting operation, cutting gas selection plays a major role. For precise cutting of material, selection of plasma gas is important. Argon gas was selected for plasma gas and oxygen for shielding gas. The oxygen supply was fixed at 25 Mpa. Voltage kept constant at 400 volts. 2mm diameter of swirl nozzle of tungsten material was taken as electrode. The input process parameter was selected as cutting current, standoff distance (SOD) and gas supply pressure. The corresponding output responses was measured as material removal rate, kerf width and dross. The range of variables are shown in Table 2. The experimental result are furnished in Table 3.

Table 2: Values of input process parameters

Symbol	Input parameters	Units	Level 1	Level 2	Level 3
A	Arc current	A	60	70	80
B	SOD	mm	2	3	4
C	Gas pressure	bar	5	6	7

Table 3. Experimental results

Test	Process parameter			Responses		
	Current	SOD	Gas pressure	MRR	Kerf	Dross
1	60	2	5	3152.96	2.58	3.32
2	60	3	6	3142.89	2.67	3.55
3	60	4	7	3114.74	2.68	3.81
4	70	2	6	3047.27	2.51	4.07
5	70	3	7	3063.21	2.59	4.29
6	70	4	5	3091.7	2.62	3.58
7	80	2	7	3001.87	2.43	4.81
8	80	3	5	3022.3	2.5	3.99
9	80	4	6	3015.21	2.59	4.33

RESULTS AND DISCUSSION

Development of mathematical model

The output dependent variables such as material removal rate, dross and kerf can be related as a linear function of such independent variables i.e. cutting current, gas supply pressure and standoff distance. The following regression equations shows the relation of responses with variable in uncoded unit.

MRR = 3583 - 6.19 A + 3.26 B - 14.5 C

(R^2 = 96.8 %, R^2 (adj) = 94.8 %)

KERF = 2.87 - 0.00683 A + 0.0617 B + 0.00000 C

(R^2 = 95.2 %, R^2 (adj) = 92.2 %)

DROSS = - 0.666 + 0.0408 A - 0.0800 B + 0.337 C

(R^2 = 99.7 %, R^2 (adj) = 99.5%)

The mathematical model and the goodness of fit were verified using significance test. The tests performed for regression model and individual model coefficient for verify the significance [8]. To verify the significance level of the model developed, analysis of variance applied. This analysis is performed at a significance level of 5% or confidence level of 95 % which is shown in Table 4, Table 5 and Table 6. The models are said to be statically significant when the P value is less than 0.05. From the ANOVA, it is perceived that the developed models are significant and the variables have significant effects on the reposes.

Table 4 ANOVA table of first order model for MRR

Source	DF	Seq SS	Adj MS	F	P value	Remarks
Regression	3	24295.4	8098.5	50.64	0.000	Significant
Residual Error	5	799.6	159.9			
Total	8	25095.0				

Table 5 ANOVA table of first order model for Kerf

Source	DF	Seq SS	Adj MS	F	P value	Remarks
Regression	3	0.050833	0.016944	32.73	0.001	Significant
Residual Error	5	0.002589	0.000518			
Total	8	0.053422				

Table 6 ANOVA table of first order model for Dross

Source	DF	Seq SS	Adj MS	F	P value	Remarks
Regression	3	1.71888	0.57296	505.06	0.000	Significant
Residual Error	5	0.00567	0.00113			
Total	8	1.72456				

The determination coefficient (R^2) is also considered for the degree of fit. Higher the value of R^2, better fits the mathematical model and residual are less [9]. The obtained model presented better correlation coefficient explaining 96.8%, 95.2% and 99.7% of the variability in the material removal rate, kerf and dross respectively. It concludes that the predicted model is significant. The normal probability plot of residual for material removal rate, kerf and dross are shown in Fig. 1, Fig. 2 and Fig. 3 respectively. From this plot of individual responses, it is also revealed that the data closely follows near straight line and P value is greater than 0.05 at 95% confidence interval. It means that the data follow a normal distribution and the model is adequate. The residuals fall on a

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straight line and suggests that the errors are distributed normally. Residual versus fitted value of the models are shown in Fig. 4-6. From the figure, it is found that no unusual structure from the model. Fig. 7-9 shows the residual versus order of the data of the model. From figure it is found that residual are random in nature. So, the developed model can be effectively used for prediction of MRR, kerf and dross in plasma arc cutting process.

