Parametric Optimization of PMEDM Process using Graphite Powder Mixed Dielectric

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Abstract— In this research paper, an experimental study was performed to study the effect of graphite powder- mixed mineral oil EDM (PMEDM) on Material Removal Rate (MRR) and Tool Wear Rate (TWR). Current, duty cycle, pulse on time and concentration of graphite powder have been selected as input parameters. Central composite rotatable design of experiments has been used to conduct the experiments. Comparison graphs were drawn to confirm the effect of input variables on the output parameters. Optimization procedure has been performed using Response Surface Methodology to select the best possible combination of input parameters which maximize MRR and minimize TWR.

Key words: EDM; PMEDM; Optimization; MRR; TWR

I. INTRODUCTION

PMEDM is a new EDM technique where a powder is added to the dielectric fluid. Certain powders which are generally added are aluminium, silicon carbide, graphite, chromium, nickel etc. PMEDM has shown good results as compared with conventional EDM. Machining rate increases, surface finish improves and a decrease in tool wear ratio [TWR] is seen.

The working principle of powder mixed electrical discharge machining process is explained in following lines [1, 2]. When a voltage is applied between the job and the tool facing each other with a gap, an electric field of the order of 10^5–10^7 V/m is produced. The powder particles in the spark gap get energized. These charged particles act as conductors. These conductive particles promote breakdown in the gap and also increase the spark gap between the job and tool. In the sparking area, the particles come closer and arrange themselves in chain like structures between both the electrodes. The interlocking between the different powder particles takes place in the direction of current flow. This chain formation helps in bridging the discharge gap between electrodes and also results in decreasing the insulating strength of the dielectric fluid. The easy short circuit takes place, causing early explosion in the gap resulting in series discharges under the electrode area. The faster sparking within a discharge occur causing faster erosion from the workpiece surface and hence the material removal rate (MRR) increases. At the same time, the added powder also modifies the plasma channel making it enlarged and widened. The sparks are uniformly distributed among the powder particles, hence electric density of the spark decreases. Due to uniform distribution of sparks among the powder particles, shallow craters are produced on the workpiece surface resulting in improvement in surface finish.

Early research on this topic can be explained as, Erden and Bilgi observed that machining rate increased as the concentration of the impurity was increased but excessive powder concentration machining became unstable due to short circuit. Jeswani observed that at the concentration of 4g/l there was increase of MRR by 60% and 28% reduction in TWR [Tool wear ratio]. It was observed that there was increase in the inter space for electric discharge initiation and decrease in the breakdown voltage. Mohri and Saito investigated that Silicon powder with size 10-30µm was used at low discharge current [0.5-1A] for short discharge time [<3µs] with negative polarity. Surface produced was fine and corrosion resistant with surface roughness less than 2µm. Narumiya observed that Al and graphite give better results than Si powder. It was further observed that the best surface finish obtained was 2µm for Al and graphite powders having diameter less than 15µm and concentration ranges from 2 to 15g/l. Ming investigated the use of conductive and inorganic-oxide particles as impurities in PMEDM. It was observed that the MRR has increased, TWR has decreased and surface quality has improved with the powder addition. It was further observed that the high additive concentration [above 30g/l] causes powder settling problem. Wang and lin reported that due to addition of Al and Cr powders in the dielectric fluid there was an increase in the gap between the workpiece and the tool which stabilized the process and increased MRR considerably. Small size particles would have high suspension effect in the dielectric fluid due to their higher concentration. So there is higher chance of bridging the gap and producing uniform discharge depression resulting in good surface finish. Hang and chow studied the effect of SiC and Al powder in kerosene for the micro slit machining of titanium alloy using EDM. It was reported that the gap between tool and the workpiece increased which in turn improved the debris removal and increased considerably the MRR. Pecas and Henriques was observed that for the silicon concentration of 2g/l the operation time and surface roughness decreased.

