Effect of Powder Mixed Dielectric on Performance Measures of EDM for Tungsten Carbide

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Abstract— Powder mixed electric discharge machining (PMEDM) is a recent innovation of EDM for enhancing its capabilities. PMEDM is very complex in nature and controlled by a large number of parameters, which are having impact on various responses. The objective of this paper is to study the influence of operating parameters of tungsten carbide on the machining characteristics such as material removal rate. The effectiveness of PMEDM process with tungsten carbide, WC-Co is evaluated in terms of the material removal rate. It is observed that copper tungsten is most suitable for use as the tool electrode in EDM of WC-Co; better machining performance is obtained generally with the electrode as the negative and the work piece as positive. In this paper, a study was carried out on the influence of the parameters such peak current, Duty factor, pulse on time , work piece material, powder type , powder concentration and flushing pressure. Taguchi methodology has been adopted to plan and analyze the experimental results. Experiments have been performed on newly designed experimental setup. In this study seven factors with three levels are investigated using Orthogonal Array (OA) L27.Material removal rate (MRR) in this experiment was calculated by using mathematical method. The result of the experiment then was collected and analyzed using MINITAB 16 software. The recommended best parametric settings have been verified by conducting confirmation experiments for MRR. From the present experimental study it is found that addition of Silicon carbide powder enhances machining rate drastically with slightly increase in Tool wear rate.

Keywords— Powder mixed electrical discharge machining, material removal rate, Taguchi methodology, ANOVA Analysis, MINITAB 16.

I.   INTRODUCTION

Electrical discharge machining (EDM) is a nontraditional manufacturing process based on removing material from a part by means of a series of repeated electrical discharges (created by electric pulse generators at short intervals) between a tool, called electrode, and the part being machined in the presence of a dielectric fluid.[19] At present, EDM is a widespread technique used in industry for high precision machining of all types of conductive materials such as metals, metallic alloys, graphite, or even some ceramic materials. The adequate selection of manufacturing conditions is one of the most important aspects to take into consideration in the die-sinking electrical discharge machining (EDM) of conductive steel, as these conditions are the ones that are to determine such important characteristics: surface roughness, Tool wear rate (TWR) and material removal rate (MRR). In this paper, a study will be perform on the influence of the factors of peak current, pulse on time, Duty factor, work piece material, powder, powder concentration and Flushing pressure.

The material used in this study is a tungsten carbide or hard metal such as WC–11%Co. Approximately 50% of all carbide production is used for machining applications but tungsten carbides are also being increasingly used for non machining applications, such as mining, oil and gas drilling, metal forming and forestry tools. [14] Accordingly, mathematical models will be obtained using design of experiments (DOE) technique to select the optimum machining conditions for machining WC-Co using PMEDM.

The objectives of this paper are stated as follows:

1. To study the influence of powder mixed EDM on Conventional EDM.
2. To evaluate the performance of PM EDM on tungsten carbide (WC) with respect to responses such as material removal rate (MRR).
3. Taguchi methodology has been adopted to analyze and determine global solutions for optimal cutting parameters of PMEDM operation.

II. LITERATURE REIVEW

Erden and Bilgin [1] reported the effect of Cu, Al, Fe and C powders mixed into kerosene during EDM of brass–steel and copper–steel pairs. It was found that added powder improves the breakdown characteristics of dielectric. MRR increases with increase in the concentration of powder. At excessive powder concentration machining becomes unstable due to occurrence of short circuits. Jeswani [2] investigated effect of fine graphite powder into kerosene on machining of tool steels. The machining process stability was improved 60% in MRR. Mohri et al. [4], Yan and Chen [5], and Uno and Okada [8] investigated the effects of silicon powder addition on machining rate and surface roughness in EDM. Ming and He [6] reported that the high powder concentration to dielectric causes powder-settling problem. To solve this problem a new dielectric circulation system is required. Yu et al. [7] examined the higher discharge gap and improved MRR on EDM of WC using Al powder mixed dielectric. Wong et al. [9] reported that there is great influence of powder type and work piece properties on MRR. They suggested that it is important to have the correct combination of powder and work piece. Chow et al. [10] observed that addition of SiC and Al powder to

kerosene enhances the gap distance; resulting in higher debris removal rate and material removal. They discovered that SiC powder in kerosene could produce better material removal depth than Al. Tzeng and Lee [11] reported the effect of Al, Cr, Cu and SiC powders on EDM of SKD-11. It was found that the concentration, size, density, electrical resistivity and thermal conductivity of powders significantly affected the machining performance. For a fixed concentration, the smallest size of the particle led to highest MRR.