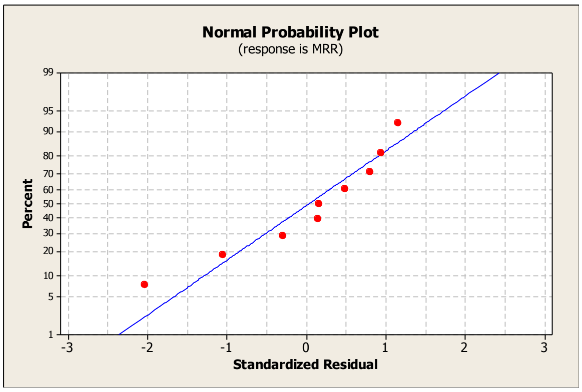

Fig. 1 Normal probability of residual for MRR

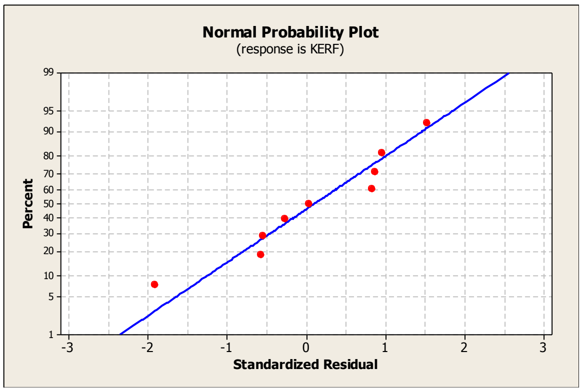

Fig. 2 Normal probability of residual for kerf

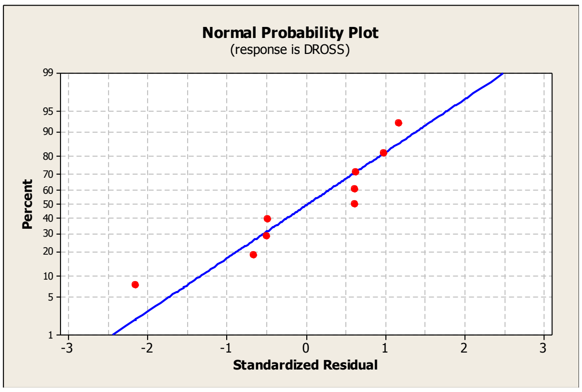

Fig. 3 Normal probability of residual for dross

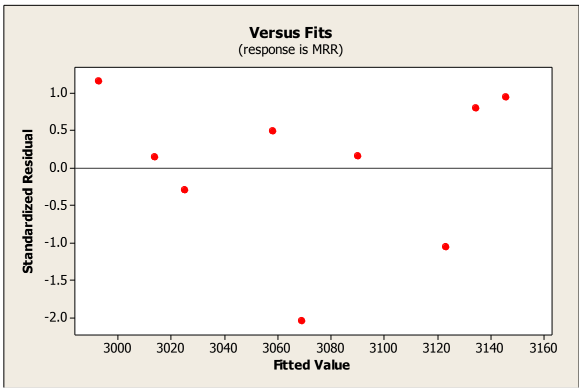

Fig.4 Residual vs. fitted value for MRR

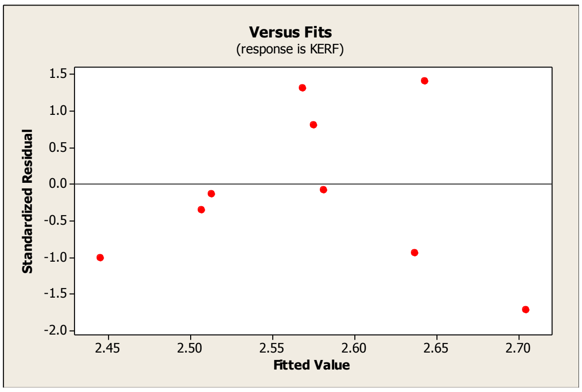

Fig.5 Residual vs. fitted value for kerf

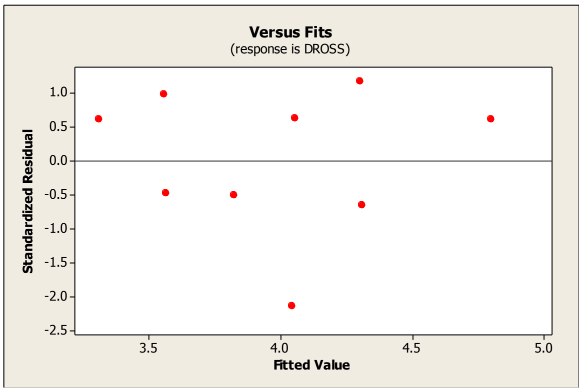

Fig.6 Residual vs. fitted value for dross

