Characterization of Machined Surface by EDM for Al/B₄C_p Composite Material

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In this study, electrical discharge machining process was performed to investigate the machinability of Al/B₄C_p metal matrix composites manufactured by powder metallurgy. For this, an experimental layout was conducted by using full factorial design. In the analysis, there are three parameters of which one is at three levels and the remaining are two levels. Totally, 48 experiments were carried out. The surface roughness (R_a) was increased with increasing the current (C), pulse-on-time (T_{on}), pulse-off-time (T_{off}) and amount of particle (PR).

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1. Introduction

During the machining of particle reinforced aluminum metal matrix composites (MMCs) by conventional machining methods, many problems occur due to the abrasive ceramic particles in the aluminum matrix [1]. Especially, the ratio of ceramic particles in the metal matrix is the most influential control factor on the machining results (surface roughness, dimensional accuracy etc.) and cutting tool wear. To eliminate the negative effects of machining method, cutting tool on the machined surface and to provide dimensional accuracy, the non-conventional machining (laser based machining-LBM, EDM, WEDM and water jet) methods are effective methods for machining of aluminum MMCs [1, 2].

Electrical discharge machining (EDM) is one of the thermal machining methods and is used to produce tools, dies and other precision parts [3] and this method is evaluated with many electrical discharge (sparks) generated by an electrical energy between an electrode and a material immersed in the dielectric medium [4]. Due to the thermal energy produced by sparks, an amount of material is removed from the interaction region. EDM can be used for machining of geometries having complex shapes due to non-contact machining process [3]. In the paper by Tak et al. [5], micro-EDM experiments were performed on alumina matrix composites reinforced with carbon nanotubes (CNTs). The dimensional accuracy and circularity of holes has been investigated. Patel et al. [6] studied on EDM parameters for Al₂O₃-SiCw-TiC ceramic composite material, the surface roughness and material removal rate has been correlated to process parameters. Habib [7] performed studies to develop a mathematical model for the correlation of the variety machining parameters of Al/SiC_p metal matrix composites on the most dominant machining criteria, such as electrode wear ratio, metal removal rate, surface finish and the gap size. To the best of our knowledge, there is no study concentrated on the effect of EDM parameters on the surface roughness of Al/B₄C_p MMCs.

In the present study, the effect of EDM parameters on the surface roughness was investigated for Al/B₄C_p MMCs. This study will contribute to the related literature in this respect.

2. Experimental studies

In this study, samples were manufactured through a conventional powder metallurgy (P/M) process. In the experiments, 3, 9, 15 wt% of B₄C particle reinforcement (53 μ m) were added to the aluminum matrix (84 μ m) and mixed for 60 min at 50 rpm. After the powder mixtures were loaded into the die, they were cold pressed uniaxially at 440 MPa. Sintering process was carried out at 150, 300, 450 °C for 30 min then there was final heating to 600 °C keeping at that temperature for two hours.

EDM process parameters. TABLE I

Symbol	Parameters	Levels		
C	current [A]	1	2	4
T_{on}	pulse on time [μ s]	20	40	–
T_{off}	pulse off time [μ s]	40	60	–

The EDM process was conducted on a die sinking EDM machine (OSCARMAX S43OSNC). Kerosene was used as the dielectric fluid. The selected EDM process parameters, which directly affect the surface roughness, are: current, pulse-on-time and pulse-off-time. The levels of each parameter were given in Table I. Using these parameters given in Table I, an experimental plan was constituted (see Table II). The electrode material used in the experiments was graphite having perpendicular shape (10 $\times$ 10 mm²). The square holes were machined with a depth of 0.5 mm. The process performance was evaluated by surface roughness and characterized by R_a surface roughness parameters. The Mitutoyo Surf test 301J surface roughness tester was used for determining the surface roughness. The surface roughness was calculated by the average value of at least three measurements taken

TABLE II

EDM experimental plan and data taken from machined surface.

