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ELECTRIC DISCHARGE MACHINING OF 7075Al-10 wt. % SiC_p COMPOSITES USING ROTARY TUBE BRASS ELECTRODES

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Abstract: The present work reports the effect of input parameter viz. rotating speed of electrode, hole diameter and grain size of SiC on the output parameters i.e. the tool wear rate (TWR), metal removal rate (MRR) and radial over cut (ROC) obtained during electrode discharge machining of 7075Al-10 wt. % SiC composites. 7075Al alloy -SiC composite a lightweight, improved mechanical properties which are exploited for application in diverse field like aerospace, defense and automotive field. The 7075Al- 10 wt. % SiC composite plates were caste using die casting process with induction furnace melting. Through holes drilling on Al-SiC composite plates using EZNC EDM machine were done using hollow tube brass electrodes of 15 mm diameter with through hole centre flushing. The hole diameter was varied from 0 to 6 mm and the electrode rotation speed was varied between 0 to 460 rpm. The Three level full factorial design was used to study the effect of input parameters on the output variables.

Key words: Al-alloy-SiC_p composites, Electric discharge machining, full factorial design, grain size, Rotary tube electrode.

1. Introduction

In this paper, the machining phenomena in the electrical discharge machining (EDM) process are investigated through three level factorial design method in which we take three suitable input parameters through which the material removal rate (MRR), radial over cut (ROC) and tool wear rate (TWR) is calculated. The aim of this study is to understand the effect of these input parameter on output parameters and to improve the machining rate. The input parameters are subdivided into three levels that are low (-1) medium (0) and high (+1).

MMCs are made by dispersing a reinforcing material into a metal matrix. The reinforcement surface can be coated to prevent a chemical reaction with the matrix. For example, carbon fibers are commonly used in aluminum matrix to synthesize composites containing low density and high strength.

The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal or its alloy such as aluminum, magnesium or titanium and provides a compliant support for the reinforcement. The reinforcement material is embedded into the matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change the properties such as wear resistance, friction coefficient or thermal conductivity. The reinforcement can be either continuous, or discontinuous.

EDM of LM 25 Al-alloy-SiC composites using copper electrode was done by Karthikeyan et al. (1999) and the effects of volume percent of SiC, current and pulse duration on MRR, TWR and surface roughness were studied. Singh et al. (2004) have studied the effect of current, pulse on time and flushing pressure on MRR, TWR, taper and surface roughness using 2.7 mm diameter electrode. MRR was found to be higher for larger current and pulse on time setting at the expense of taper, ROC and surface finish. TWR was also found to be higher, larger then MRR for larger current setting. Dhar et al. (2007) have studied the effect of current, pulse on time and gap voltage on MRR, TWR and ROC during EDM of Al-4Cu-6Si alloy-10 wt. % SiC_p

composites using 30 mm diameter brass electrode. It was reported that the MRR, TWR and ROC increases in a non linear fashion with increase in current. MRR and ROC increases with increase in pulse on time.
Mohan et al. (2002) have studied the effect of polarity of the electrode, current, electrode material, volume percent of SiC particles and pulse duration on the MRR, TWR and surface roughness during EDM of Al-SiC composites. It was reported that the increase in volume percent of SiC decreases the MRR, increases the TWR and improves surface roughness. It was also reported that increasing the rotation speed of electrode increases the MRR, TWR and improve surface roughness. The effects of current, volume percent of SiC and pulse duration on MRR, EWR and surface roughness during EDM of 6025Al-SiC composite were studied by Mohan et al. (2004). The pulse duration was found to have inverse effect on material removal rate (MRR), electrode wear rate (EWR) and surface roughness (SR). It was reported that decrease in hole diameter and increase in rotation speed of tube electrode resulted in increase in MRR, decrease in EWR and surface roughness. Genatic algorithm was used for optimization of process parameters.
The present work reports on the EDM of 7075Al-10 wt. % SiC composites using 15 mm diameter brass electrode. The effect of SiC grain size, electrode roation speed and hole diameter was studied on the output variable viz. MRR, TWR and ROC.

2. Experimental Procedure

2.1 Material Removal Rate (MRR)

Material removal rate is the mass of work piece material removed per unit time.

$$\text{MRR} = \frac{\text{WORK PIECE WEIGHT LOSS}}{\text{MACHINING TIME}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

2.2 Tool Wear Rate (TWR)

Tool wear rate is the mass of electrode consumed per unit time.

$$\text{TWR} = \frac{\text{ELECTRODE WEIGHT LOSS}}{\text{MACHINING TIME}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

2.3 Radial Over Cut

Radial over cut was calculated as follows:

$\text{ROC} = (D_w - D_t)/2$ …………………………………………………………….. (3)

Where D_t is diameter of tool
and D_w is diameter of drilled hole

3. Design of Experiment

The three level full factorial design has been used during the experiment. For three factor, three level full factorial design the total number of experiments to be conducted is twenty seven (Montgomery, 1984). The values of the input parameters for low (-1), medium (0) and high (+1) level are shown in Table 1.

4. Conduct of Experiment

7075Al-alloy with 10 wt. % silicon carbide particulates composite plate was electric discharge machined using brass electrode of 30 mm diameter on an EZNC EDM machine. Positive polarity was maintained for the work piece and negative polarity for the brass tool. High grade kerosene was used as the dielectric fluid and jet flushing was used to flush away the eroded material from the sparking zone. Table 2 shows the composition of Al-Alloy-SiC composite plate. Table 3 shows the readings of the output parameters viz. material removal rate (MRR), tool wear rate (TWR) and radial over cut (ROC) for different setting of the input parameters.

