Parametric optimization of powder mixed Electro-discharge machining using Taguchi Technique

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Abstract: In the research work, a study has been made to optimize the input parameters of powder mixed electrical discharge machining (PMEDM). Taguchi technique has been employed to investigate the trials. Current, pulse on time, pulse off time have been chosen as input parameters to study the performances in terms of material removal rate and tool wear rate. Experiments are performed on a newly designed experimental setup developed in the laboratory. The results determine the most essential parameters to get maximum material removal rate and minimum tool wear rate. The confirmation experiments were done in order to justify the optimal process conditions.

Keywords: Material removal rate, tool wear rate, powder mixed EDM, Taguchi technique, Optimization

I. INTRODUCTION

Electrical discharge machining (EDM) is the widely used technique for processing the surfaces of dies. However, machining of these surfaces consumes more time because of the low material removal rate (MRR). Over the past few years, researchers have worked for improving the efficiency of the EDM process. An alternative method to improve efficiency was discovered by adding metal powder or alloy powder to the dielectric fluid. Proper input parameter values have been set for a particular combination of work piece–tool materials to optimize the EDM output performance; however, many researchers have carried out to determine optimal process parameters. The EDM process has many variables, which makes it difficult to attain an optimal set of input parameters. This has resulted in an increase in the cost of research work and 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 is described here. The effect of the electrical conductivity of the powder mixed into the dielectric fluid has been examined by many researchers. The chromium powder concentration (2 to 6 gram/litre), electrical discharge intensities and electrode size were the parameters that strongly influence the MRR and tool wear rate (TWR) [1]. Graphite powder (10 µm, 4 gram/litre) mixed in the dielectric fluid increases and decreases the MRR and TWR by 68 % and 28 %, respectively. [2]. The surface roughness (R_a) 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 R_a and alters the thickness of the white layer. The aluminum powder mixed into the dielectric fluid increases the MRR in EDM [5]. 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 R_a, 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 R_a. Using aluminum powder (300 – 400 µm) increases the MRR and decreases the TWR and R_a; this improves the productivity and quality of the machining process [8]. Concentration of the silicon powder and intensity of the electrical discharge are parameters that strongly influence the MRR [9]. When Gr powder is used, the TWR of thermally treated copper is lower than that of non-thermally treated copper [10]. The machining of 718 grade stainless steel using Al powder showed that opposite electrode polarity led to an increase in the MRR. Taguchi methods were used to optimize the processes, which contributed to improved quality and lower production costs [11]. The effect of current, pulse-on time, and pulse-off time on the TWR of copper electrodes during the machining of EN31 grade steel was assessed using Taguchi methods [12]. The results showed that adding powder reduced the TWR, whereas an increase in current and pulse-on time increased the TWR. Negative electrode polarity and Al powder mixed into the dielectric fluid reduced the R_a of an H13 steel work piece [13]. R_a increased with increased current and duration of the pulses. Powder mixed in the dielectric fluid led to an increase in the MRR and led to a maximum MRR at a powder concentration of 6 g/l [14]. Both MRR and R_a were influenced by the concentration of powder and intensity of the electrical discharge [15]. The PMEDM process efficiency showed better results than the plain EDM process [16]. Three different powder materials were used in the dielectric media: Gr, silicon carbide (SiC) and aluminum oxide (Al_2O_3). Gr powder increased the MRR and SiC powder reduced the TWR [17]. The use of SiC powder significantly improved the productivity of the EDM process during the machining of tungsten carbide (WC) [18]. The MRR with PMEDM was 90 % higher than the EDM process. The maximum value of MRR was obtained by Taguchi methods at a powder concentration of 8 g/l. Studying the effect of the amount and concentration of Al powder on the MRR, TWR, and R_a indicated that extreme values of both factors led to an increase in the MRR [19]. TWR and R_a both reduced when metal powder or alloy powder was mixed with the dielectric fluid. PMEDM studies have shown that this is a very promising method to improve the productivity and quality of the work piece. The influence of titanium powder mixed with the dielectric fluid in EDM on the SR and micro-hardness (HV) of surface machining is shown in some studies [20–22]. However, the effect of using zirconium powder in PMEDM on the MRR and TWR has not been published yet. In order to assess comprehensively the influence of zirconium powder mixed in the dielectric fluid in fine machining by PMEDM, this study examined the optimization of the MRR and TWR during machining of D2 Die Steels using zirconium powder mixed in the dielectric fluid. The influence of the process parameters on the MRR and TWR was investigated using Taguchi methods.