Further, Uno and Okada observed that the surface of aluminium bronze alloy was modified as a layer was formed over the surface which made the surface abrasion resistant. Rozenek studied the stability of PMEDM process. Mixture of kerosene and deionised water with various abrasives powders was studied. It enhanced both MRR and TWR. While enhancing MRR is good from the productivity point of view but on the other hand increase in TWR negatively affects the process. It was reported that the absence of particles may cause arcing while presence of too much powder particles may make the process unstable. A stable process requires evenly distributed discharge locations which depend on powder concentration and its distribution, bubbles, deionization of dielectric fluid and surface irregularities of the work piece. Saurabh Sharma studied tool wear rate during powder mixed EDM of Hastelloy steel. It was reported that Tool wear rate improved

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with the cold treatment of the copper electrode and Polarity has a little effect on the tool wear rate; value of tool wear rate is lower at the positive polarity. Bajpai reported that Cutting rate for graphite powder mixed mineral oil was higher by 37.87 % than the mineral oil alone for all values of current, duty cycle, pulse on time and wire speed. It was also reported that surface roughness (R_a) increased with the increase in current and pulse on time. In the case of duty cycle, initially it decreased and there after started increasing again.

II. DESCRIPTION OF EXPERIMENT

A. Experimental Set-Up

Figure 1 shows line diagram of experimental setup used for experimentation. All the experiments carried out on Z numerically controlled (ZNC) oil die sinking EDM machine (R50 # ZNC) which is made by Elektra, Electronica Machine Tools India.

The powder should not enter the main dielectric tank to avoid filtering of powder particles. The dielectric should be continuously stirred or circulated to prevent settling of the powder and to maintain uniform concentration.

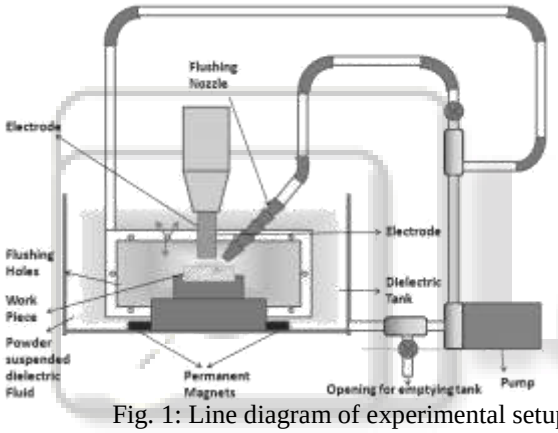

Fig. 1: Line diagram of experimental setup

The main dielectric sump has been disconnected from dielectric tank by valve arrangements. To obtain even and homogeneous distribution of powder particles in suspended form in dielectric, a flush mixing was provided in the tank by means of 25mm diameter plastic pipe with 03mm diameter holes in it. The dielectric was sucked from bottom level of tank by means of a pump (power- 1.5 W, and maximum discharge-5500 LPH) and was pumped into plastic pipe frame. The output from pump is divided into two parts and from one part flushing nozzle is connected. Flow through flushing nozzle is adjusted to 500 lit /hour through 4 mm opening nozzle by adjusting valve opening.

B. Materials used in Experiments

The work piece material used in this study is EN-8 steel. The chemical composition of steel as determined by optical emission spectrophotometer analysis is summarized in TABLE 1.

EN-8 Steel	C%	Si%	Mn%	S%	P%	Iron
Composition	0.35	0.05	0.60	0.06%	0.06%	97.86%

Table. 1: Chemical composition of steel

Also, the properties of Graphite powder suspended in dielectric have been summarized in TABLE 2

Element	Carbon	Sulphur	Phosphorus	Impurities
Content (%)	98%	0.1%	0.5% (max)	Rest

Table. 2: Chemical Composition Of Graphite Powder Element

III. EXPERIMENTAL PROCEDURE

A. Planning of Experiments

In the present experiments, the effect of four input parameter (discharge current, pulse on time, duty cycle, concentration of powder) on the Material Removal Rate (MRR) and Tool Wear Rate (TWR) during wire EDM of EN8 material with graphite powder mixed dielectric has been studied. The regression equations are then formulated for MRR and TWR in terms of above mentioned four input parameters. Regression equations are given by the software design expert 7.0.0. A central rotatable composite design is used to plan the experiments. Relationships between coded X values and original scale (absolute value of input parameter) was determined. The lowest and highest values are +2 and -2for four input variable in central rotatable composite design. The output parameters which have to be measured are Material Removal Rate and Tool Wear rate

B. Experimental Design

Response surface methodology (RSM) is used in design matrix formation which is an empirical modeling approach using polynomials as the local approximations to obtain true input/output relationships. The experimental plans were designed on the basis of the central composite design (CCD) technique of RSM. The factorial portion of CCD is a full factorial design with all 16 combinations of the factors at two levels (high, +2 and low, −2) and composed of the eight axial points and six central points (coded level 0). Central points are the midpoint between the high and low levels. The axial points are at the face of the cube portion on the design that corresponds to an α value of 2. In this study, the experimental plan was conducted using the stipulated conditions according to the CCD and involved a total of 30 experimental observations at four independent input variables. This was set up before the operation of the machine reached the stable state. The levels of design factors have been selected in accordance with literature consulted as well as by personal experience. The design factors selected for study with their low and high levels are summarized in TABLE 3.