5. Mathematical Modeling

The purpose of developing the mathmatical model relating the response variable and the input process parameters was to facilitate the optimization of the electric discharge machining of aluminum matrix composites.The mathematical model is repersented by

$Y = \phi\,(D, N, G)$ ……………………………………………(4)

Where
Y is response variable
D is hole diameter of electrode
N is rotating speed of electrode
G is grain size of electrode
In the present work the model chosen was quadratic (second order) in nature involving linear and quadratic interactions of process variables. A program was first written in MATLAB to obtain the desired model. The second order model equations obtained for MRR, TWR and ROC are as follows:

MRR = $2.4553 + 0.1403 * x_1 + 0.2592 * x_2 + 0.3344 * x_3 - 0.0852 * x_1^2 + 0.0848 * x_2^2 - 0.0394 * x_3^2 + 0.0455 * x_1 * x_2 - 0.0301 * x_2 * x_3 + 0.0416 * x_1 * x_3$ ……………………….(5)

TWR = $8.3633 - 0.5961 * x_1 - 0.2900 * x_2 + 0.6989 * x_3 + 3.0983 * x_1^2 + 0.0367 * x_2^2 - 1.2800 * x_3^2 - 0.6233 * x_1 * x_2 + 0.3867 * x_2 * x_3 - 0.8108 * x_1 * x_3$ ……………………. (6)

ROC = $7.8570 + 0.2583 * x_1 - 0.1622 * x_2 + 1.3122 * x_3 - 0.1094 * x_1^2 + 0.4489 * x_2^2 + 1.2722 * x_3^2 - 1.0000 * x_1 * x_2 - 0.1100 * x_2 * x_3 - 0.0258 * x_1 * x_3$ ……………………. (7)

6. Analysis of Variance (ANOVA)

The analysis of variance (ANOVA) for the MRR, TWR and ROC was done using MINITAB software. The analysis of variance for MRR, TWR and ROC are shown in table 4, 5 and 6 respectively.

7. Results and discussions

From the data obtained, the parameters for mathematical model were determined as shown earlier. The significance of the models and parameters was analyzed using analysis of variance (ANOVA) method. The result of analysis of variance for ROC, TWR and MRR are shown in table 4, 5 and 6 respectively. The main effect plot for MRR, TWR and ROC are shown in Figure 1, 2 and 3 respectively.

7.1 Material removal rate (MRR)

As shown in the main effect plot for MRR (Fig. 1) the MRR increases with increase in rotation speed of the electrode because of the improved debris removal at higher speed. In case of stationary electrode lower ejection force causes part of the molten metal to remain as recast layer, which reduces the MRR (Mohan et al., 2002). MRR increases with increase in hole diameter of the electrode because of the higher dielectric flow rate with larger hole diameter. Higher dielectric flow rate improves the flushing of debris and hence increases MRR. MRR increases with decrease in grain size of the SiC particulates because the larger grains of SiC are difficult to remove. The three interaction plots for MRR are shown in Figure 4, 5 and 6. Results of the analysis of variance for MRR are shown in Table 4. The summary of ANOVA for MRR is shown in Table 5. Multiple regression coefficient R^2 of the model for MRR as shown in Table 4 indicates that the model can explain variation in MRR to the extent of 87.8 %. Thus the model is adequate to represent the process.

7.2 Tool wear rate (TWR)

As shown in main effect plot for TWR (Fig. 2) the TWR increases with decrease in grain size. This is because of the increase in MRR with decrease in grain size. The TWR decreases with increase in hole diameter of the electrode. The TWR is minimum with medium rotation speed and maximum with maximum speed so it overall increases with increase of rotating speed of electrode. This is because of the increase in MRR with increase in rotation speed. The three interaction plots for TWR are shown in Figure 7, 8 and 9. Results of the analysis of variance for TWR are shown in Table 6. The summary of ANOVA for TWR is shown in Table 7. Multiple regression coefficient R^2 of the model for TWR as shown in Table 6 indicates that the model can explain variation in TWR to the extent of 56.6 %.

7.3 Radial over cut (ROC)

As shown in the main effect plot for ROC (Fig. 3) the ROC is minimum at medium grain size of SiC and maximum at medium hole diameter of the electrode. The ROC increases with increase in rotation speed of the electrode because of the increase in MRR at higher rotation speed. The three interaction plots for ROC are shown in Figure 10, 11 and 12. Results of the analysis of variance for ROC are shown in Table 8. The summary of ANOVA for ROC is shown in Table 9. Multiple regression coefficient R^2 of the model for ROC as shown in Table 8 indicates that the model can explain variation in ROC to the extent of 75.4 %. Thus the model is adequate to represent the process.

8. Conclusions

Following conclusions has been drawn from the main effect and interaction plots for MRR, TWR and ROC:

- The MRR increases with decrease of grain size of SiC particulates.
- The MRR increases with increase of hole diameter of electrode.
- The MRR increases with increase of rotating speed of electrode.
- The TWR increases with decrease of grain size of SiC particulates.
- The TWR decreases with increase of hole diameter of the electrode.
- The TWR is minimum with medium speed and maximum with maximum speed so it overall increases with increase of rotating speed of electrode.
- The ROC is minimum for medium grain size of the SiC particulates.
- The ROC is minimum for solid electrode and maximum for medium hole diameter of the electrode.
- The ROC increases with increase of rotating speed of the electrode.
- The results of the work can be used to select the suitable parameters while machining of Al alloy-SiC composite components for different applications.