Some confirmation experiments were conducted for validation of the models. Comparison of MRR, kerf and dross between the experimental result and model value are shown in Table 5.The calculated error for material removal rate lies between -0.3 to 0.72, for kerf lies -1.56 to 1.84 and for dross lies -0.7 to 1.33. So, the developed mathematical model can be used to predict the material removal rate, kerf and dross within the limits.

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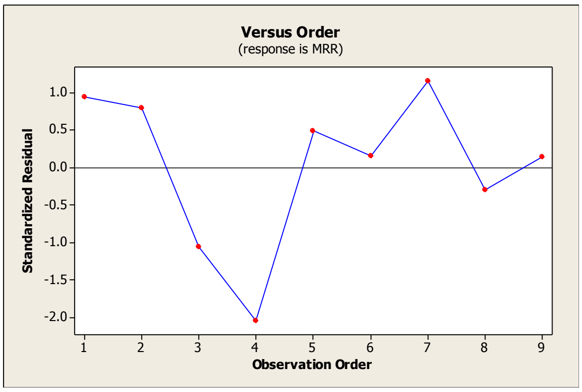

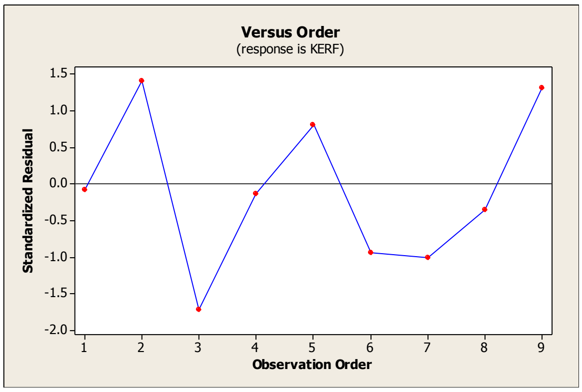

Fig. 7 Residual vs. order of the data for MRR *Fig. 8 Residual vs. order of the data for kerf*