Zhao et al. [12] used Al with 40 g/l and 10 μm granularities and discovered that machining efficiency was improved from 2.06 to 3.4 mm3/min. The result shows that Al powder leads to highest MRR. Wu et al. [14] reported that Al powder in the dielectric has more effect on distribution of electrical discharge energy.

Kansal et al. [15] established optimum process conditions for PMEDM using the RSM with Si powder 20-30 μm. Pulse on time, duty cycle, peak current and concentration of Si powder were chosen as variables to study MRR of EN-31 tool steel and Cu electrode. Sharif et al. [16] showed that MRR is greatly influenced by the current, voltage and pulse on time and the surface roughness was highly influenced by the presence of SiC additives.

H.K. Kansal et al. [17] studied effects of Si powder mixed EDM on D2 die steel. Optimization to maximize MR has been done using Taguchi method. Kuang-Yuan Kung, Jenn-Tsong Horng, Ko-Ta Chiang [20] considered four parameters: discharge current, pulse on time, grain size, and concentration of aluminum powder particle for the evaluation of MRR.

III. EXPERIMENTAL DETAILS

In the present study experiments were carried out on Electronica make electrical discharge machine; model SMART ZNC (S50) with some modifications are done on existing EDM to suit present requirements of study as shown in fig.1 The dielectric flow system was modified for circulation of powder suspended dielectric medium in small quantities to prevent contamination of whole of dielectric fluid. WC-CO (specimen 51mm X 26mm X 5mm) was selected as work piece. Cylindrical copper tungsten electrode (φ 15.0 mm) was used as an electrode for conducting the experiments, it has been decided to follow the Taguchi method of experimental design and an appropriate orthogonal array is to be selected after taking into consideration the above design variables. The effect of suspended powder on the phenomenon of surface modification should be studied in order to correctly understand its behavior. Hence, it was decided to conduct experiments with each combination of work material, electrode and powder. Out of the above listed design variables, the orthogonal array was to be selected for seven design variables (namely peak current, pulse on-time, Duty factor, work piece material, powder type, powder concentration and flushing pressure The machining process parameters set up as shown in Table I keeping all other parameters constant.
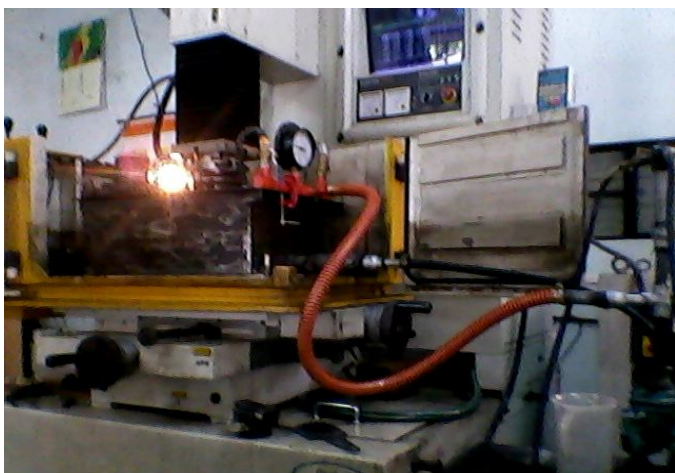

Fig.1 Photograph of PMEDM experimental setup   *Figure 2 Dielectric Tank with Stirrer*

Attachment
TABLE II VALUES OF FIXED INPUT PARAMETERS

Sr.No.	Parameter	Value
1	Open circuit voltage	70+/-5%
2	Polarity	Straight
3	Spark energy	High
4	Machining time	60 minutes

TABLE III FACTORS AND THEIR LEVELS FOR EXPERIMENTS

Sr. No.	factor	Level1	Level2	Level3
1	Current (A)	4	6	8
2	Pulse on time(µs)	100	150	200
3	Duty factor (%)	7	9	11
4	Work Piece	W20	W30	W40
5	Powder type	Al	Gr	SiC
6	Powder Conc. (Grams / Liters)	4	8	12
7	Flushing Pressure (kg/cm^2)	0.5	1.0	1.5