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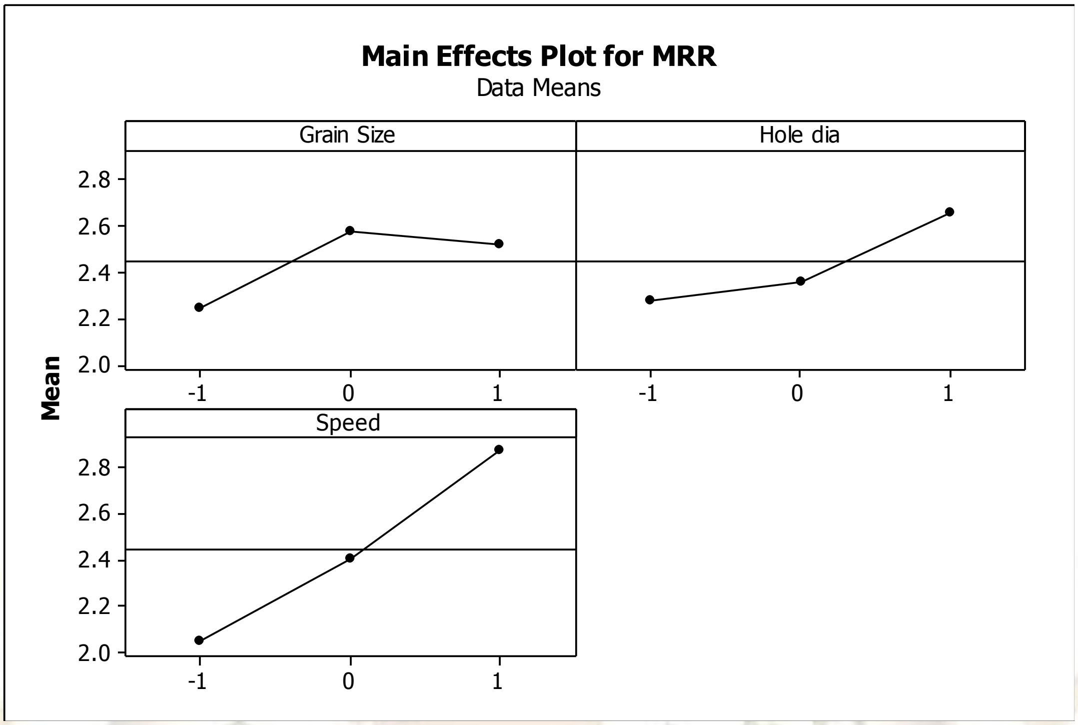

Fig. 1 Main Effect Plot for Material removal rate (MRR)

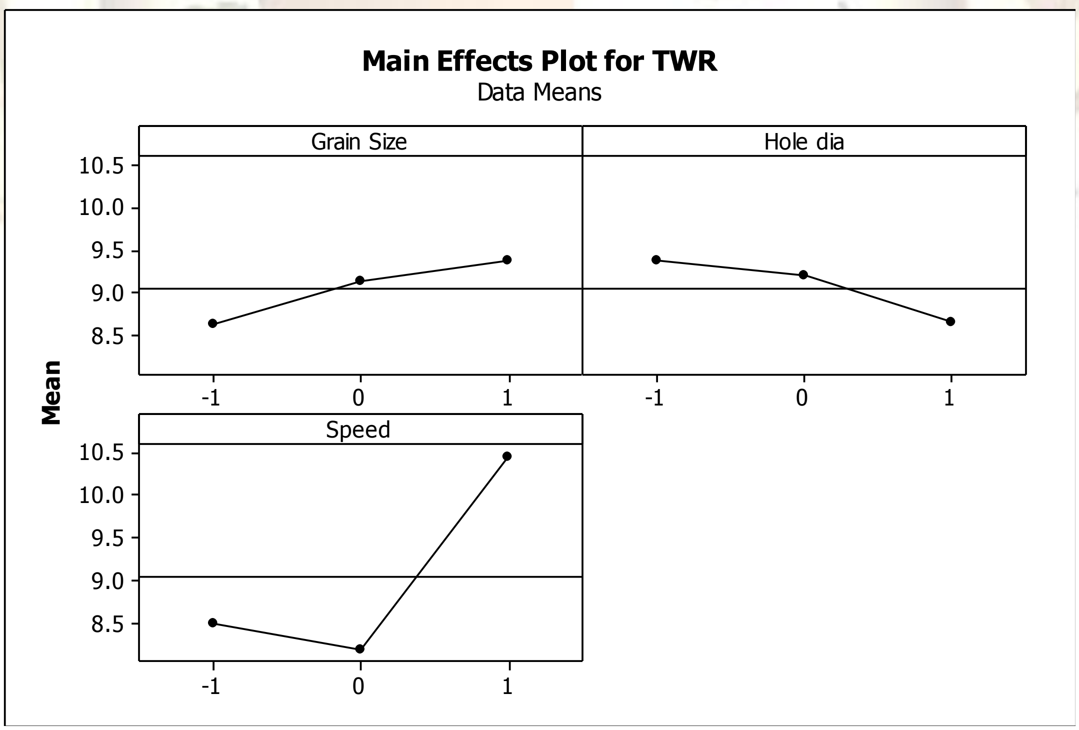

Fig. 2 Main effect plot for Tool wear rate (TWR)

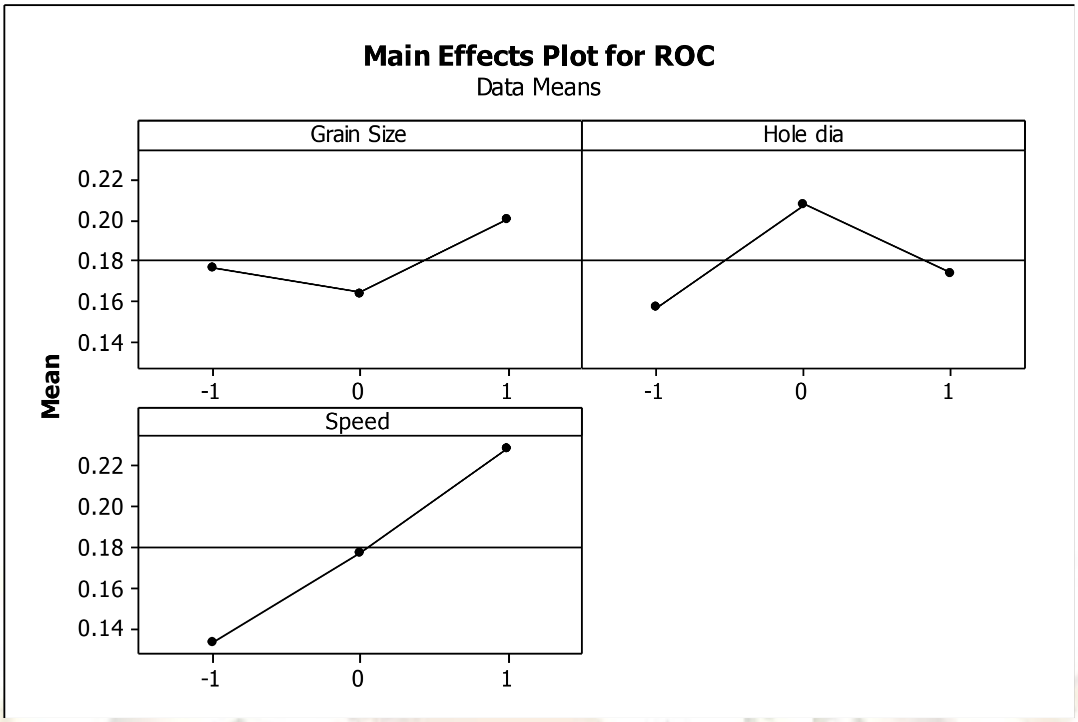

Fig. 3 Main effect plot for Radial over cut (ROC)