II. EXPERIMENTAL PROCEDURE

From the literature survey, it has been observed that considerable work has been done on various aspects of electrical discharge machining of low carbon steels, carbides, few die steels but sufficient data is not available on powder mixed EDM D2 Die steel even though it is widely used in die and mould making industries. There is a need to investigate the machining of this material with copper electrode and using powder mixed EDM oil as dielectric fluid by varying different machining parameters like current, pulse on time and pulse off time. D2 Die stel steel (Dimensions: 62.5 mm x 50mm x 10mm, and Composition: C=1.4-1.6%, Mn=0.60%, Si=0.60%, Cr=11-13%, Ni=0.3%, Mo=0.7-1.2%, V=1.1%, Cu=0.25%, P=0.03%, S=0.03%, Fe=remaining %) is selected as work material because of its high abrasion resistance, excellent wear resistance and high compressive strength. The electrode material selected for the present work is copper (99.99% Cu) electrode and the powder selected is zirconium powder of 300 mesh size (46 microns). Experiments have been performed on Sparkonix S25/50 ZNC EDM with newly designed experimental setup consisting of mild steel tank placed in the work tank. Various machining conditions used during experimentation are listed in table 1. In this work, 9 experiments were conducted at the stipulated conditions and their levels were given in table 2 and the main objective of this paper is to maximize the material removal rate and also to minimize the tool wear rate.

Table 1: Machining conditions

Tool	**Copper**
Work piece	**D2 Die Steel**
Polarity	**Straight**
Time of trial	**10 mins**
Dielectric	**EDM Oil**
Voltage	**60 V**

Table 2: Parameters and levels

Parameters	**Level 1**	**Level 2**	**Level 3**
Current (A)	5	6	7
Pulse on time (µs)	9	49	99
Pulse off time (µs)	2	6	9

III. MACHINING RESPONSES

Material removal rate (MRR) and tool wear rate (TWR) has been selected as the output responses in this research work and the formula for calculating the MRR and TWR were shown in eqn (1) and eqn (2). MRR is defined as the total weight of the material removed or machined to the machining time.

$$MRR = [(Initial – Final)\ weight / time] \quad (1)$$

Similarly, the tool wear rate is nothing but the amount of tool removed during machining and it has been calculated using

$$TWR = [(\text{Initial} – \text{Final}) \text{ weight} / \text{time}] \quad (2)$$

IV. RESULTS AND DISCUSSIONS

After experimentation, the analysis and discussion of results have to be carried out. In this section the effect of input parameters such as current, pulse on time and pulse off time on MRR and TWR were presented. The plots showing the effect of parameters on responses have drawn accounting the effect of all factors. Table 3 shows the input parameters and their responses.

Table 3: Input parameters with their responses

Parameters	Current	Pulse on time	Pulse off time	MRR (g/min)	TWR (g/min)
1	5	9	2	0.0652	0.0301
2	5	49	6	0.0965	0.0021
3	5	99	9	0.1571	0.0036
4	6	9	6	0.0682	0.0093
5	6	49	9	0.0985	0.0028
6	6	99	2	0.1678	0.0033
7	7	9	9	0.0695	0.0055
8	7	49	2	0.1011	0.0022
9	7	99	6	0.1598	0.0027

V. EFFECT OF INPUT PARAMETERS ON MRR

The signal to noise (S/N) ratio for MRR has been obtained using MINITAB 15 software and has been shown in fig 1.

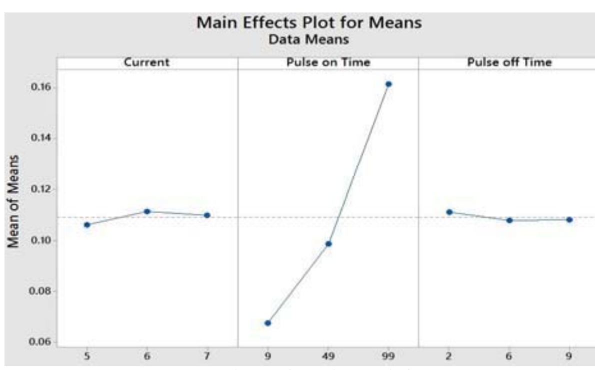

Fig 1. S/N ratio graph for MRR

From fig 1, it is clear that the MRR increases up to certain point as the current increases, and then drops whereas there is a sharp increase and decrease of MRR in pulse on time and pulse off time, respectively. The optimal values are A2-B3-C1, i.e. current 6A, pulse on time and pulse off time are 99 µs and 2 µs, respectively. The response table for MRR are given in table 4, as this indicates the most significant parameter is current, followed by pulse on time and pulse off time. ANOVA has been carried out to indicate the significance of individual process parameters and this has been produced in table 5. It's been clear that, the current is the most significant parameter with 72.3 %, followed by pulse on time with 24.3% and the pulse off time with 2.7%.

