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Effect of Process Parameters on Machined Surface Hardness after Electrical Discharge Machining

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Abstract—*In the machining process, it is difficult to solve problems due to the relationship between productivity and quality, for example, as the productivity increases, the quality of reprocessing may decrease. Some methods only address specific objectives, such as the quality of the machining method, the machining productivity, the quality, or even the cost. In this study, micro-hardness (HV) of the machined surface after titanium powder mixed electric discharge machining (PMEDM) is presented. The Taguchi method is applied to the processing parameters to investigate. The intent of the present study is to study the effect of different input parameters, namely, workpiece material, tool material, polarity, pulse-on time, intensity of discharge, pulse-off time, powder concentration and some their interactions on the micro hardness. Electrode material, pulse on time, powder concentration, and interactions (A×G, B×G) have a strong influence on HV. Powder concentration affected most strongly to HV.*

Keywords— *HV, PMEDM, Taguchi*.

I. INTRODUCTION

Past research into powder mixed electric discharge machining (PMEDM) methods have proven promising as methods to improve both the productivity and quality in electric discharge machining (EDM). A suitable powder is mixed into the dielectric fluid used in EDM, which can lead to the micro-hardness (HV) of the surface machining can be greatly increased. Furthermore, increasing the concentration of powder 2-6g / l can lead to an increased MRR, while concurrently reducing the TWR [1]. The quality of the surface layer of steel H13 after machining by PMEDM, has also been improved significantly [2]. Results have demonstrated that an increase in the electrode size can lead to an increase in both surface roughness and thickness. Research results of the influence of some kinds of powder materials on the SR, MRR, and TWR in PMEDM have shown that graphite powder is more influential than silicon powder [3]. An increase in concentration has led to increases in MRR increases and decreases in SR. The Productivity and quality surface machining of EDM can be increased with Al powder mixed into the dielectric fluid [4]. Results have shown that the MRR increases, while both the TWR and SR decrease. Results obtained are similar for silicon powder as well as other powders with an increased concentration, all which led to an increase in the MRR [5].

Taguchi method has been widely used to optimize quality characteristics in the field of EDM [6]. The effect of current, pulse-on time, and pulse-off time on the TWR of the copper electrode during machining of EN31 was assessed using the Taguchi method [7]. The results showed that using powder reduces the TWR. Conversely, an increase in current and pulse on time increased the TWR. Taguchi's method was used to evaluate the level of influence of aluminum powder on SR during machining of a H13 workpiece [8]. Negative electrode polarity and Al powder mixed into the dielectric fluid helped to reduce SR. The SR increased due to an increase in the current and duration of the pulses. An optimal value of MRR was determined by Taguchi's method [9]. Powder mixed in the dielectric fluid led to an increased MRR. The maximum value of the MRR obtained was 12.47 mm^3/min with powder concentrations of 6 g/L. During the machining of EN31 steel using a PMEDM process, MRR and SR were optimized. The results showed that the MRR and SR were strongly influenced by the concentration of powder and the intensity of electrical discharge [10]. The PMEDM process efficiency was better than that of the EDM process [11]. This contributed to the effectiveness of the PMEDM method. Three different powder materials were used, namely Gr powder, SiC, and Al_2O_3, in the dielectric media. The Gr powder helped to increase the MRR, while SiC powder helped to reduce the TWR [12]. By using SiC powder, the productivity of the EDM process improved significantly during the machining of WC [13]. The MRR was increased by 90% in comparison to the EDM process. The maximum value of the MRR (1.419 mm^3/min) was obtained using Taguchi's method with a powder concentration of 8 g/L. Singh et al. studied the effect of Al powder size and concentration on the MRR, TWR, and SR. The results indicated that the size and concentration of powder, whether too small or too high, led to an increased MRR. The TWR and SR were reduced when mixed powder was added to the dielectric fluid [14]. Ganachari et al. used Taguchi's method, combined with the GRA method to optimize the parameters of PMEDM [15]. The Al and SiC powders were used in the dielectric fluid and SR were selected as the response. The best quality of machining surface was obtained when a PMEDM process was used. The relationship between MRR and EDM process parameters, including time pulse generator, current and solvent flow, were shown during the drilling of the EDM hole [16]. The increase in the duration of pulses, as well as the intensity of electrical discharge led to an increased MRR. However, an increase in the value of feed rate reduced the MRR. One of the disadvantages of the Taguchi method was that it could only optimize one of the quality characteristics of PMEDM. It was effective only for individual cases where the productivity was the highest or where the surface roughness or TWR were the smallest. Thus, the results processed by Taguchi's method can only be used to solve problems and are not able to evaluate the overall effectiveness of PMEDM.