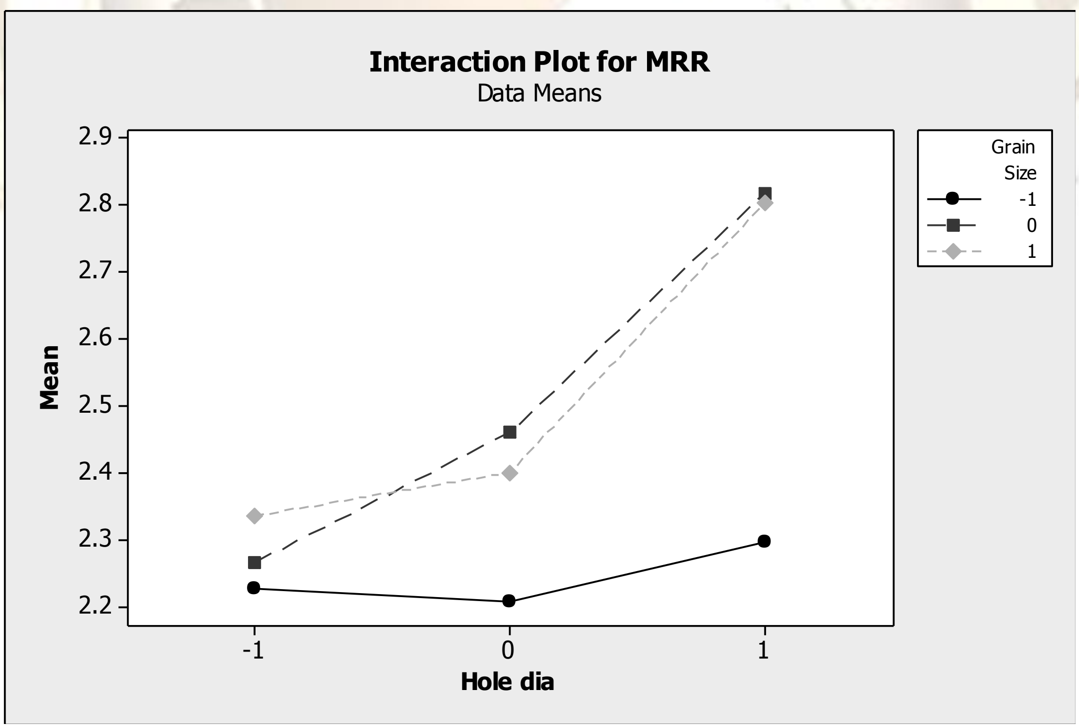

Fig. 4 Interaction plot for MRR (Hole diameter and Grain size)

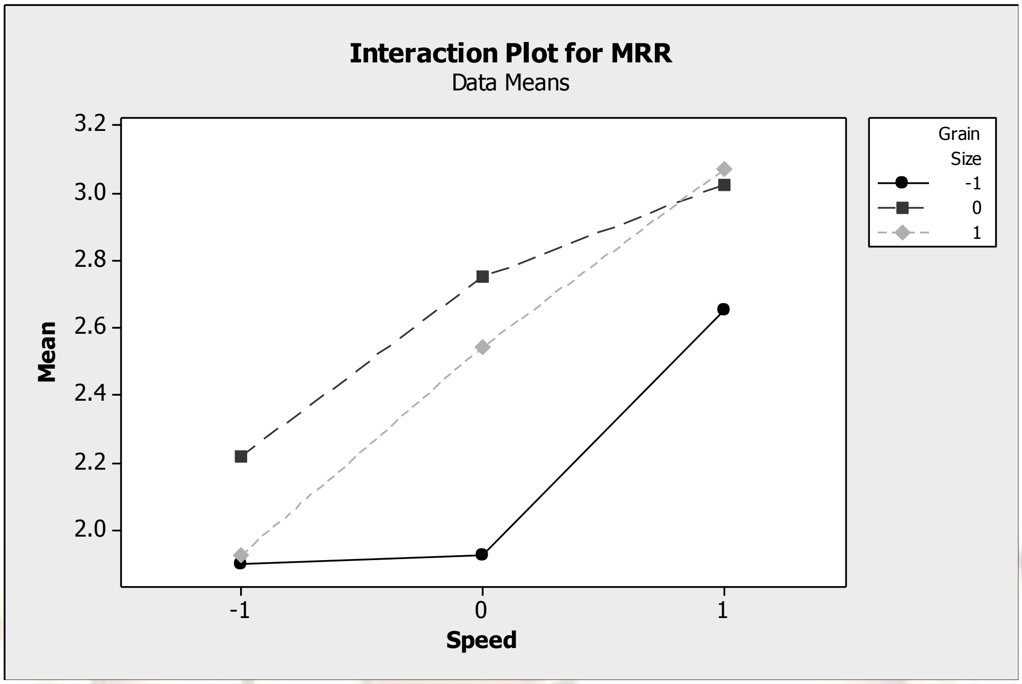

Fig. 5 Interaction plot for MRR (Rotation speed and grain size)

