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# The Influence of Process Parameters of EDM on the Surface Roughness of Aluminum Matrix Composites Reinforced with SiC Particulates

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This paper investigates the effect of electrical discharge machining parameters on the surface roughness as an alternative method for machining of Al/SiC$_p$ metal matrix composites produced with the powder metallurgy. Current, electrode type, pulse-on-time, particle reinforcement weight ratio and voltage were used as the process parameters. An experimental plan ($L_{18}$) was constituted by using the Taguchi orthogonal design. Results of experiments showed that pulse-on-time (34%) and current (31.26%) is the most influencing parameters. Besides this, the percentage contribution of particle reinforcement on the surface roughness is 6.71%.

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## 1. Introduction

Advanced surface machining techniques are gradually improving in the use of difficult to machine materials like ceramic particulate reinforced metal matrix composites (MMCs). Electrical discharge machining (EDM) process which is the one of advanced surface machining technique is non-contact [1] and thermal machining process also is characterized by a spark occurring between the electrode and workpiece submerged in a dielectric fluid [2, 3]. During a series of sparks, the temperature of workpiece at the interaction area rises to the melting or vaporization point and thus, an amount of material is removed [4] and eventually the craters occur on the machined surface. These craters determine the surface roughness of the work pieces.

This study focuses on the investigation of the effects of EDM process parameters on surface roughness namely current, electrode type, particle reinforcement weight ratio (SiC$_p$, %), voltage and pulse on time. In this paper, the correlation between the EDM process parameters and surface roughness has been evaluated.

## 2. Experimental studies

The EDM experiments were carried out by the AJAN 983 type EDM machine. The process condition is determined by the five process parameters which are current, electrode type, pulse-on-time, weight percentage of particle reinforcement, voltage.

Table I presents the process parameters and their levels. In the current study, the surface roughness was selected as the performance evaluation criteria. For the purpose of determining the effects of process parameters on the surface roughness, an experimental layout was constituted by using the Taguchi method.

With the use of five factors of which one has two level and the remaining have three levels, $L_{18}$ orthogonal array given in Table II was selected as the experimental layout. Mitutoyo Surftest SJ 301 profilometer was used for measuring the surface roughness of the samples. Totally, at least four measurements at the scan direction and perpendicular to scan direction were performed to determine the ultimate surface roughness ($R_a$).

TABLE I

EDM process parameters.

| Symbol | Parameters | Levels | | |
|---|---|---|---|---|
| ET | electrode type | Cu | G | – |
| PR | particle wt ratio [%] | 5 | 10 | 20 |
| $C$ | current [A] | 3 | 6 | 12 |
| $T_{on}$ | pulse on time [$\mu$s] | 1.5 | 2 | 2.5 |
| $V$ | voltage [V] | 50 | 75 | 100 |

Conventional powder metallurgy (P/M) process was used for manufacturing of the samples. In the experiments, 5, 10, 20 wt% of SiC$_p$ was used. After the weighed powders were placed in a three-dimensional mixing machine, they were mixed for 60 min at 50 rpm. Following the completion of the mixing procedure, green samples were obtained by waiting for 5 min under 440 MPa pressure by pressing cold uniaxially. After the sintering process was carried out at 150, 300, 450 °C for 30 min, final heating to 600 °C was performed keeping at that temperature for two hours.

For the experiments, an experimental layout was constituted by using the $L_{18}$ orthogonal array. Accordingly, with the use of eighteen different machining conditions, we tried to evaluate the EDM process on Al/SiC$_p$. Taguchi uses three quality characteristics. These are "the smaller the better", "the nominal the better" and "the larger the better" [5]. The objective is to minimize the surface roughness. Among these, "the smaller the better" is selected as the quality characteristic of present study and following equation (Eq. (1)) is used to determine the

TABLE II

EDM experimental plan and data taken from machined surface.

| No. | ET | PR | $C$ | $T_{\text{on}}$ | $V$ | $R_{\text{a}}$ [$\mu$m] | S/N$_{\text{Ra}}$ [dB] |
|---|---|---|---|---|---|---|---|
| 1 | Cu | 5 | 3 | 1.5 | 50 | 6.32 | −16.01 |
| 2 | Cu | 5 | 6 | 2.0 | 75 | 10.52 | −20.44 |
| 3 | Cu | 5 | 12 | 2.5 | 100 | 12.36 | −21.84 |
| 4 | Cu | 10 | 3 | 1.5 | 75 | 7.87 | −17.92 |
| 5 | Cu | 10 | 6 | 2.0 | 100 | 9.9 | −19.91 |
| 6 | Cu | 10 | 12 | 2.5 | 50 | 11.11 | −20.91 |
| 7 | Cu | 20 | 3 | 2.0 | 50 | 7.52 | −17.52 |
| 8 | Cu | 20 | 6 | 2.5 | 75 | 8.29 | −18.37 |
| 9 | Cu | 20 | 12 | 1.5 | 100 | 9.49 | −19.55 |
| 10 | G | 5 | 3 | 2.5 | 100 | 9.07 | −19.15 |
| 11 | G | 5 | 6 | 1.5 | 50 | 8.77 | −18.86 |
| 12 | G | 5 | 12 | 2.0 | 75 | 11.68 | −21.35 |
| 13 | G | 10 | 3 | 2.0 | 100 | 9.89 | −19.90 |
| 14 | G | 10 | 6 | 2.5 | 50 | 10.15 | −20.13 |
| 15 | G | 10 | 12 | 1.5 | 75 | 8.65 | −18.74 |
| 16 | G | 20 | 3 | 2.5 | 75 | 9.9 | −19.91 |
| 17 | G | 20 | 6 | 1.5 | 100 | 8.08 | −18.15 |
| 18 | G | 20 | 12 | 2.0 | 50 | 9.43 | −19.49 |

signal-to-noise (S/N) ratio. Using Eq. (1), eighteen data taken from measurement of machined surface were transferred to the S/N ratio. The greatest S/N ratio for each parameter refers to the optimal level. In this analysis, the greater S/N ratio was selected to determine the most effective level for each parameter

$$\eta = \frac{\text{S}}{\text{N}} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} Y_i^2\right), \tag{1}$$

"where $Y_i$ is the performance characteristic for surface roughness or engraving depth. $n$ is the number of experiment" [6].