Design Expert 7.0.0 software was used for design of experiments, and regression and graphical analysis of data obtained. The optimum conditions have been obtained by solving the regression equations and by analyzing response surface contours.

Parameters	Coded Notations	Units	Range and levels				
			-2	-1	0	1	2
Current	A	A	5	11	17	24	30
Concentration	B	gm/l	2	4	6	8	10
Pulse-on Time	C	µs	10	100	150	250	300
Duty Cycle	D	%	16	40	56	80	96

Table. 3: Range and Level of Input Parameters

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IV. RESULTS AND DISCUSSIONS

30 experimental runs have been conducted and values of MRR and TWR along with design matrix are given in TABLE 4 to avoid any systematic error creeping into system. Analysis of variance (ANOVA) is performed on collected data for testing significance of regression model and model coefficients.

Serial No.	Input Variables				Output Variables	
	(A)	(B)	(C)	(D)	MRR (mm^3/sec.)	TWR (mm^3/sec.)
1	17	6	150	56	0.6	0.0237
2	24	8	100	80	0.993	0.1678
3	11	4	100	80	0.271	0.0016
4	17	6	150	56	0.572	0.0194
5	17	6	10	56	0.114	0.0758
6	24	4	100	80	0.721	0.0425
7	17	6	150	16	0.343	0.0205
8	24	4	100	40	0.6053	0.0638
9	11	8	100	80	0.288	0.0272
10	17	6	150	56	0.572	0.0209
11	11	8	100	40	0.265	0.0025
12	17	6	300	56	0.604	0.0021
13	11	8	200	80	0.325	0.00101
14	24	8	200	80	0.768	0.0218
15	24	4	200	40	0.835	0.0772
16	17	6	150	96	0.703	0.0192
17	5	6	150	56	0.03	0.0005
18	24	4	200	80	0.944	0.0453
19	11	4	200	80	0.317	0.0016
20	11	4	100	40	0.256	0.0096
21	17	6	150	56	0.572	0.0194
22	24	8	100	40	0.53	0.0721
23	17	6	150	56	0.572	0.0194
24	30	6	150	56	1.203	0.1871
25	17	6	150	56	0.572	0.0194
26	11	4	200	40	0.242	0.0021
27	17	2	150	56	0.371	0.00613
28	17	10	150	56	0.651	0.0064
29	11	8	200	40	0.275	0.000616
30	24	8	200	40	0.652	0.0255

Table. 4: Experimental Data

A. Analysis of MRR

As can be seen from these figures, the MRR tends to increase, considerably with increase in current for any value of other factors. Hence, maximum MRR is obtained at high current. The MRR increases with increase in concentration first but after certain level, the MRR tends to decrease due to inefficient flushing. MRR also first increases with pulse-on time due to increase in energy but after a certain value excessive short circuit causes MRR to decrease. MRR is found to increase with duty cycle. Powder concentration has much significant effect on MRR. At higher duty cycle ignition conditions improve due to strong heat, since the pulse interval is shortened as the pulse duty factor rises with simultaneous growth in the amount of removed material.

It can be inferred from the above discussion and Figure 2 maximum MRR can be obtained at high values of current and at the optimum value of concentration. From Figure 3 Amount of change in MRR (till the optimum value of on-time) with change in on time is higher at higher values of current. Amount of change in MRR with change in current is higher at higher values of on time. From Figure 4 amount of change in MRR with change in duty cycle is higher at higher values of current & amount of change in MRR with change in current also higher at higher value of on time.