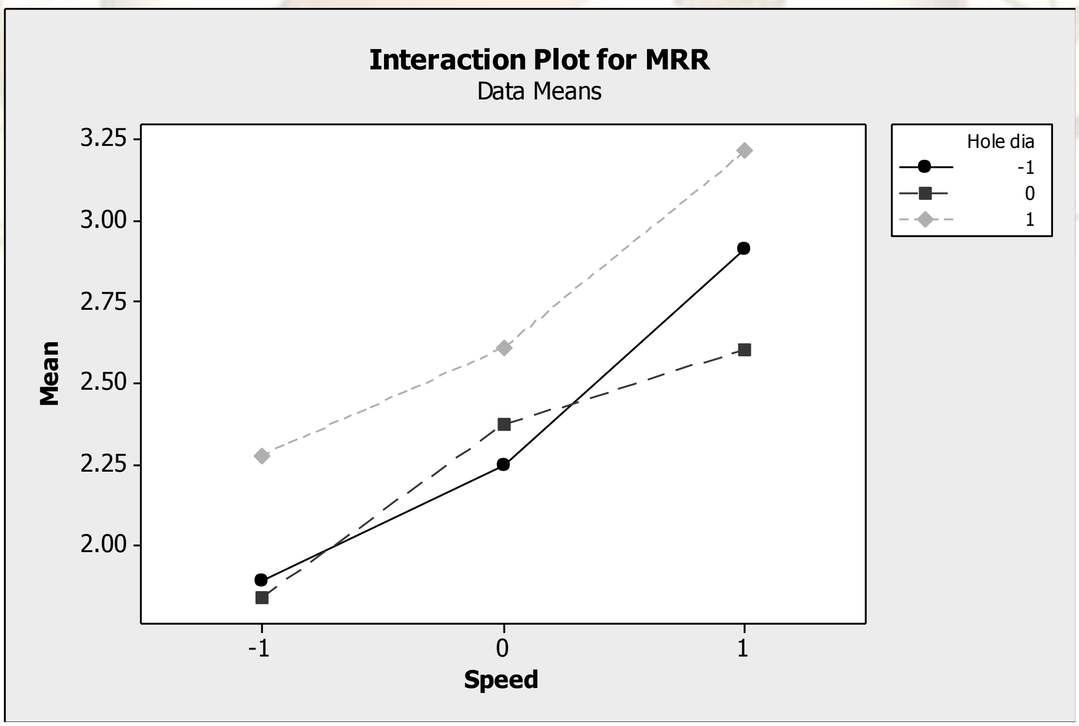

Fig. 6 Interaction plot for MRR (Rotation speed and hole diameter)

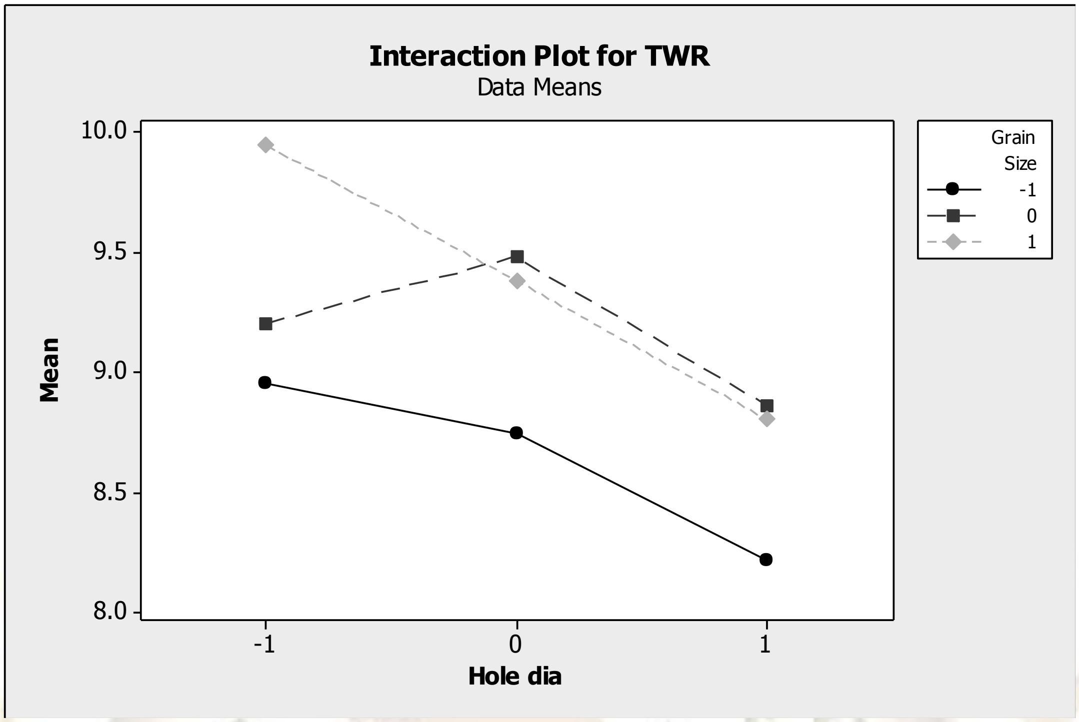

Fig. 7 Interaction plot for TWR (Hole diameter and grain size)