TABLE VI EXPERIMENTAL OBSERVATIONS (OA L27)

Factor	A	B	C	D	E	F	G	MRR Mean
1	4	100	7	20	Al	4	0.5	0.1910
2	4	100	7	20	Gr	6	1.0	0.1797
3	4	100	7	20	Sic	8	1.5	0.3937
4	4	150	9	30	Al	4	0.5	0.1730
5	4	150	9	30	Gr	6	1.0	0.2084
6	4	150	9	30	Sic	8	1.5	0.5150
7	4	200	11	40	Al	4	0.5	0.1090
8	4	200	11	40	Gr	6	1.0	0.1080
9	4	200	11	40	Sic	8	1.5	0.2208
10	6	100	7	40	Al	6	1.5	0.2680
11	6	100	7	40	Gr	8	0.5	0.2896
12	6	100	7	40	Sic	4	1.0	0.3347
13	6	150	9	20	Al	6	1.5	0.2770
14	6	150	9	20	Gr	8	0.5	0.2278
15	6	150	9	20	Sic	4	1.0	0.2907
16	6	200	11	30	Al	6	1.5	0.2928
17	6	200	11	30	Gr	8	0.5	0.2576
18	6	200	11	30	Sic	4	1.0	0.2601
19	8	100	7	30	Al	8	1.0	0.6446
20	8	100	7	30	Gr	4	1.5	0.7569
21	8	100	7	30	Sic	6	0.5	0.6875
22	8	150	9	40	Al	8	1.0	0.3038
23	8	150	9	40	Gr	4	1.5	0.3585
24	8	150	9	40	Sic	6	0.5	0.4143
25	8	200	11	20	Al	8	1.0	0.3914
26	8	200	11	20	Gr	4	1.5	0.3491
27	8	200	11	20	Sic	6	0.5	1.007

A- current in Amp, B- Pulse on time (µs) ,C - Duty factor (%), D - Work Piece material (W20- 20, W30 -30 , W40 -40)
E - Powder type , E - Powder Concentration (Grams / Liter) ,G - Flushing Pressure (kg/cm^2)

A. Measurement Techniques for MRR

MRR for each experimental run is to be calculated by weight difference of specimen before and after machining. For this purpose high accuracy electronic balance of Contech model CA-503 with accuracy of 1 mg is used.

$$MRR = \frac{(W_i - W_f)}{\rho \times t} \, X \, 1000 \, mm^2/min$$

………………..Equation 1

Where

W_i = Initial weight of work piece material (grams)
W_f = Final weight of work piece material (grams)
     t = Time period of trails in minutes
     ρ = Density of work piece in grams/cm^3

IV. EXPERIMENTATION AND DATA COLLECTION

Experiments are performed in two sets and average values of MRR are taken for further analysis. Main points in experiment are: (i) Dielectric is stirred continuously to prevent powder settling and (ii) Proper electrical conductivity between the tool and work piece interface must be maintained.

V. DATA ANALYSIS AND DISCUSSIONS

As the experimental design is orthogonal, it is possible to separate out the effect of each parameter at different levels. All observations are transformed into S/N ratio. The analysis and graphical presentations are made using MINITAB. ANOVA is done to determine which parameters significantly affect on to the selected response. Then meaningful conclusions are drawn.

B. Taguchi Analysis for MRR

The S/N ratio consolidates several repetitions into one value and is an indication of the amount of variation present. The S/N ratios have been calculated to identify the major contributing factors and interactions that cause variation in the MRR. MRR is "Higher is better" type response which is given by:

$$(S/N)_{HB} = -10 \log (MSD)_{HB}$$

$$\text{Where } MSDHB = \frac{1}{R} \sum_{j=1}^{R} \left(\frac{1}{y_j^2} \right)$$

MSDHB=Mean Square Deviation for higher-the-better response.

From the observation Table III, S/N ratio values of each run of MRR are used to calculate mean of S/N ratios at three levels of all factors and are given in Table IV. It gives us rank of all factors in this study considering the mean of S/N ratios for MRR at different levels

TABLE IV MEANS OF SIGNAL TO NOISE RATIOS FOR MRR

Level → Factor ↓	1	2	3	Delta	Rank
Current (A)	-13.7	-11.177	-6.012	7.734	1
Pulse on time(μs)	-8.79	-10.696	-11.453	2.669	4
Duty factor (%)	-10.939	-9.285	-10.711	1.654	7
Work Piece	-9.927	-8.749	-12.258	3.509	3
Powder type	-11.655	-11.528	-7.751	3.903	2
Powder Conc. (Grams / Liters)	-11.255	-10.219	-9.460	1.795	6
Flushing Pressure (kg/cm^2)	-10.568	-11.396	-8.970	2.426	5

As MRR is Higher the Better type quality characteristic, therefore, greater S/N values are considered to be optimal. The graph 1 shows the individual effect of the control factors on MRR.