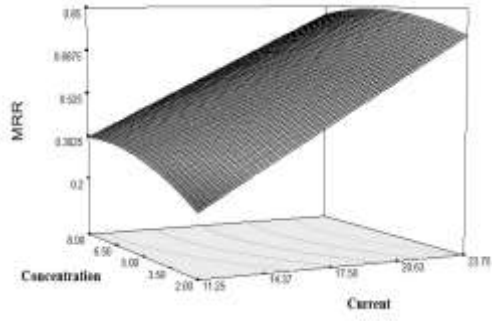

Fig. 2: Variation of MRR with current and concentration

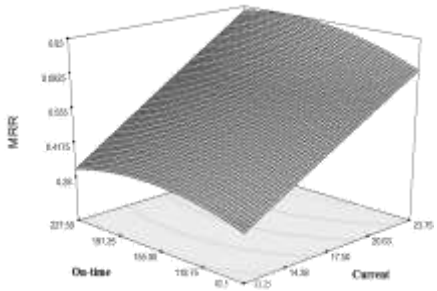

Fig. 3: Variation of MRR with on-time and current

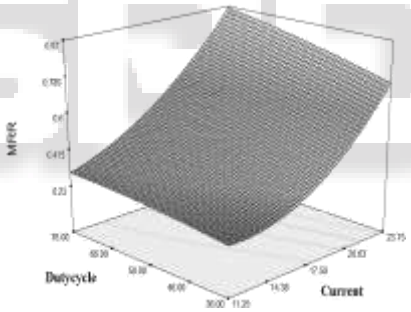

Fig. 4: Interaction curves of duty cycle and current

B. Analysis of TWR

Figure 5, Figure 6 and Figure 7 shows the estimated response surface for TWR in relation to the design parameters of average current with powder concentration, pulse on time and duty cycle. As can be seen from these figures Current is the most significant parameter. The TWR increases with increase in current.

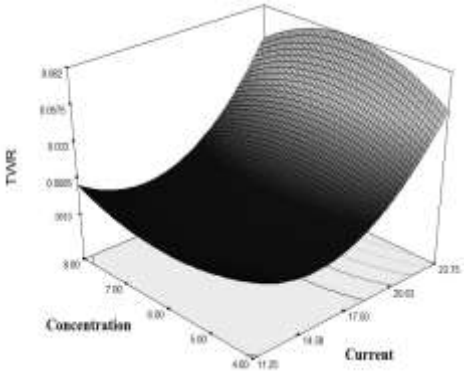

Fig. 5: Variation of TWR with current and concentration

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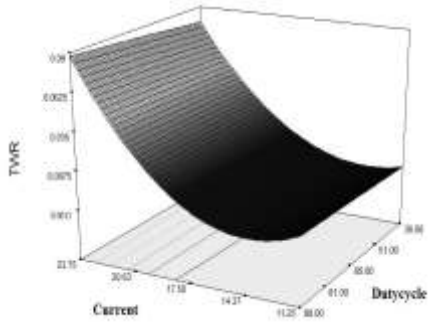

Fig. 6: Variation of TWR with current and Duty cycle

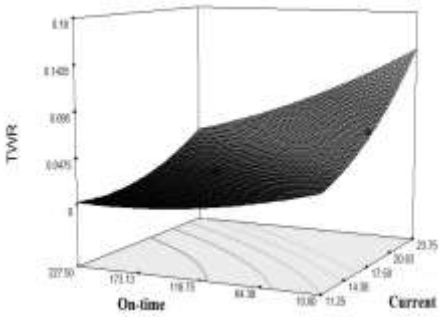

Fig. 7: Variation of TWR with on-time and current

C. Parametric Optimization

Optimization of parameters with the help of software suggests the following results. Following constraints on the design space has been applied as shown in TABLE 5.

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Current	Is in range	11.25	25	1	1	3
Concentration	Is in range	4	8	1	1	3
Pulse on time	Is in range	50	250	1	1	3
Duty	Is in range	36	80	1	1	3
MRR	Maximize	0.03037418	1.2039627	1	1	3
TWR	Minimize	0.00048774	0.1871059	1	1	3

Table 5: Range of parameters chosen for optimization

On basis of these range selected for different parameters the optimum value obtained is listed in TABLE 5

Current (A)	Concentration (gm/l)	Pulse on time (µs)	Duty Cycle (%)	MRR (mm^3/sec.)	TWR (mm^3/sec.)	Desira
25 A	6.94 gm/l	155 µs	80%	1.03681 mm^3/sec.	0.0190108 mm^3/sec.	0.9

Table 6: Optimum values of parameters for powder mixed dielectric EDM

V. CONCLUSIONS

- It was found that MRR increases with the increase in current and duty cycle while with the increase in concentration and pulse on time it first increases then decreases.
- It was found that TWR increases with the increase in current and duty cycle while with increase in concentration it first decreases then increases and in case of pulse on time, first increases then deceases.

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