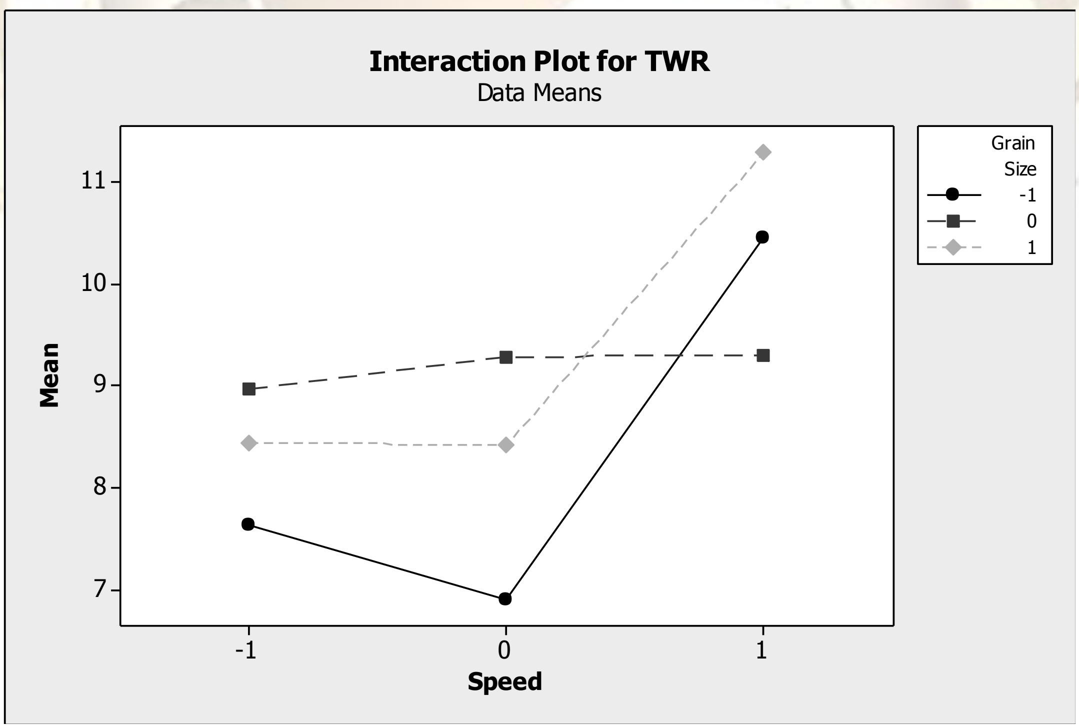

Fig. 8 Interaction plot for TWR (Rotation speed and grain size)

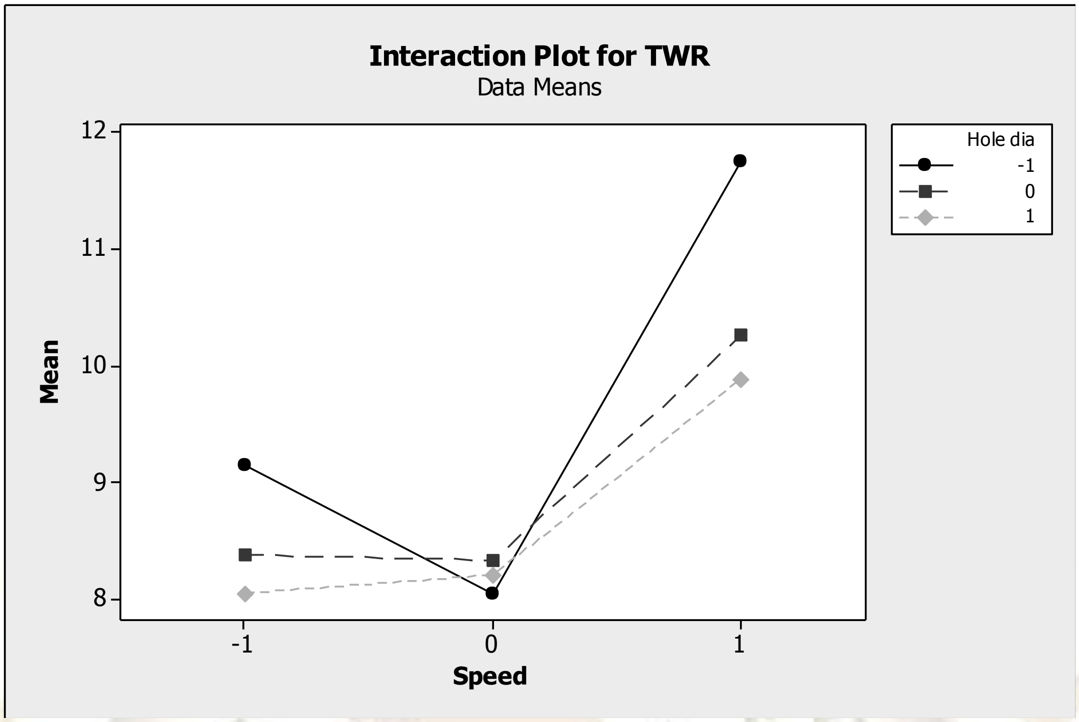

Fig. 9 Interaction plot for TWR (Rotation speed and hole diameter)

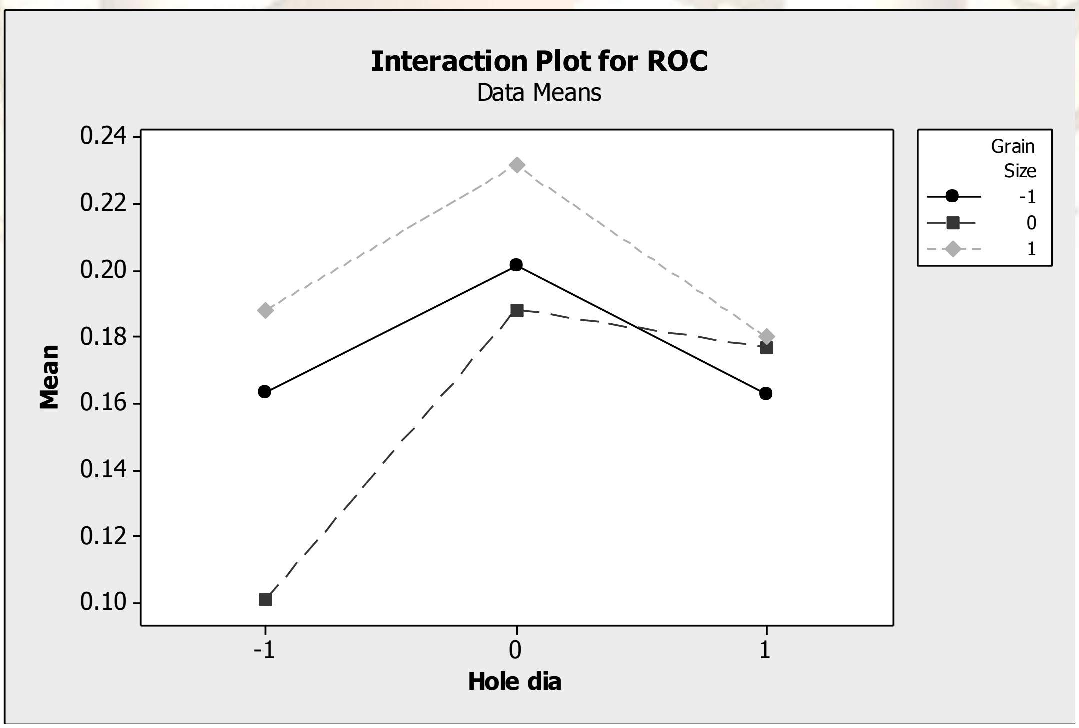

Fig. 10 Interaction plot for ROC (Hole diameter and Grain size)

