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Study and Analysis of Zinc PMEDM Process Parameters on MRR.

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Abstract— **Powder mixed electrical discharge machining (PMEDM) is one of the recent innovations thermo-electrical process for the improvement of the capabilities of EDM process. In this paper, the effects of various process parameters; powder concentration, peak current, pulse off time, tool electrode diameter and flushing pressure of powder mixed EDM (PMEDM) have been investigated to reveal their impact on material removal rate (MRR) of EN-8 steel by mixing Zinc (Zn) powder to kerosene dielectric. Taguchi's L-27(3*5) Orthogonal Array (OA) designs is considered to design and analyze the experiments. The optimal set of process parameters has also been predicted to maximize MRR. It is found that powder concentration and peak current are the significant parameters for MRR. All recommended conditions have been verified by performing a confirmation test.**

Keywords-- **PMEDM, MRR, EN-8, Mist EDM, Zn powder**

I. Introduction

Electric discharge machining (EDM) is a non-conventional thermo-electrical machining process to machine hard and electrically conductive materials for making of mould, die, aerospace, automotive and surgical components [1]. EDM does not make direct contact between the tool and workpiece thus eliminating mechanical stresses, chatter and vibration problems during machining [1],[2],[4],[5]. In this process material removal takes place through the process of controlled spark generation between a pair of electrodes which are submerged in a dielectric medium [3]. The material is removed with the erosive effect of the electrical discharges from tool and work piece [2], [6]. On the other hand, it has some limitations like low volumetric material removal rate and poor surface finishing so restricted its further applications [8]. To improve capabilities of EDM process, powder mixed EDM (PMEDM) has developed as one of the advanced techniques by mixing suitable powder form (are aluminum, chromium, graphite, copper, silicon or silicon carbide etc.) into the dielectric fluid of EDM [7]-[9]. The powder particles in the spark gap get energized and accelerated in a zigzag fashion by the developed electric field and act as conductors.

The conductive particles promote breakdown in the gap and also increase the spark gap between tool and the workpiece. Under the sparking area, the particles come closer and arrange themselves in the form of clusters structures between both the electrodes [9]. 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 and increases the spark gap distance between the tool electrode and workpiece [9]-[13]. The schematic diagram of principle of PMEDM is shown in FIG I.

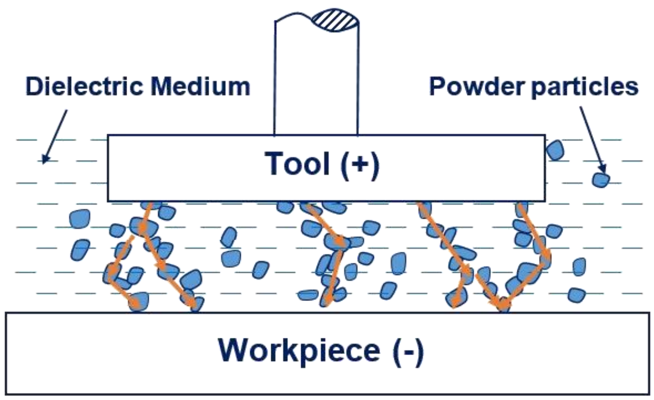

FIG I: Principle of Powder Mixed EDM

Due to bridging effect, the insulating strength of the dielectric fluid decreases. The easy short circuit takes place, which causes early explosion in the gap. As a result, a 'series discharge' starts under the electrode area. As a result, the faster sparking within a discharge occur causing faster erosion from the workpiece surface thereby improving material removal rate (MRR). The added powder modifies the plasma channel between tool and workpiece. The plasma channel becomes enlarged and widened [8]. The sparking is uniformly distributed among the powder particles, hence electric density of the spark decreases. Consequently, uniform erosion (shallow craters) occurs on the workpiece surface. This results in improvement in surface finish at better machining rates [9].