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In this study, the effect of different input parameters, namely, workpiece material, tool material, polarity, pulseon time, current, pulseoff time, and powder concentration and some their interactions on the HV in PMEDM using titanium powder. The effect of various input parameters on output response have been analyzed using Analysis of Variance (ANOVA). Main effect plot and interaction plot for significant factors for HV.

II. EXPERIMENTAL

An electrical discharge machine, AG40L (Sodick, Inc. USA), was used. A stirrer was employed in the container where machining was performed. It was used to prevent deposition of titanium powder at the bottom of the container, and mixing of powder properly took place. Titanium powder of size less than 45 µm and were mixed with the dielectric fluid (oil HD-1) during the experiment. The workpiece materials included SKD61, SKD11, and SKT4 mound steel, where the common type used in industry standards were selected for this study. Samples measured 45x27x10mm. Furthermore, Cu, Gr are among the two materials most commonly used, and have been a focus of recent research. The electrode was shaped into a circular cylinder and it had a diameter measuring 23 mm. The machined surface hardness (HV) was measured by a 1106 Met Indenta (airline BUEHLER - USA).

TABLE 1. Input parameters and its levels.

No	Factors	Symbols	Level		
			Level 1	Level 2	Level 3
1	Workpiece material	A	SKD61	SKD11	SKT4
2	Electrode material	B	Cu	Cu*	Gr
3	Polarity	C	-	+	-*
4	Pulse-on time (µs)	D	5	10	20
5	Current (A)	E	8	4	6
6	Pulse-off time (µs)	F	38	57	85
7	Powder concentration Ti (g/l)	G	0	10	20
8	Interaction of workpiece material and tool material	AxB	-	-	-
9	Interaction of workpiece material and powder concentration	AxG	-	-	-
10	Interaction of tool material and powder concentration	BxG	-	-	-
11	Total				

TABLE 2. Experimental design based on L27 orthogonal array.

Exp. No	Workpiece material	Electrode material	Electrode polarity	Pulse on time (µs)	Current (A)	Pulse of time (µs)	Powder concentration (g/l)
1	SKD61	Cu	-	5	8	38	0
2	SKD61	Cu	+	10	4	57	10
3	SKD61	Cu	-*	20	6	85	20
4	SKD61	Cu*	+	10	6	85	0
5	SKD61	Cu*	-*	20	8	38	10
6	SKD61	Cu*	-	5	4	57	20
7	SKD61	Gr	-*	20	4	57	0
8	SKD61	Gr	-	5	6	85	10
9	SKD61	Gr	+	10	8	38	20
10	SKD11	Cu	+	20	4	85	0
11	SKD11	Cu	-*	5	6	38	10
12	SKD11	Cu	-	10	8	57	20
13	SKD11	Cu*	-*	5	8	57	0
14	SKD11	Cu*	-	10	4	85	10
15	SKD11	Cu*	+	20	6	38	20
16	SKD11	Gr	-	10	6	38	0
17	SKD11	Gr	+	20	8	57	10
18	SKD11	Gr	-*	5	4	85	20
19	SKT4	Cu	-*	10	6	57	0
20	SKT4	Cu	-	20	8	85	10
21	SKT4	Cu	+	5	4	38	20
22	SKT4	Cu*	-	20	4	38	0
23	SKT4	Cu*	+	5	6	57	10
24	SKT4	Cu*	-*	10	8	85	20
25	SKT4	Gr	+	5	8	85	0
26	SKT4	Gr	-*	10	4	38	10
27	SKT4	Gr	-	20	6	57	20