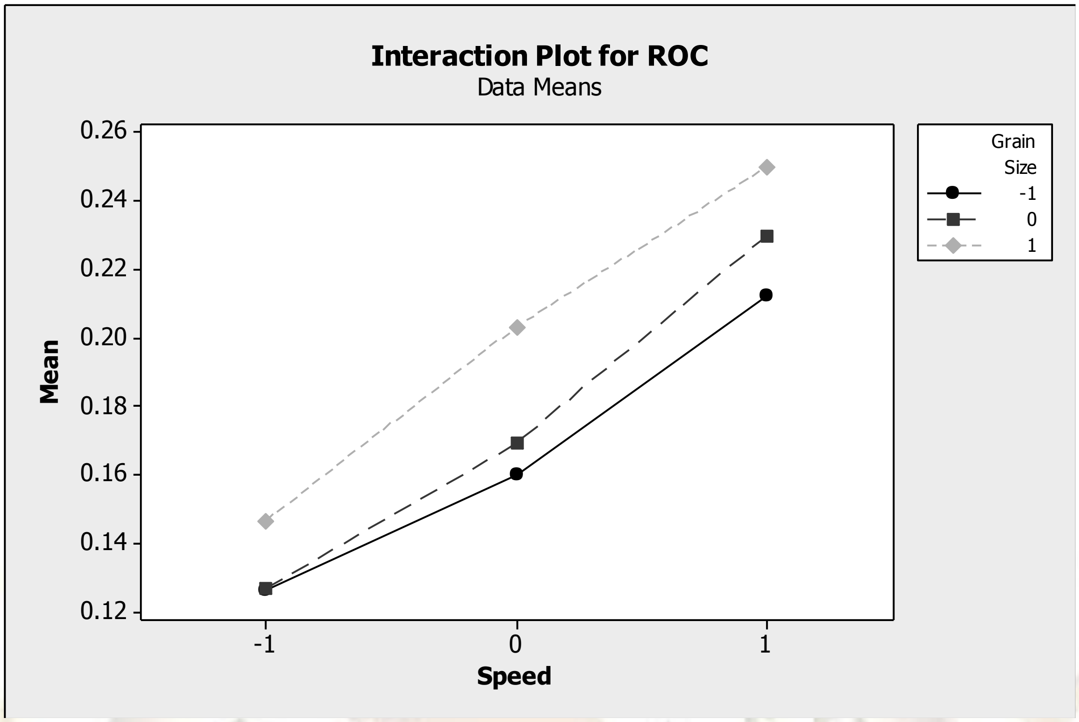

Fig. 11 Interaction plot for ROC (Rotation speed and Grain size)

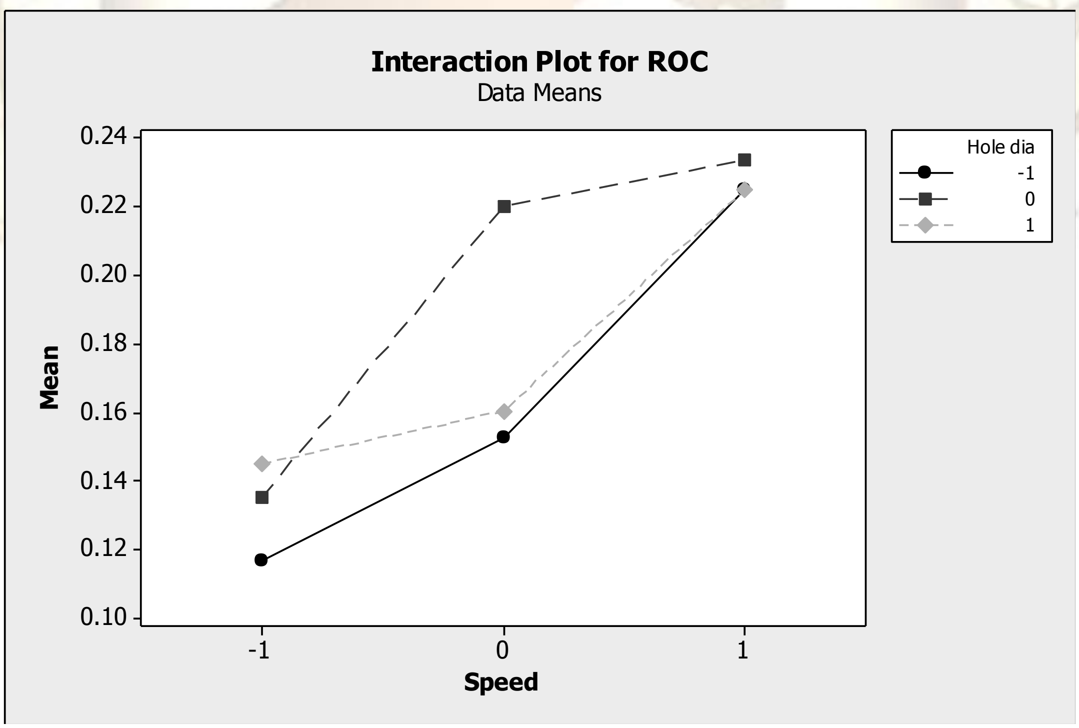

Fig. 12 Interaction plot for ROC (Rotation speed and Hole diameter)

Table 1 : Process parameter and their levels

Levels	Grain size (mesh number)	Hole diameter (mm)	Speed (rpm)
-1	60	0	0
0	80	3	230
1	120	6	460

Table 2 : Composition of the cast Al-alloy-SiC_p composite plates

Material	Percentage Composition (by weight)
Zinc	5.6 %
Copper	1.1 %
Chromium	0.3 %
Magnesium	2.5 %
SiC	10 %
Aluminum	Balance