Next analysis was performed by using analysis of variance (ANOVA). The analysis was performed by using the S/N ratio. With the help of this analysis, the statistical significance and the percentage contribution of each parameter on surface roughness can be determined. The statistical significance of each parameter is tested by the probability ($p$) value. The significance of each parameter was tested at 95% confidence level and the smaller value than 0.05 ($\alpha$-level) indicates that the related parameter is statistically significant.

## 3. Data analysis with S/N ratio

The surface roughness is the main process response considered in the investigation of the effect of process parameters. Therefore, to assess the effect of process parameters on surface roughness, the data taken from measurements of the machined surface were transformed into the S/N ratio using Eq. (1). In this context, eighteen S/N ratios in total were calculated and results were given in Table II.

Moreover, the mean value of S/N ratio for each level of parameters was also calculated and results were given in Table III. We previously mentioned that the greatest S/N ratio corresponds to the better process response. Hence, for the purpose of determining the optimal level for each parameter, the greatest S/N was selected by using data in Table III. According to data in Table III, when electrode type was at level 1 (Cu), particle reinforcement weight ratio at level 3 (20% SiC$_p$), discharge current at level 1 (3 A), pulse-on-time at level 1 (1.5 $\mu$s) and voltage at level 1 (50 V) the surface roughness was at minimum.

TABLE III

Main effects of S/N$_{\text{Ra}}$.

| Level | ET | PR | $C$ | $T_{\text{on}}$ | $V$ |
|---|---|---|---|---|---|
| 1 | −19.16* | −19.61 | −18.40* | −18.20* | −18.82* |
| 2 | −19.52 | −19.59 | −19.31 | −19.77 | −19.46 |
| 3 | – | −18.83* | −20.31 | −20.05 | −19.75 |

The next analysis is performed by using ANOVA and used to test the statistical significance of parameters on surface roughness. The ANOVA results for S/N ratio were given in Table IV. The significance of parameters was tested by probability ($p$) value at the 95% confidence level. The results indicated that the current ($C$) and pulse-on-time ($T_{\text{on}}$) are the statistically significant parameters because of the less than 0.05$\alpha$-level. Other remaining factors that have the $p$ value higher than 0.05 were considered statistically insignificant. Besides this, the $T_{\text{on}}$, $C$, $V$, PR, and ET affect the $R_{\text{a}}$ by 34%, 31.26%, 7.7%, 6.71%, and 1.63%, respectively.

TABLE IV

ANOVA results for S/N$_{\text{Ra}}$.

| Parameters | ET | PR | $C$ | $T_{\text{on}}$ | $V$ | Error | Total |
|---|---|---|---|---|---|---|---|
| D.F. | 1 | 2 | 2 | 2 | 2 | 8 | 17 |
| seq. SS | 0.57 | 2.35 | 10.94 | 11.9 | 2.70 | 6.54 | 34.997 |
| $F$ | 0.70 | 1.44 | 6.69 | 7.27 | 1.65 | | |
| $p$ | 0.428 | 0.29 | 0.02 | 0.016 | 0.251 | | |
| $P.C$ [%] | 1.63 | 6.71 | 31.26 | 34 | 7.7 | 18.69 | |

The optimum value of surface roughness is predicted with the usie of optimal combination which contains the optimum level of process parameters. For the purpose of predicting the surface roughness of optimal combination, following equation is used [6]:

$$\eta = \eta_m + \sum_{i=1}^{n}(\eta_i - \eta_m), \tag{2}$$

"where $\eta$ is the estimated S/N ratio for optimal combination of milling parameters, $\eta_m$ is the mean value of S/N ratio, $n$ is the number of parameters and $\eta_i$ is the mean S/N ratio at the optimal parameters" [7]. Using Eq. (2), the $R_{\text{a}}$ and S/N$_{\text{Ra}}$ were calculated and results are 6.002 $\mu$m and −16.057 dB, respectively. When the S/N$_{\text{Ra}}$ is compared with the calculated value from the experiments, the result indicated that the calculated value is the almost similar to the Exp. No. 1. However, when the predicted value is compared with the data measured from machined surface, it is seen that the predicted $R_{\text{a}}$

value is the smallest value within the measured values. For the purpose of testing the accuracy of predicted surface roughness for optimal combination, a conformation experiment was performed using the optimum combination. The surface roughness value taken from confirmation experiment is 6.21 $\mu$m.

## 4. Conclusions

With the use of five EDM parameters, totally eighteen experiments were performed. Accordingly, the $T_{\text{on}}$ and $C$ is the most influencing parameters that affect the surface roughness by percentage contribution of 34% and 31.26%, respectively. The electrode type has the lowest effect (1.63%) on the surface roughness. The result of verification experiment showed that the predicted optimum experimental combination can be used in the machining of Al/SiC$_p$ MMCs produced by P/M.

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