Table 4. Response table for MRR

Level	**Current (A)**	**Pulse on time (µs)**	**Pulse off time (µs)**
1	-23.40	-20.03	-19.71
2	-20.12	-19.65	-19.85
3	-15.84	-19.66	-19.79
Delta	7.56	0.38	0.15
Rank	1	2	3

Table 5. Anova Table for MRR

Parameters	Deg. Of freedom	S of Sq	Var	F values	P (%)
Current (A)	2	6.17	1.13	40.26	72.3
Pulse on time (µs)	2	2.07	0.167	5. 96	24.3
Pulse off time (µs)	2	0.23	0.071	2.56	2.7
Error	2	0.06	0.028	--	0.7
Total	8	8.533	--	--	100

VI. EFFECT OF INPUT PARAMETERS ON TWR

The S/N ratio for TWR has been obtained and has been shown in fig 2., and it is clear that the TWR increases up to certain point as the current increases, and then drops whereas again there is a sharp increase and decrease of TWR in pulse on time and pulse off time, respectively. The optimal values are A1-B1-C3, i.e. current 5A, pulse on time and pulse off time are 9 µs and 9 µs, respectively. The response table for TWR are given in table 6, as this indicates the most significant parameter is current, followed by pulse on time and pulse off time. ANOVA has been carried out to indicate the significance of individual process parameters that affects the TWR and this has been produced in table 7. It's been clear that, the current is the most significant parameter with 65.44 %, followed by pulse on time with 19.32% and the pulse off time with 11.26%.

Table 6. Response table for TWR

Level	**Current (A)**	**Pulse on time (µs)**	**Pulse off time (µs)**
1	38.75	44.29	44.40
2	52.59	47.11	48.52
3	49.96	49.91	48.37
Delta	13.84	5.62	4.12
Rank	1	2	3

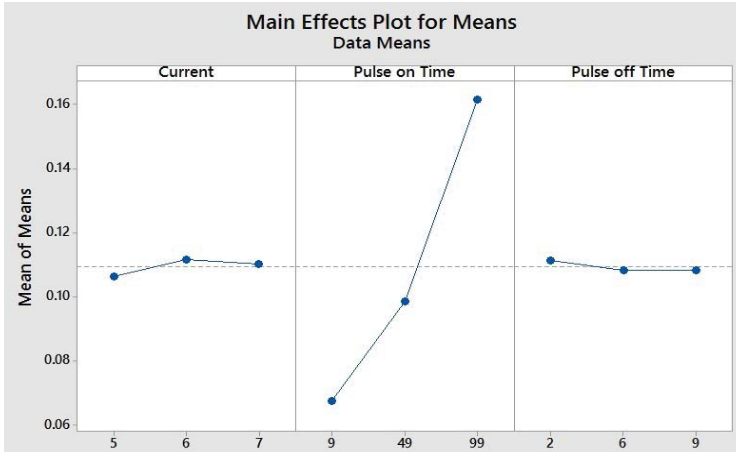

Fig 2. S/N ratio graph for TWR

Table 7. Anova Table for TWR

Parameters	Deg. Of freedom	S of Sq	Var	F values	P (%)
Current (A)	2	10.83	55.56	35.62	65.44
Pulse on time (µs)	2	3.20	20.67	13.25	19.32
Pulse off time (µs)	2	1.86	8.77	5.62	11.26
Error	2	0.658	1.56	--	3.98
Total	8	16.55	--	--	100

VII. CONCLUSION

This article has presented an investigation on the optimization of machining parameters on the MRR and TWR in EDM. The significance of the parameters on MRR and TWR is determined by using ANOVA. Based on ANOVA, current with 6A have been found to be significant parameter for best MRR and the same current with 5A plays a significant role in the tool wear rate. With the increasing in pulse on time, the MRR increases but it falls when the pulse off time increases. The similar case has been found with TWR also. The results were confirmed experimentally at 95% confidence interval. The future scope of this research work is to attempt with different dielectric materials with optimized process parameters.

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