No.	C	T_{on}	T_{off}	0%	3%	9%	15%
1	1	20	40	6.74	6.02	6.56	6.94
2	1	20	60	6.76	6.98	7.06	7.10
3	1	40	40	6.94	7.26	7.32	7.48
4	1	40	60	7.05	7.07	7.42	7.56
5	2	20	40	7.20	7.04	7.27	7.39
6	2	20	60	7.28	6.38	7.36	7.59
7	2	40	40	7.40	7.33	7.47	7.66
8	2	40	60	7.33	7.36	7.69	7.64
9	4	20	40	7.6	8.34	8.55	8.67
10	4	20	60	7.28	8.63	8.66	8.86
11	4	40	40	8.25	8.78	9.5	9.67
12	4	40	60	8.35	9.01	9.3	9.95

from different region on the surface. The full factorial design was used to analyze the effects of parameters on surface roughness and a mathematical model was established using the linear regression analysis.

3. Data analysis

In this study, main parameters namely current (C), pulse-on-time (T_{on}) and pulse-off-time (T_{off}) of EDM process was correlated with the reinforcement ratio of B_4C_p in aluminum MMCs manufactured by P/M. By using of full factorial design, totally 12 experiments were performed for each group of samples. Table II shows the experimental design and results of experiments.

The effect of parameters was analyzed by using Fig. 1 which was drawn according to the results given in Table II. It is clearly shown in Fig. 1 that the R_a were increased with increasing current (C) and pulse-on-time (T_{on}). And also, the similar effect was observed in the pulse-off time (T_{off}), but the trend in the change of R_a is not clear and also the statistical analysis given in Table III supports this result. As for the effect of amount of particle reinforcement on R_a , the R_a increased with increasing amount of particle reinforcement. It can be concluded that the R_a increases with increase in values of each parameter that were investigated. The statistical significance of each parameter was analyzed at the 95% coefficient level (0.05α -level).

TABLE III

Parameters	DF	SS	MS	F	P	P.C. [%]
C	2	25.98	12.99	128.40	0.000	70.29
T_{on}	1	3.27	3.27	32.32	0.000	8.85
T_{off}	1	0.1	0.11	1.08	0.305	0.27
PR	3	3.55	1.18	11.68	0.000	9.60
error	40	4.05				0.11
total	47	36.96

Fig. 1. The effects plot (data means) for R_a .

According to the results in Table III, except T_{off} , all other parameters and constant value are statistically significant at 0.05α -level.

TABLE IV

The results of regression analysis.

Parameters	Coef.	P
constant	4.99	0.000
C	0.583	0.000
T_{on}	0.0261	0.000
T_{off}	0.00477	0.324
PR	0.0468	0.001

ANOVA results for model.

TABLE V

Parameters	DF	SS	MS	F	P
regression	4	32.24	8.06	73.48	0.000
error	43	4.71	0.109		
total	47	36.96			

In order to establish a mathematical relation between the parameters and R_a , the linear regression analysis was performed with the use of 48 experiments and the following regression equation was established:

$$R_a = 4.99 + 0.583C + 0.0261T_{on} + 0.00477T_{off} + 0.0468PR. \quad (1)$$

The statistical significance of the coefficient and model was tested by the probability (p) value and results were given in Table IV and Table V, respectively. The results of analysis of variance (ANOVA) show that the estimated regression model is statistically significant at the 95% coefficient level due to α value less than 0.05. For the purpose of evaluating the accuracy of model, 48 experimental conditions were inserted in the model given in Eq. (1). The actual value (A.V.) taken from measurements and the predicted value (P.V.) taken from mathematical model were compared and the results were given in Fig. 2. Results showed that the values were determined to be almost close to each other in most of conditions.

Fig. 2. Comparative results for R_a .

4. Conclusion

The EDM experiments were performed in accordance with the experimental layout conducted by full factorial design. Results showed that the R_a value was increased with increasing the current (C), pulse-on-time

(T_{on}), pulse-off-time (T_{off}) and amount of particle reinforcement (PR). Except T_{off} , all other parameters and constant value is statistically significant at 0.05 α -level. The effect of each parameter as percentage contribution on surface roughness is 70.29% for C , 9.6% for PR , 8.85% for T_{on} , and 0.27% for T_{off} .

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