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Research Article

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Effect of Process Parameters on Material Removal Rate in PMEDM

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Abstract The use of powder mixed electrical discharge machining helps overcome this drawback and increases the efficiency of the machining process. This study focused on the machining of SKD61, SKD11, and SKT4 die steels using titanium powder. Taguchi methods and analysis of variance were employed to identify the main parameters that affect the material removal rate (MRR). The other process parameters considered were the electrode material, workpiece material, electrode polarity, pulse-on time, pulse-off time, electric current, and titanium powder concentration. The results indicated that electric current, electrode material, and powder concentration were the most significant parameters that influenced the MRR. A powder concentration of 20 g/l increased the MRR by 42.1%, as compared with no-powder machining.

Keywords Process Parameters, Material Removal Rate

1. Introduction

Electrical discharge machining (EDM) is the most common method for processing the surfaces of dies and molds. An alternative method to improve efficiency was discovered by adding metal powder or alloy powder to the dielectric fluid. Issues with the powder mixed electrical discharge machining (PMEDM) process still exist because of its stochastic nature. No set input variable values have been defined for a particular combination of workpiece–tool materials to optimize the EDM response; however, empirical/exploratory research has been carried out to determine reasonable process parameters. The EDM process involves many factors, which makes it difficult to attain an optimal set of input variables; the complex processing mechanisms are still unclear. This has resulted in an increase in the cost of experimental studies. To ensure the economic efficiency of technical research in the EDM field, many different experimental design methods have been tested, including full factorial design, response surface methodology, and Taguchi methods.

Some of the research methods followed in the field of PMEDM are described here. The effect of the electrical conductivity of the powder mixed into the dielectric fluid has been examined by many researchers. The concentration of chromium powder (2–6 g/l), intensity of the electrical discharges, and electrode size are parameters that strongly influence the MRR and tool wear rate (TWR) [1]. Graphite powder (10 μm, 4 g/l) mixed in the dielectric fluid increases the MRR by 68% and reduces the TWR by 28% [2]. Moreover, the breakdown voltage of the dielectric fluid reduces by 30%. The surface roughness (SR) and other surface properties of H13 steel were found to be affected by the electrode size in PMEDM using silicon powder [3, 4]. An increase in electrode size increases the surface roughness and alters the thickness of the white layer. The aluminum powder mixed into the dielectric fluid increases the MRR in EDM [5]. However, the removal of the machined chips mixed with the powder are issues that need to be addressed. The optimal values of the electrical parameters of PMEDM using silicon powder were identified as developmental directions in EDM [6]. Boric acid (H_3BO_3) powder had a milder effect on the SR, MRR, and TWR than graphite (Gr) powder [7]. Increasing the concentration of boric acid powder results in an increase in the MRR and microscopic surface hardness, and reduces the TWR and SR. Using aluminum powder (300–400 μm) increases the MRR and decreases the TWR and SR; this improves the productivity and quality of the machining process [8]. PMEDM studies have shown that this is a very promising method to improve the productivity and quality of the workpiece.

This study examined the effect of process parameters of the MRR during machining of SKD61, SKD11, and SKT4 steels using titanium powder mixed in the dielectric fluid. The influence of the process parameters on the MRR was investigated using Taguchi methods and analysis of variance. The process parameters included electrode materials, current, pulse-on time, pulse-off time, electrode polarity, and concentration of titanium powder. The interaction terms included electrode material cf. workpiece material, workpiece material cf. powder concentration, and electrode material cf. powder concentration.

2. Experimental Procedure

For this study, the main effects and interaction of the input parameters that were considered are shown in Table 1. In the field of PMEDM, researchers have studied the effect of powder size, workpiece material, electrode material, current, pulse-on time, and pulse-off time. The selection of an orthogonal array depends upon the number of factors and degrees of freedom of each factor. For this study, seven main factors were considered, with two factors at two levels each having one degree of freedom (DOF). The five main factors had three levels, each having two DOFs and three interactions; thus, the total sum of DOFs including the main factors and interaction terms was twenty (Table 1). To accommodate the 20 DOFs, an L_{27} orthogonal array was selected as it had 26 DOFs. The remaining 6 DOFs were assigned to random errors. The L_{27} orthogonal array had 13 columns, and each column had 2 DOFs. Coefficient A was assigned to column 1, B to column 2, G to column 5, C to column 9, D to column 10, E to column 12, and F to column 13, as shown in Table 2.

Experiments were conducted using a die-sinking EDM platform, a model AG40L CNC from Sodick Inc., USA. The container was made of steel CT3 with a size of 330 × 180 × 320 mm. The mass of the workpiece before and after processing was measured with an electronic scale: AJ 203 model (Shinko Denshi Co. LTD, Japan), which can weigh up to a maximum of 200 g with an accuracy of 0.001 g.

Table 1: Input parameters and their levels

TT	Factors	Symbols	Level			DOF
			Level 1	Level 2	Level 3	
1	Workpiece material	A	SKD61	SKD11	SKT4	2
2	Tool material	B	Cu	Cu*	Gr	1
3	Polarity	C	-	+	-*	1
4	Pulse-on time (μs)	D	5	10	20	2
5	Intensity of discharge(A)	E	8	4	6	2
6	Pulse-off time (μs)	F	38	57	85	2
7	Powder concentrationTi(g/l)	G	0	10	20	2
8	Interaction of workpiece material and tool material	AxB	-	-	-	2
9	Interaction of workpiece material and powder concentration	AxG	-	-	-	4
10	Interaction of tool material and powder concentration	BxG	-	-	-	2
11	Total					20

