An Experimental Investigation on Electrical Discharge Machining of Al-SiC_p Metal Matrix Composite

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Abstract **- In the present investigation a Metal Matrix Composite (MMC) material Al7075-SiC_p has been fabricated by Stir Casting method. The SiC particles are fabricated in 10 W% of the Aluminum Matrix. Electrical Discharge Machining of the MMC has been performed. EDM experiments have been performed as per the design of experiments. Experiments have been designed by Face Centered Composite Design of Response Surface Methodology. The Suitable mathematical models have been developed for each response characteristic. Influence of process parameters on EDM response characteristics has been studied by Analysis of Variance (ANOVA) technique.**

KeywordS: Metal matrix composite, Aluminum 7075, Silicon Carbide, Electrical Discharge Machining, Mathematical Modeling.

ABBRIVIATIONS: CCD – Central Composite Design, DOEx - Design of Experiment, EDM - Electrical Discharge Machining, IP – Pulse Current, MMC - Metal Matrix Composite, MRR - Material Removal Rate, RSM - Response Surface Method, SR - Surface Roughness, TWR - Tool Wear Rate

1. INTRODUCTION

Metal matrix Composite (MMC) materials are popular material for many engineering applications due to their versatile properties i.e. good mechanical properties, light weight, low thermal expansion coefficient and good wear resistance[1]. The reinforcements reflect their exceptional mechanical and physical properties to composite material. Properties of composite cannot be achieved from the individual constituent materials[2]. These materials are widely used in engineering applications like aerospace and automotive structures[3]. Aluminum 7xxx series have the best mechanical properties among all aluminum grades. The MMC composed with metal matrix of Al7075 and reinforcement of SiC particles. The material Al7075 is having good mechanical properties. Silicon Carbide is a abrasive material which exhibits very high mechanical properties. SiC may help in enhancement of mechanical properties for the MMC material [4]. MMC materials are difficult to machine due to high hardness and Strength of the reinforcement forms. Hence, Electrical Discharge Machining (EDM) can be a viable option for the machining[4]. Generally it has been observed that the Response Characteristics gets influenced by the percentage of reinforcement fabricated in the MMC[5].

The general phenomenon for EDM process is increase in peak current and Pulse on time increases the MRR, TWR and SR[6]; increase in pulse off time gives the opposite results. The present investigation has been carried out to check the influence of process parameters on responses characteristics. The investigation has been aimed to develop the mathematical models of the response characteristics of EDM process for Al7075-SiC_p material.

2. EXPERIMENTAL DETAILS

2.1 Design of Experiments

In the present investigation Experiments have been designed based on Central Composite design (CCD) of Response Surface Method (RSM). Three factors Pulse on time (T_{on}), Pulse off time (T_{off}) and Pulse current (IP) with three levels (+1, 0,-1) have been introduce to the design. MRR, TWR and SR have been selected as the process responses. The design consists of the eight star points, six central points (coded level 0), and six axial points (+1.68179, -1.68179). Total 20 different parametric combinations have been chosen according to CCD in RSM. The experiments have been performed according to run order based on the CCD given in Table 1.

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Table 1: Parametric Settings.

Run Order	T_{on}	T_{off}	I.P
01	06	06	08
02	04	04	16
03	04	08	08
04	06	06	12
05	06	08	12
06	04	04	08
07	08	06	12
08	08	04	08
09	06	04	12
10	08	04	16
11	06	06	12
12	04	08	16
13	08	08	08
14	06	06	12
15	04	06	12
16	06	06	12
17	06	06	12
18	08	08	16
19	06	06	16
20	06	06	12

3. RESULTS AND DISCUSSION

The material used in present investigation is a Metal Matrix Composite of Aluminum 7075 and 10% Silicon Carbide particles with average particulate size of 10 µm. The material has been fabricated by Stir casting method. The machining of the material has been done on Die-Sinking Spark Electrical Discharge Machine. The responses of EDM process are given in Table 2. The work material of 6mm thickness and copper electrode of 10mm diameter has been used in this experiment. The machining has been performed up to 0.6mm depth from the surface of workpiece for each parametric setting. The MRR and TWR have been calculated as volumetric reduction per unit time. Volumetric reduction has been found by weight reduction for each experiment to average density of the MMC material. Weights of workpiece and tool have been measured by the weighing scale of 0.001gm precision, before and after the machining. The average surface Roughness (R_a) has been measured using Taylor Hobson Profilometer and given in the Table 2.