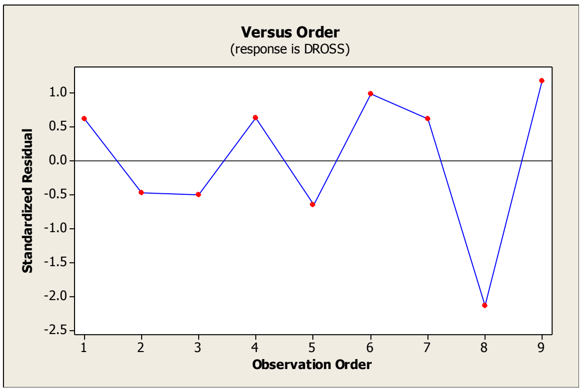

Fig. 9 Residual vs. order of the data for dross

Table 5 Comparison of results obtained from experiment with model

Test	Process parameter			Experimental			Predicted			Error		
	Current	SOD	Gas pressure	MRR	KERF	DROSS	MRR	KERF	DROSS	MRR	KERF	DROSS
1	60	2	5	3152.96	2.58	3.32	3145.62	2.60	3.31	-0.23	0.96	-0.39
2	60	3	6	3142.89	2.67	3.55	3134.38	2.64	3.56	-0.27	-0.95	0.39
3	60	4	7	3114.74	2.68	3.81	3123.14	2.68	3.82	0.27	0.18	0.29
4	70	2	6	3047.27	2.51	4.07	3069.22	2.54	4.05	0.72	1.18	-0.44
5	70	3	7	3063.21	2.59	4.29	3057.98	2.58	4.31	-0.17	-0.40	0.44
6	70	4	5	3091.7	2.62	3.58	3090.24	2.61	3.56	-0.05	-0.20	-0.70
7	80	2	7	3001.87	2.43	4.81	2992.82	2.47	4.80	-0.30	1.84	-0.27
8	80	3	5	3022.3	2.5	3.99	3025.08	2.51	4.04	0.09	0.39	1.33
9	80	4	6	3015.21	2.59	4.33	3013.84	2.55	4.30	-0.05	-1.56	-0.69

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Effect of process parameters

The effect of process parameters on material removal rate, kerf and dross have been studied using analysis of variance and main effect plot. The influence of process parameter and its significance achieved through ANOVA test. The F-test has executed at 95% confidence level. The ratio of mean square deviations of each parameter and the mean square of corresponding parameter is the F-value. The factors are significant if P-value (probability of significance) is less than 0.05 at 95% confidence interval.Table 6, Table 7 and Table 8 show the result of ANOVA for material removal rate, dross and chamfer respectively. From Table 6, it reveals that current is the only significant process parameter whose P-value is less than 0.05 at 95% confidence interval during the ANOVA test of MRR. From Table 7, it is apparent that, the P-value of SOD and gas pressure is less than 0.05. It means both the process parameter are significant for ANOVA test of kerf. Current is the most significant process parameter followed by SOD. From Table 8, it is disclosed that the all the process parameters are significant because all the P-values is less than 0.05 during the ANOVA test of dross. Current is the most effective parameter followed by gas pressure and SOD. This trend has also been noticed from the main effect plot responses.

Table 6. ANOVA for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Remarks
A	2	23081.7	23081.7	11540.9	41.87	0.023	Significant
B	2	124.4	124.4	62.2	0.23	0.816	
C	2	1337.7	1337.7	668.9	2.43	0.292	
Error	2	551.2	551.2	275.6			
Total	8	25095					

Table 7. ANOVA for Kerf

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Remarks
A	2	0.028022	0.02802	0.01401	34.08	0.029	Significant
B	2	0.023489	0.02349	0.01174	28.57	0.034	Significant
C	2	0.001089	0.00109	0.00054	1.32	0.43	
Error	2	0.000822	0.00082	0.00041			
Total	8	0.053422					

Table 8. ANOVA for Dross

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Remarks
A	2	1.00069	1.00069	0.500344	919.00	0.001	Significant
B	2	0.04216	0.04216	0.021078	38.71	0.025	Significant
C	2	0.68062	0.68062	0.340311	625.06	0.002	Significant
Error	2	0.00109	0.00109	0.000544			
Total	8	1.72456					