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II. Literature Review

In the year 1980, Erden and Bilgin [14] was first investigated the effect of powder particles (copper, aluminum, iron and carbon) mixed into dielectric fluid (kerosene) of EDM. They conclude that MRR increases with increase in the concentration of powder and also concluded that at excessive powder concentration machining becomes unstable due to occurrence of short circuits. Later in year 1981, Jeswani [15] investigated the effect of fine graphite powder into kerosene oil on machining of tool steels. They observed that the machining process stability was improved 60% in MRR and tool wear ratio decreased by 15%. Chow et al. [16] suggested that addition of SiC and Al powder to kerosene widen the gap distance; so improve material removal rate. They concluded that SiC powder in kerosene could give better material removal depth than Al powder. Wong et al. [13] compares the near-mirror-finish phenomenon using graphite, silicon (Si), aluminium (Al), crushed glass, silicon carbide (SiC) and molybdenum sulphide powder with different grain size to obtain near-mirror-finish. They reported that Al powder has better finishing for SKH-51 work pieces, but not on SKH-54 work pieces. They also suggested that it is important to know the correct combination of powder and work piece materials and an understanding of the fundamental mechanisms affecting such combinations will promote the applications of PMEDM to feasibly produce superior surface finish. In the year 2001, Tzeng and Lee [17] reported that the concentration, size, density, electrical resistivity and thermal conductivity of Al, Cr, Cu and SiC powders significantly affected the machining performance. The smallest size of the particle led to highest MRR for a fixed concentration. Kansal et al. [9] investigated into the optimization of the EDM process by adding silicon powder the dielectric fluid. They suggested that the concentration of added silicon powder, peak current and pulse duration significantly affect the MRR and SR in PMEDM. Pecas & Henrique [18] compared the performance of PMEDM technology with conventional EDM when dealing with the generation of high-quality surfaces. They suggested that a significant performance is improved when the powder mixed dielectric is used. Kung et al. [19] reported that the aluminum powder particle suspended in the dielectric fluid disperses and makes the discharging energy dispersion uniform; it displays multiple discharging effects within a single input pulse in the PMEDM. They are studied only for the finishing stages considered four parameters: discharge current, pulse on time, grain size, and concentration of aluminum powder particle for the evaluation of MRR.

From the available literature, it is concluded that the machining characteristics to cut material is not enough for zinc powder mixed in the dielectric fluid of EDM.

III. Experiment Setup

The experiments were conducted on an Electric Discharge Machine, Savita-Economy (India makes). To conduct experiments a separate dielectric re-circulating system was fabricated and attached to the machine table. Commercial kerosene has been chosen as dielectric fluid. To avoid filtering of powder particles, the powder should not go into the main dielectric tank. Experiment have been conducted by choosing EN-8 steel material as workpiece. Commercial copper with 99% purity is used as tool electrode. The chemical properties of copper tool and EN8 steel workpiece have been shown in TABLE I.

TABLE I
Chemical Properties of Copper and EN8 Steel

Material	Copper	EN8 Steel
Composition	Copper (99%)	(C + Si + Mn + S + P) = 0.40 + 0.25 + 0.80 + 0.05 +0.05
Hardness	40 BHN	255 BHN
Density	8.90 g/cm^3	7.8 g/cm^3
Melting Point	1083 ^{0}C	1370 ^{0}C

For mixing Zinc (Zn) powder of 100 mesh size to kerosene dielectric, a small tank made of thin mild steel sheet was placed in the main machining tank to isolate it from the filtering system of the machine. This tank was provided with a stirrer to prevent settling and to maintain uniform concentration of the powder in the dielectric throughout the machining cycle. Levels for various control factors were tabulated in TABLE II through review of literature and pilot study.

TABLE II
Levels for Various Control Factors

Factor	Name	Units	Nos. of Levels	Level Values		
				1	2	3
A	Powder Concentration	gL^{-1}	3	2	4	6
B	Peak Current	A	3	170	190	210
C	Pulse Off Time	µs	3	48	50	52
D	Tool Diameter	mm	3	8	10	12
E	Flushing Pressure	kgf/cm^2	3	.5	1	1.5

EXPLORING RESEARCH AND INNOVATIONS

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The experimental observations are further transformed into a signal-to-noise (S/N) ratio. There are several S/N ratios available depending on the type of characteristics. The characteristic that higher value represents better machining performance, such as MRR, is called 'larger is better. Inversely, the characteristic that lower value represents better machining performance, such as tool wear rate and surface roughness, are called 'lower is better'. Therefore, S/N ratio function for objective of larger is better equation 1.

$$S/N_{\text{(larger is better)}} = -10 \log[1/n \textstyle\sum_{i=1}^{n} Y_i^{-2}] \quad \text{--------} \quad 1$$

Where S/N denotes the Signal and Noise ratios calculated from observed values, Y_i represents the experimentally observed value of the i^{th} experiment and n=1 is the repeated number of each experiment.

Actual amount of material removed from tool during EDM is calculated by weight loss method as given in equation 2.

$$\mathbf{MRR} = \frac{[\text{workpiece weight loss in gms}]\ X\ 1000}{[\text{Density in}\frac{\text{gm}}{\text{cc}}]x[\text{Machining time in mins}]} \quad \text{---}\ 2$$

IV. OBSERVATION

The response observation table for MRR is shown in Table III along with the control factors.