Table 2: EDM Responses for each Parametric Setting

Run Order	T_{on}	T_{off}	I.P	MRR (mm^3/min)	TWR (mm^3/min)	SR (Ra) (µm)
1	6	6	8	8.7864	0.2036	5.4370
2	4	4	16	13.1148	0.3421	5.2414
3	4	8	8	0.8934	0.0296	3.3492
4	6	6	12	13.4127	0.2675	5.9592
5	6	8	12	9.2849	0.1555	6.0127
6	4	4	8	8.0476	0.1605	3.6967
7	8	6	12	15.8379	0.3104	7.3747
8	8	4	8	14.4822	0.3000	6.7992
9	6	4	12	16.5618	0.3180	6.0009
10	8	4	16	20.6780	0.4951	7.4667

11	6	6	12	13.3333	0.2774	5.6489
12	4	8	16	5.8784	0.1351	4.2626
13	8	8	8	8.4967	0.1836	6.0884
14	6	6	12	13.3333	0.2809	5.6718
15	4	6	12	9.1211	0.2050	4.2423
16	6	6	12	13.5743	0.2707	5.6870
17	6	6	12	13.4902	0.2644	5.6893
18	8	8	16	15.1429	0.2568	7.2525
19	6	6	16	15.5496	0.3314	6.5117
20	6	6	12	13.4127	0.2675	5.7550

3.1 Mathematical Models for MRR, TWR and SR

The process responses i.e. MRR, TWR and SR have been modeled based on the fully quadratic model. All terms have been tested under ANOVA to check their influence on models. The significant terms have been included in the model and non-significant terms have been removed. The fit summary of the regression model cleared the picture of the adequacy of the model. The fit summary has been checked from the values of R^2 and the Adjusted R^2 of the model. It is always desired to have higher values of R^2 and the Adjusted R^2 to say that the regression model as obtained by RSM methodology is statistically significant. The fitness of mathematical models confirmed their statistical significance to the process variables. The values obtained are as follows: R^2 = 0.9968 and Adjusted R^2 = 0.9944 for MRR, R^2 = 0.9917 and Adjusted R^2 = 0.9887 for TWR and R^2 = 0.9686 and Adjusted R^2 = 0.9602 for SR.

$$MRR = -13.60 + 3.523\times T_{on} - 0.824\times T_{off} + 2.300\times I.P - 0.2255\times(T_{on})^2 - 0.1145\times(T_{off})^2 - 0.0758\times(I.P)^2 + 0.0897\times T_{on}\times T_{off} + 0.0436\times T_{on}\times I.P \quad \text{(eq 1)}$$

$$TWR = -0.3776 + 0.03368\times T_{on} + 0.0851\times T_{off} + 0.03564\times I.P - 0.00756\times(T_{off})^2 - 0.003094\times T_{off}\times I.P \quad \text{(eq 2)}$$

$$SR = -1.701 + 1.492\times T_{on} - 0.1124\times T_{off} + 0.1341\times I.P - 0.0652\times(T_{on})^2 \quad \text{(eq 3)}$$

3.2 Effect of Process Parameters on the output Characteristics of EDM Process

The analysis of MRR has been done by plotting contour plots for understanding the combined effect of any two parameters while the other parameters are kept constant. Figure 1 and Figure 2 are drawn based on eq. 1. The combined effect of Pulse on time (T_{on}) and Peak Current (I.P) on MRR can be studied from these plots. An observation can be made that MRR is found to be minimum, if T_{off} kept at higher constant values. In general MRR increases with increase in T_{on} and I.P at constant T_{off} values. It is observed that MRR found maximum at higher values of T_{on} and I.P with T_{off} kept at lower constant values. However, the trend seems to be similar in both higher and lower constant values of T_{off}, but the stiffness of contour with higher constant T_{off} value is more than the lower constant value of T_{off}.

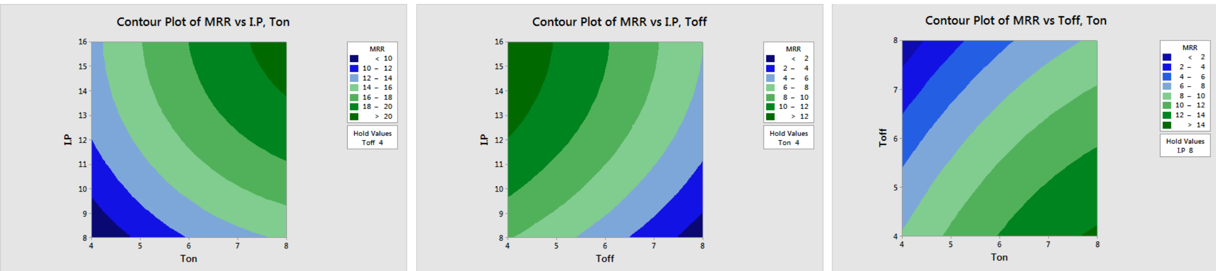

Fig. 1: Contour plots of MRR showing the combined effects of pulse on time (T_{on}), Peak Current (I.P) and Pulse off time (T_{off}) at lower value settings of constant parameter