Table 3 : Observation Table

S. No.	Grain Size	Hole diameter	Speed	Time taken (Minutes)	D (max.) (mm)	D (min.) (mm)	Tool wear (gm)	TWR x 10^{-4} (gm/sec.)	ROC (mm)	MRR x 10^{-3} (gm/sec.)
1.	-1	-1	-1	31	15.2	13.20	1.5	8.06	0.1	1.8
2.	-1	0	-1	32	15.2	14.60	1.6	8.33	0.1	1.95
3.	-1	-1	0	32	15.28	13.98	1.4	7.2	0.14	1.88
4.	-1	0	0	31	15.41	13.47	1.1	5.9	0.205	1.89
5.	-1	1	1	22	15.4	14.60	1.3	9.84	0.2	2.88
6.	-1	-1	1	20	15.5	13.70	1.4	11.6	0.25	3
7.	-1	1	-1	30	15.4	13.80	1.3	7.2	0.2	2
8.	-1	0	1	22	15.6	13.90	1.6	12	0.3	2.78
9.	-1	1	0	26	15.27	12.00	1.2	7.6	0.135	2.01
10.	0	-1	-1	32	15.2	14.20	1.6	8.3	0.1	1.94
11.	0	0	-1	32	15.25	13.70	1.4	7.29	0.125	1.88
12.	0	-1	0	24	15.15	14.25	1.1	7.6	0.075	2.59
13.	0	0	0	24	15.6	14.10	1.4	9.7	0.3	2.64
14.	0	1	1	21	15.5	14.20	1.2	9.52	0.25	3.02
15.	0	0	1	22	15.4	14.20	1.1	8.33	0.2	2.86
16.	0	-1	1	20	15.4	14.40	1.3	10.8	0.2	3.19
17.	0	1	0	28	15.4	14.20	1.5	8.9	0.2	2.25
18.	0	1	-1	22	15.3	14.00	1.4	10.6	0.15	2.807
19.	1	0	0	23	15.5	13.85	1.3	9.4	0.25	2.58
20.	1	1	0	22	15.29	13.76	1	7.5	0.145	2.79
21.	1	0	1	22	15.6	13.60	1.3	9.84	0.3	2.82

22.	1	1	1	18	15.5	14.20	1.2	11.1	0.25	3.57
23.	1	-1	1	21	15.4	13.10	1.5	11.9	0.2	2.82
24.	1	1	-1	32	15.4	14.60	1.5	7.81	0.2	2.05
25.	1	-1	-1	31	15.3	13.30	1.8	9.6	0.15	1.925
26.	1	-1	0	24	15.02	13.80	1.2	8.33	0.215	2.26
27.	1	0	-1	31	15.3	14.00	1.3	6.9	0.15	1.8

Table 4 : **ANOVA for Material Removal Rate (MRR)**

Predictor	Degree of Freedom	Seq SS	Coef	SE Coef	T	P-Value
Constant			0.4499	0.8	21.92	0.000
X1	1	0.32670	0.13472	0.0574	.60	0.019
X2	1	0.41648	0.15211	0.05174	2.94	0.009
X3	1	4.63297	0.50733	0.05174	9.81	0.000
X1^2	1	0.23325	-0.19717	0.0896	-2.20	0.04
X2^2	1	0.10507	0.13233	0.08961	1.48	0.158
X3^2	1	0.01859	0.05567	0.08961	0.62	0.543
X1*X2	1	0.11900	0.09958	0.06337	0.57	0.134
X2*X3	1	0.01191	0.03150	0.06337	0.50	0.625
X1*X3	1	0.02297	0.04375	0.06337	0.69	0.499

S = 0.2195 R-Sq = 87.8 % R-Sq(adj.) = 81.3 %

Table 5 : Summary of ANOVA for MRR

Source	DF	SS	MS	F	P
Regression	9	5.88694	0.65410	13.58	0.000
Residual Error	17	0.81909	0.04818		
Total	26	6.70603			

Table 6 : ANOVA for Tool Wear Rate (TWR)

Predictor	Degree of Freedom	Seq SS	Coef	SE Coef	T	P-Value
Constant			8.4348	0.6337	13.31	0.0000
X1	1	2.457	0.3694	0.2933	1.26	0.225
X2	1	2.000	-0.3333	0.2933	-1.14	0.272
X3	1	19.055	1.0298	0.2933	3.51	0.003
X1^2	1	0.111	-0.1361	0.5081	-0.27	0.792
X2^2	1	0.302	-0.2244	0.5081	-0.44	0.664
X3^2	1	9.916	1.2856	0.5081	2.53	0.022
X1*X2	1	0.120	-0.1000	0.3592	0.33	0.748
X2*X3	1	0.166	0.1175	0.3592	0.33	0.748
X3*X1	1	0.145	-0.1100	0.3592	-0.31	0.763

S = 1.244 R-Sq = 56.6% R-Sq(adj.) = 33.6%

Table 7 : Summary of ANOVA for TWR

Source	DF	SS	MS	F	P
Regression	9	34.272	3.808	2.46	0.053
Residual Error	17	26.328	1.549		
Total	26	60.600			

Table 8 : ANOVA for Radial Over Cut (ROC)

Predictor Constant	Degree of Freedom	Seq SS	Coef 0.18881	SE Coef 0.01866	T 10.12	P-Value .0000
X1	1	0.002616	0.012056	0.008637	1.40	0.181
X2	1	0.001780	0.009944	0.008637	1.15	0.266
X3	1	0.051200	0.053333	0.008637	6.17	.000
X1^2	1	0.003472	0.02406	0.01496	1.61	0.126
X2^2	1	0.010059	-0.04094	0.01496	-2.74	0.014
X3^2	1	0.000076	0.00356	0.01496	0.24	0.0.815
X1*X2	1	0.000044	-0.00192	0.01058	-0.18	0.858
X2*X3	1	0.000002	-0.00042	0.01058	-0.04	0.969
X1*X3	1	0.000631	-0.00725	0.01058	-0.69	0.502

S = 0.03664 R-Sq = 75.4% R-Sq(adj.) = 62.3%

Table 9 : Summary of ANOVA for ROC

Source	DF	SS	MS	F	P
Regression	9	0.069880	0.007764	5.78	0.001
Residual Error	17	0.022828	0.001343		
Total	26	0.092708			