TABLE III
RESPONSE TABLE

A	B	C	D	E	MRR (mm^3/min)
2	170	48	12	0.5	9.054
2	170	50	10	1	8.183
2	170	52	8	1.5	7.431
2	190	48	10	1	11.254
2	190	50	8	1.5	9.764
2	190	52	12	0.5	10.208
2	210	48	8	1.5	12.079
2	210	50	12	0.5	10.958
2	210	52	10	1	9.547
4	170	48	10	1.5	9.268
4	170	50	8	0.5	8.514
4	170	52	12	1	9.893
4	190	48	8	0.5	14.872
4	190	50	12	1	14.656
4	190	52	10	1.5	14.647
4	210	48	12	1	10.843
4	210	50	10	1.5	10.234
4	210	52	8	0.5	10.842
6	170	48	8	1	11.04
6	170	50	12	1.5	11.462
6	170	52	10	0.5	11.238
6	190	48	12	1.5	10.357
6	190	50	10	0.5	11.07
6	190	52	8	1	11.158
6	210	48	10	0.5	12.501
6	210	50	8	1	10.064
6	210	52	12	1.5	11.455

V. RESULTS & ANALYSIS

The influence of various machining parameter; powder concentration, peak current pulse off time, tool electrode diameter and flushing pressure of PMED on MRR has shown in main effect plot for S/N ratios of MRR (Larger is better) in FIG II by using the Minitab 16 software. The S/N ratio analysis suggests the levels of the parameters (A_3, B_2, C_1, D_3, E_1) as the best levels for maximum MRR.

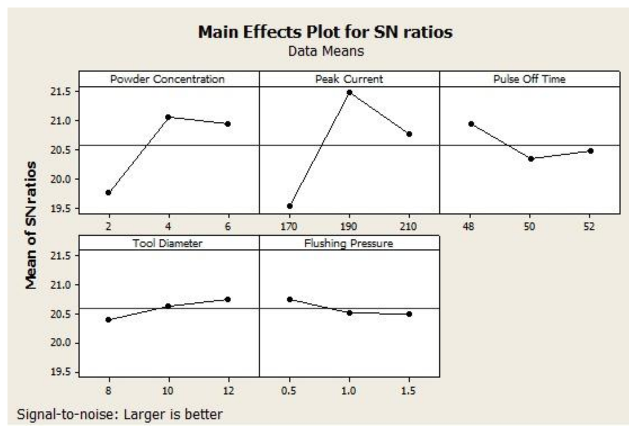

FIG II. MAIN EFFECT PLOT FOR SN RATIOS FOR MRR

Average S/N ratio for every level of experiment is calculated by Taguchi method for the recorded value as shown in TABLE IV.

TABLE IV

RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS (LARGER IS BETTER)

Level	Powder Concentration	Peak Current	Pulse Off Time	Tool Diameter	Flushing Pressure
1	19.76	19.52	20.93	20.39	20.74
2	21.06	21.47	20.34	20.62	20.52
3	20.93	20.76	20.47	20.75	20.49
Delta	1.3	1.94	0.59	0.36	0.26
Rank	2	1	3	4	5

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Different values of S/N ratio between maximum and minimum are also shown. The factor A (powder concentration) and factor B (peak current) are two factors that have highest different values are 1.3 and 1.94 respectively. Based on the Taguchi prediction that the bigger different value (delta) of S/N ratio will gives a more effect on MRR or more significant. So, it can be concluded that increase the powder concentration and Peak current will increased the MRR significantly.

In order to study the significance of the parameters in effecting the quality characteristic of interest i.e. MRR, ANOVA test was performed.

TABLE V
ANOVA TABLE FOR MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of Contri.
A	2	9.2165	9.216	4.608	13.35	**0.017**	**22.3%**
B	2	17.412	17.412	8.706	25.23	**0.005**	**42.2%**
C	2	1.7247	1.7247	0.862	2.5	0.198	4.2%
D	2	0.5993	0.5993	0.299	0.87	0.486	1.5%
E	2	0.3535	0.3535	0.176	0.51	0.634	0.9%
AxB	4	19.1343	19.1343	4.783	13.86	**0.013**	**23.2%**
AxC	4	2.7182	2.7182	0.679	1.97	0.264	3.3%
BxC	4	0.7363	0.7363	0.184	0.53	0.721	0.9%
Residual	4	1.3804	1.3804	0.345			
Total	26	53.2759		20.645			

It is found from TABLE V that factor powder concentration (A), Peak Current (B) and A*B are treated as the significance factor whereas factor C, D and E are less significant factors for maximization of MRR. The contribution of the A, B and A*B are 22.3%, 42.2% and 23.2 respectively, whereas the contribution of the other factors are very low for maximization of MRR. The significant factors for MRR are Peak Current (P=0.005), powder concentration (P=0.017) and Interaction of both Peak Current, powder concentration (P=0.013) for the 95% confidence level i.e. P = 0.05.