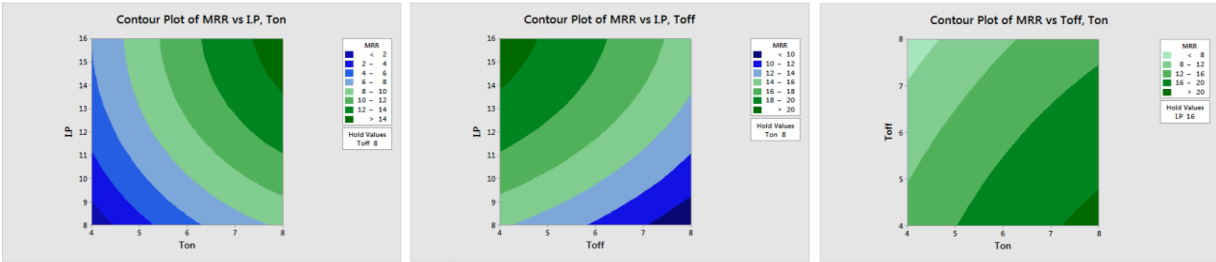

Fig. 2: Contour plots of MRR showing the combined effects of pulse on time (T_{on}), Peak Current (I.P) and Pulse off time (T_{off}) at higher value settings of constant parameter

The TWR has been analyzed by plotting contour plots for understanding the combined effect of any two parameters while the other parameters are kept constant. Fig. 3 and Fig. 4 are drawn based on eq.2. The combined effect of Pulse on time (T_{on}) and Peak Current (I.P) on MRR can be studied from these plots. An observation can be made that TWR is found to be minimum, if T_{off} kept at higher constant values. In general TWR increases with increase in T_{on} and I.P at constant T_{off} values. It is observed that TWR found maximum at higher values of T_{on} and I.P with T_{off} kept at lower constant values. However, the trend seems to be similar in both higher and lower constant values of T_{off}, but the stiffness of contour with higher constant T_{off} value is more than the lower constant value of T_{off}.

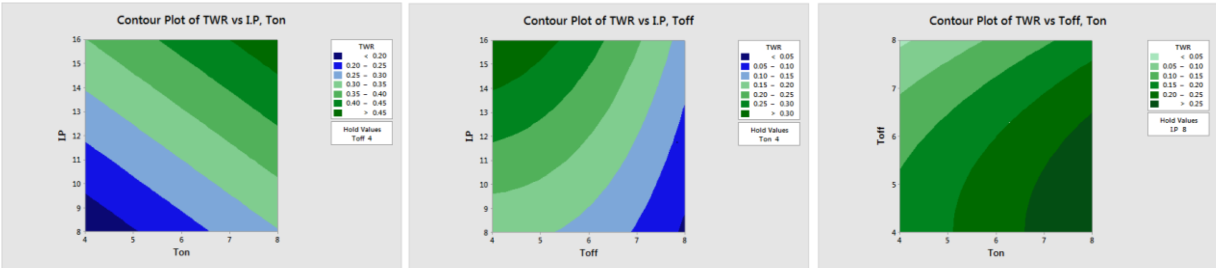

Fig. 3: Contour plots of TWR showing the combined effects of pulse on time (T_{on}), Peak Current (I.P) and Pulse off time (T_{off}) at lower values setting of constant parameter

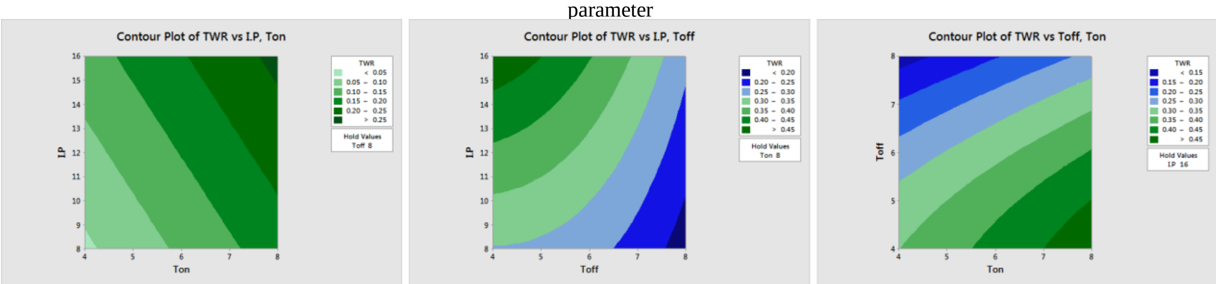

Fig. 4: Contour plots of TWR showing the combined effects of pulse on time (T_{on}), Peak Current (I.P) and Pulse off time (T_{off}) at higher values setting of constant parameter