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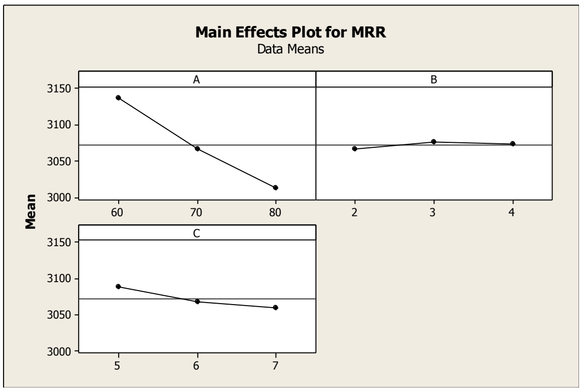

Fig. 10 Main effect plot for MRR

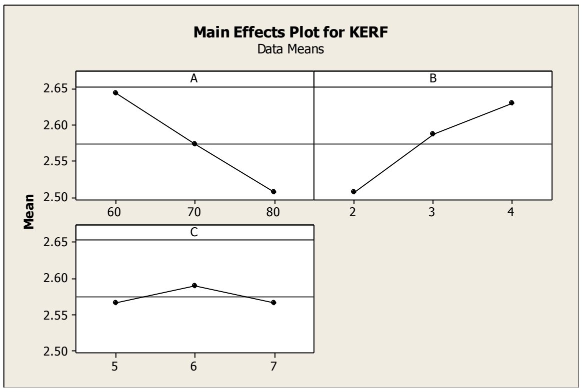

Fig. 11 Main effect plot for kerf

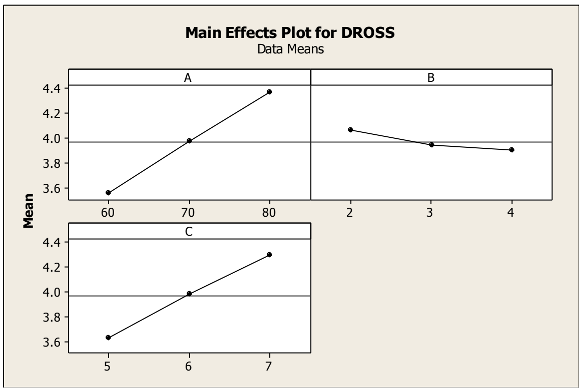

Fig. 12 Main effect plot for kerf

Figures (10-12) shows the main effect plot of various responses. From Fig. 10, the graph shows that the decreasing trend of current and gas pressure is noticed when the SOD is elevated. The experiment gives best result with lower range of current. Decreasing trend of current and increasing trend of SOD is the best alternative for the kerf found from Fig. 11 and both are the significant process parameters. From Fig. 12, it is found that the increasing trend of current and gas pressure minimizes the dross with decrease in SOD.

CONCLUSION

This study described the development of mathematical model and experimental modeling of plasma arc cutting process of abrex 400 steel using multiple regression analysis. The following conclusions were carried out based on findings of this research experiment:

- The investigation revealed that the input variables i.e. cutting current, standoff distance and gas supply pressure are the influencing factors which effects the material removal rate, kerf and dross in plasma arc cutting process. However, cutting current is the significant factor for MRR, current and standoff distance is the significant factor for kerf, current is the most significant factor followed by gas pressure and standoff distance at 95% confidence level.
- The mathematical model disclosed greater correlation coefficient that explain 96.8%, 95.2% and 99.7% of the variability in the material removal rate, kerf and dross respectively which indicates high significance of the model and explaining better goodness of fit of the model.
- The data nearly follows the straight line obtained from probability plot of individual responses. It revealed that the goodness of fit and significance model.
- The predicted and experimental values are nearly close to each other. The calculated error for material removal rate lies between -0.3 to 0.72, for kerf lies -1.56 to 1.84 and for dross lies -0.7 to

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1.33. Therefore, the developed model can be used to predict the material removal rate, kerf and dross within the limits.

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