* - Dummy treated

In the current study, the interaction effect of the input parameters were considered, as 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. In this study, the interaction terms were considered, specifically workpiece material, x-electrode material (AxB), workpiece material, x-powder concentration (AxG), and electrode material x-powder concentration (BxG). Taguchi's orthogonal array's was used for designing the experiments. There are many orthogonal array's available in the Taguchi's method, therefore selection depended upon the number of factors and degrees of freedom of each factor. In this study, seven main factors were considered, out of which, two factors were at two levels, each having one degree of freedom. Five of the main factors had three levels, with each having two degrees of freedom. Also, the study considered three interaction terms. Thus, the total sum of degrees of freedom, including the main factors as well as the interaction terms, was 20. Therefore, based on the 20 degrees of freedom, the L_{27} orthogonal array suited the present requirements as it had 26 degrees of freedom. The remaining 6 degrees of freedom were assigned as random error. The L_{27} orthogonal array had 13 columns, each with 2 degrees of freedom. Coefficient A was assigned to the 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.

III. RESULTS AND DISCUSSION

The micro hardness was measured at deposition of machined surface. The results for micro hardness at deposited region for each of the 27 treatment conditions with repetition are shown in table 3. Each experiment was repeated three times, and Minitab software was used to analyze the experimental results. The results were processed by Minitab 17 to determine the mean value of the machining characteristics. A confidence interval of 95% has been used for the analysis.

Effect of factors on TWR: The results for HV were analyzed using ANOVA for identifying the significant factors affecting the performance measures. The Analysis of Variance (ANOVA) for the mean MRR at 95% confidence interval is given in table 4. The variance data for each factor and their interactions were F-tested to find significance of each. The principle of the *F* test is that the larger the *F* value for a particular parameter, the greater the effect on the performance characteristic due to the change in that process parameter. ANOVA table shows that powder concentration (F value 46.4) and electrode material (F value 8.9) factors that significantly affect the HV. The interaction of Electrode material × powder concentration (F value 4.52) and the interaction of Workpiece material × powder concentration (F value 4.31) are significant. All other factors are insignificant to affect the HV. Powder concentration has the highest rank signifying highest contribution to HV and Electrode polarity has the lowest and was observed to be insignificant in affecting HV. Main effect plots had shown in the figure 1 shows that micro hardness has increased with addition of powder in dielectric medium. The micro hardness increased with increase in current. The interaction plot for micro hardness is shown in figure 2.

TABLE 3. Results of experiments.

Exp.no	A	B	C	D	E	F	G	HV
1	SKD61	Cu	-	5	8	38	0	506.7
2	SKD61	Cu	+	10	4	57	10	658.96
3	SKD61	Cu	-*	20	6	85	20	581.6
4	SKD61	Cu*	+	10	6	85	0	496.68
5	SKD61	Cu*	-*	20	8	38	10	828.92
6	SKD61	Cu*	-	5	4	57	20	629.84
7	SKD61	Gr	-*	20	4	57	0	544.58
8	SKD61	Gr	-	5	6	85	10	748.42
9	SKD61	Gr	+	10	8	38	20	626.18
10	SKD11	Cu	+	20	4	85	0	509.72
11	SKD11	Cu	-*	5	6	38	10	679.54
12	SKD11	Cu	-	10	8	57	20	664.2
13	SKD11	Cu*	-*	5	8	57	0	546.02
14	SKD11	Cu*	-	10	4	85	10	679.2
15	SKD11	Cu*	+	20	6	38	20	655.18
16	SKD11	Gr	-	10	6	38	0	469.82
17	SKD11	Gr	+	20	8	57	10	907.64
18	SKD11	Gr	-*	5	4	85	20	683.52
19	SKT4	Cu	-*	10	6	57	0	530.72
20	SKT4	Cu	-	20	8	85	10	624.58
21	SKT4	Cu	+	5	4	38	20	631.68
22	SKT4	Cu*	-	20	4	38	0	468.04
23	SKT4	Cu*	+	5	6	57	10	544.38
24	SKT4	Cu*	-*	10	8	85	20	613.84
25	SKT4	Gr	+	5	8	85	0	445.44
26	SKT4	Gr	-*	10	4	38	10	681.22
27	SKT4	Gr	-	20	6	57	20	832.66