Fig. 5 and Fig. 6 are drawn based on eq. 3. The combined effect of Pulse on time (T_{on}) and Peak Current (I.P) on SR can be studied from these plots. An observation can be made that SR is found to be minimum, if T_{off} kept at higher constant values. In general SR increases with increase in T_{on} and I.P at constant T_{off} values. It is observed that SR found maximum at higher values of T_{on} and I.P with T_{off} kept at lower constant values.

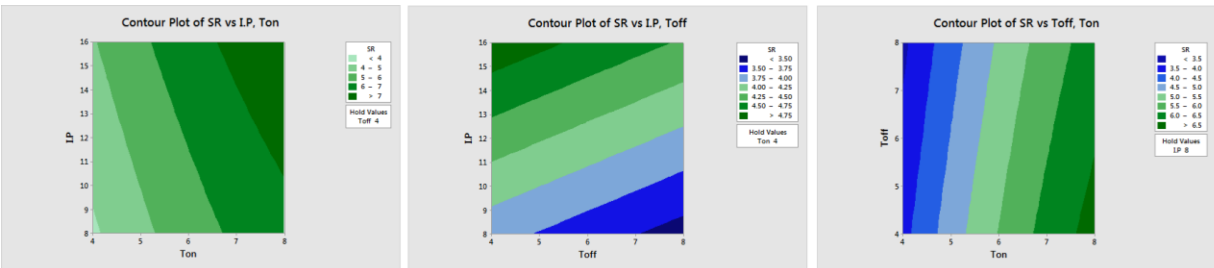

Fig. 5: Contour plots of SR showing the combined effects of pulse on time (T_{on}), Peak Current (I.P) and Pulse off time (T_{off}) at lower value setting of constant parameter

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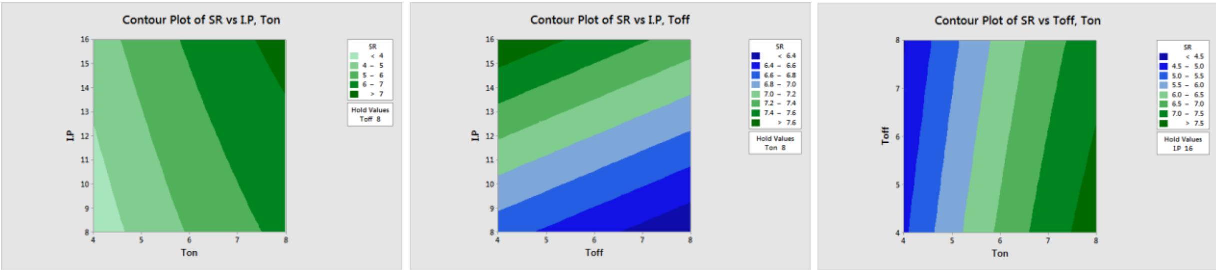

Fig. 6: Contour plots of SR showing the combined effects of pulse on time (T_{on}), Peak Current (I.P) and Pulse off time (T_{off}) at higher value setting of constant parameter

4. CONCLUSIONS

Based on the results of the experiments and analysis of the data obtained from Electrical discharge machining of metal matrix composite Al7075-SiC_p, following conclusions can be drawn.

- The predicted values obtained by the regression models and the experimental values for material removal rate (MRR), Tool wear rate (TWR) and surface roughness (SR) are found to be in reasonable argument. The contour plots have been developed from the response surface design analysis. With the use of these plots one can predict the response value at a given parametric setting of any two parameters where the other parameter is kept constant. One can also have an idea about the changes in response when any two parameters are varied keeping the other parameter constant.
- MRR, SR and TWR increases in general with increase in pulse on time T_{on} and vise-versa within the experimental domain, while other process parameters are kept constant.
- Increase in T_{off} results to decrease in all three responses and vise-versa, while other parameters are kept constant.
- Increase in peak current I.P results to increase in all three responses and vise- versa, while other parameters are kept constant.
- The results of the experiments can be influenced by the distribution of the particulates and porosity content. So it is demanding to develop such robust methodology to fabricate MMCs which can reduce the porosity issue with a homogeneous distribution of the material.
- Electrical Discharge Machining can be proved a viable option for machining of hard materials like MMCs with proper selection of process parameters. This, however require more and extensive research work.

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