Table 2: Experimental design based on L_{27} orthogonal array

Exp. No	A	B	C	D	E	F	G	MRR (mm^3/min)
1	1	1	1	1	1	1	1	10.487
2	1	1	2	2	2	2	2	8.169
3	1	1	3	3	3	3	3	3.152
4	1	2	2	2	3	3	1	10.239
5	1	2	3	3	1	1	2	14.304
6	1	2	1	1	2	2	3	0.089
7	1	3	3	3	2	2	1	37.466
8	1	3	1	1	3	3	2	23.575

9	1	3	2	2	1	1	3	38.843
10	2	1	2	3	2	3	1	18.882
11	2	1	3	1	3	1	2	3.857
12	2	1	1	2	1	2	3	14.496
13	2	2	3	1	1	2	1	10.608
14	2	2	1	2	2	3	2	0.320
15	2	2	2	3	3	1	3	23.577
16	2	3	1	2	3	1	1	23.885
17	2	3	2	3	1	2	2	59.669
18	2	3	3	1	2	3	3	17.159
19	3	1	3	2	3	2	1	1.252
20	3	1	1	3	1	3	2	20.745
21	3	1	2	1	2	1	3	4.374
22	3	2	1	3	2	1	1	0.198
23	3	2	2	1	3	2	2	6.782
24	3	2	3	2	1	3	3	19.682
25	3	3	2	1	1	3	1	10.649
26	3	3	3	2	2	1	2	25.970
27	3	3	1	3	3	2	3	54.360

3. Results and Discussion

The MRR was determined by the mass of the workpiece and the duration of the experiment. Each experiment was repeated three times. Minitab software was used to analyze the experimental results. The results were processed using the software Minitab 17 to determine the mean value of the MRR. The ANOVA analysis results were used to determine the impact of the coefficient on the average MRR. ANOVA analysis for MRR was carried out at 90% confidence intervals as shown in Table 3. ANOVA results showed that electrode material (F = 148.24), pulse-on time (F = 27.98), current (F = 9.94), interaction between workpiece material and titanium powder concentration (F = 7.68), pulse-off time (F = 6.45), titanium powder concentration (F = 6.24), electrode polarity (F = 5.7), and the interaction between the electrode material and titanium powder concentration (F = 4.03) were the main factors that influenced the MRR. Figs. 1 and 2 show the effect of the main factors and the interaction between the workpiece material and electrode material (AxB), electrode material and powder concentration (BxG), and workpiece material and powder concentration (AxG) on the MRR.

Table 3: ANOVA of MRR

Source	**DOF**	**SS**	**V**	**F**	**F_{table}**	**P**
Workpiece material (A)	2	55.45	27.73	1.01	3.463	-
Electrode material (B)	1	3142.51	3142.51	**148.24**	3.776	49.31
Electrode polarity (C)	1	120.78	120.78	**5.7**	3.776	1.61
Pulse on time (D)	2	1186.1	593.05	**27.98**	3.463	18.58
Current (E)	2	421.26	210.63	**9.94**	3.463	6.50
Pulse of time (F)	2	273.41	136.71	**6.45**	3.463	4.17
Powder concentration (G)	2	164.49	82.25	**6.24**	3.463	2.45
AxB	2	21.39	10.70	0.5	3.463	-
AxG	4	651.34	162.84	**7.68**	3.180	10.21
BxG	2	170.79	85.40	**4.03**	3.463	2.55
Error	6	127.2	21.20			
Total	26	6334.72				
e pooled	11	204.04	18.55			

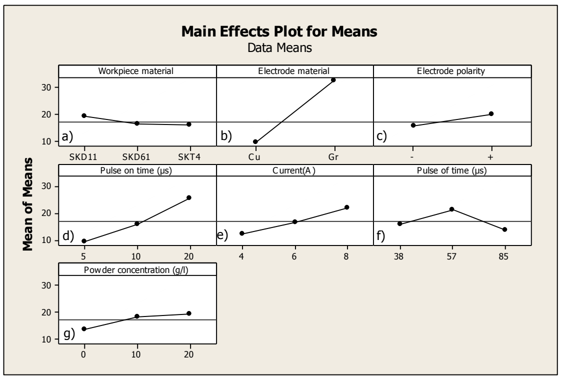

Figure 1: Main effects plot for $\overline{MRR}$

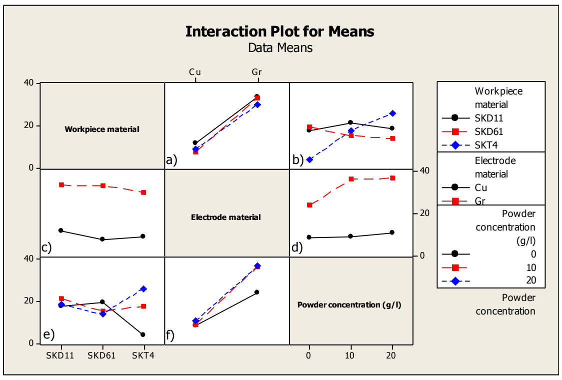

Figure 2: Interaction plot for $\overline{MRR}$

4. Conclusion

This study is aimed at optimizing the MRR using Taguchi methods to identify the main factors that influence the MRR. Based on the experimental and statistical results, the electrode material, current, and the interaction between workpiece material and titanium powder concentration were the main factors that influenced the MRR. Titanium powder mixed with the dielectric fluid increased the MRR. A powder concentration of 10 g/l provided an MRR 32.1% higher than machining with no powder. The maximum increase in the MRR was 42.1% with a powder concentration of 20 g/l. The MRR increased by 240.6% when a Gr electrode was used, higher than the increase for a Cu electrode. Positive electrode polarity showed a maximum MRR greater than negative electrode polarity with a 29.04% increase. An increase in the current and pulse-on time resulted in an increased MRR..

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