* - Dummy treated

TABLE 4. ANOVA for HV.

TT	Source	DOF	SS	V	P	Rank
1	Workpiece material (A)	2	10015	5007.5	0.251	5
2	Electrode material (B)	1	19614	19614	0.025	3
3	Electrode polarity (C)	1	2423	2423	0.335	7
4	Pulse –on time (D)	2	21183	10591.5	0.057	2
5	Current (E)	2	4805	2402.5	0.394	6
6	Pulse – off time (F)	2	12990	6495	0.128	4
7	Powder concentration (G)	2	204407	102203.5	0.000	1
8	A×B	2	3967	1983.5	0.455	-
9	A×G	4	37981	9495.25	0.055	-
10	B×G	2	19930	9965	0.063	-
11	Error	6	13217	2202.833	–	-
12	Total	26	350531	–	–	-

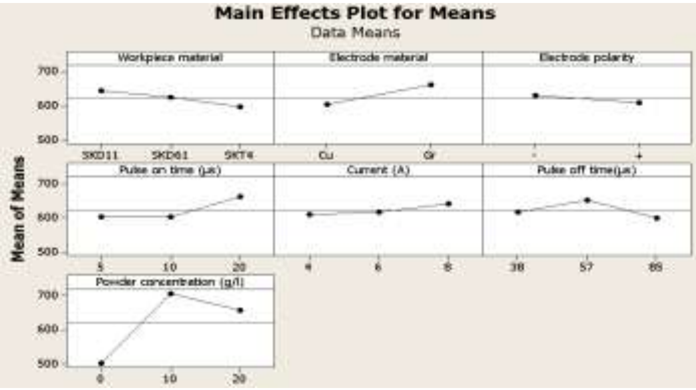

Fig. 1. Main effects plot for HV.

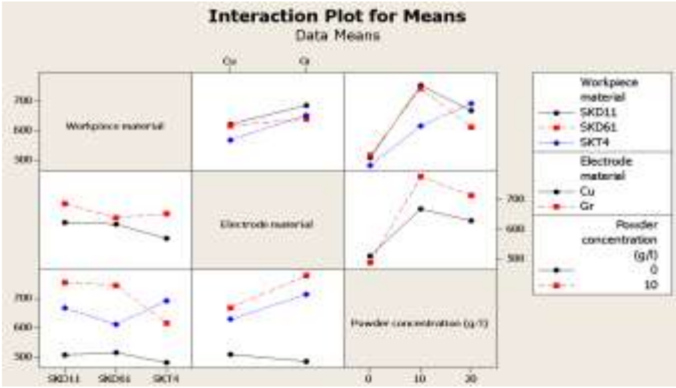

Fig. 2. Interaction plot for HV.

IV. CONCLUSIONS

Research has shown that titanium powder mixed into the dielectric fluid in the EDM has improved the HV of machined surface of fine machining. Ti powder concentration is the parameter which influence the most to the average micro-hardness of machined surface layer. Electrode material, pulse on time, the interaction of electrode material and powder concentration, and interaction of workpiece material and powder concentration have strong influence on HV. Workpiece material, electrode polarity, current, pulse on time and the interaction of workpiece material and electrode material mainly influence HV. Ti powder mixed into dielectric fluid make HV to increase as compared to without using Ti powder.

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