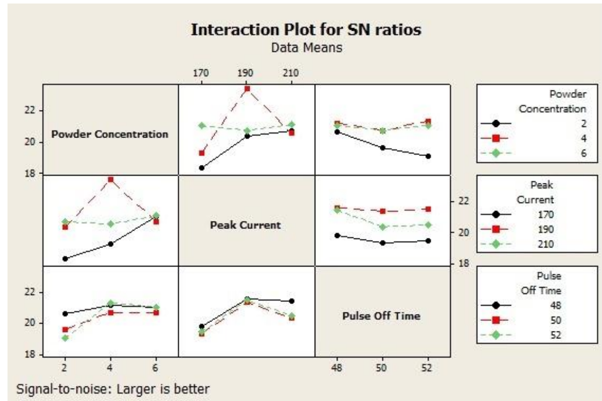

FIG III: INTERACTION PLOT FOR SN RATIOS

Interaction Plot for SN ratios is shown in FIG III. It is found that factor A and B has large Interaction value.

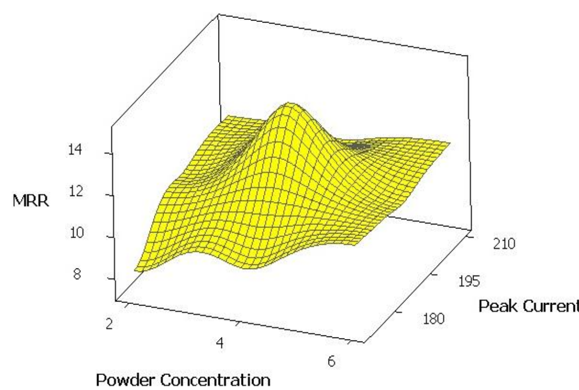

Fig. IV: SURFACE PLOT OF MRR VS POWDER CONCENTRATION, PEAK CURRENT.

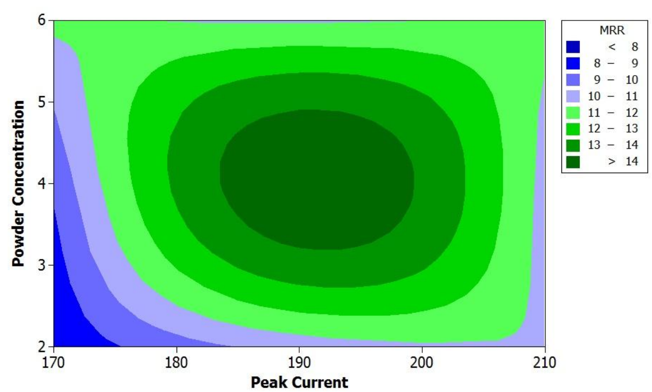

FIG V: CONTOUR PLOT OF MRR VS POWDER CONCENTRATION, PEAK CURRENT

The Surface Plot and Contour Plot of MRR vs Powder Concentration, Peak Current for significant & larger interaction is shown in FIG IV & V respectively. From the both figure, maximum MRR (>14) is occurred at the nearby value of peak current 190 A and powder concentration 4 gL^{-1}.

The final response equation for MRR is given as bellows:

*MRR = 7.55241 + 1.07294 Powder Concentration + 2.42694 Peak Current - 0.665222 Pulse Off Time - 0.173444 Tool Diameter - 0.142222 Flushing Pressure - 0.636333 Powder Concentration*Peak Current + 0.4295 Powder Concentration*Pulse Off Time - 0.231583 Peak Current*Pulse Off Time*

A. Confirmation Experiment

To check the validity of the developed models, 5 confirmation experiment is conducted and results are shown in TABLE VI. The prediction error is calculated as below equation

$$\text{Prediction error} = \left|\frac{\text{Experimental results} - \text{Predicted results}}{\text{Experimental results}}\right| \text{x}100\%$$

TABLE VI
CONFIRMATION TEST TABLE

Parameter Setting					**MRR**		
A	**B**	**C**	**D**	**E**	**Exp.**	**Pred.**	**Pred. Error (%)**
2	170	50	10	1.5	7.612	8.093	6.32%
4	190	52	12	1	13.984	15.170	8.48%
6	210	48	8	0.5	11.666	11.931	2.27%
4	170	48	12	1	8.712	9.110	4.57%
2	190	52	8	1.5	9.018	9.480	5.13%

It is observed that calculated prediction error lies within ±8.48% which is small and tolerable. So experiment have good reproducibility.

VI. CONCLUSIONS

Zinc powder is mixed with the kerosene dielectric of PMEDM. The following conclusions are found using Taguchi's L27 OA.

i. The significant factors for MRR are power concentration, Peak current and Interaction of both.
ii. The parameters pulse off time and tool electrode diameter have no significant on the material removal rate.

This work is a contribution to the on-going development of next-generation PMEDM process.

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