We look at the graph we will observe that with increase in current MRR s/n ratio increasing. Material removal rate decreases with pulse duration but after certain value of pulse duration there is increase in material removal rate, also with increase in duty factor there is increase in material removal rate but after certain value of duty factor there is decrease in material removal rate. Also we will observe that with increase in powder concentration MRR s/n ratio increasing.

A. Analysis of Variance for S/N Ratio of MRR

ANOVA is used to analyze the results of experiments and determine how much variation that each factor has contributed. By studying the main effects of each of the factors, the general trends of the influence of the factors towards the process can be distinguished.

B. Analysis of Variance for S/N Ratio of MRR

ANOVA is used to analyze the results of experiments and determine how much variation that each factor has contributed. By studying the main effects of each of the factors, the general trends of the influence of the factors towards the process can be distinguished.

The relative importance of the parameters with respect to MRR is investigated to determine more accurately the optimum combinations of parameters and the results of (ANOVA) of S/N data of MRR are presented in table V. ANOVA determines which parameters significantly affect the MRR.
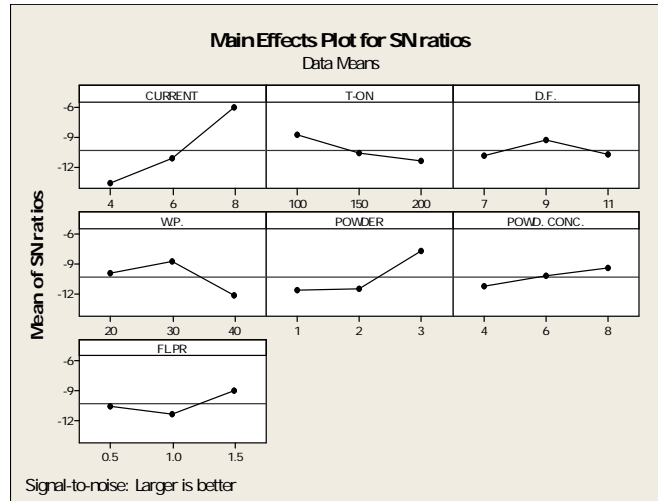
Figure 3: Main effects plot for MRR of S/N ratio

TABLE V ANOVA FOR S/N RATIO OF MRR

Source	DF	SS	Variance	F	P	Sign. or Not
Current	2	279.27	139.633	45.91	0.000	S
Pulse on Time	2	34.06	17.028	5.60	0.019	S
Duty Factor	2	14.47	7.234	2.38	0.35	NS
Work piece	2	57.40	28.701	9.44	0.003	S
Powder	2	88.54	44.272	14.56	0.001	S
Powder Conc.	2	14.61	7.307	2.40	0.133	NS
Flushing pressure.	2	27.38	13.688	4.50	0.035	S
Error	12	36.49	3.041			
Total	26	552.22				
S = 1.744 R-Sq = 93.4% R-Sq(adj) = 85.7%						

It is observed that current, pulse on time, work piece; powder and flushing pressure are most significant in controlling MRR. From graph 1 optimum combination of factors for MRR is: (A3 B1 C2 D2 E3 F3 G3). This optimum combination is not there in L27 experiment table. So, theoretical optimum MRR is required to be calculated. The estimated S/N ratio using the optimal level of the design parameters can be calculated.

$$n_{opt} = n_m + \sum_{i=1}^{a} (n_i - n_m)$$

Where n_m is the total mean S/N ratio, n_i is the mean S/N ratio at optimum level and' a' is the number of main design parameter that effect quality characteristic. Based on the above equation the estimated multiresponse signal to noise ratio can be obtained.

n_{opt}= -10.3115 + (-6.0119+10.3115) + (-8.7845+10.3115) +
(-9.28458+10.3115) +   (-8.7418+10.3115) +
(-7.75149+10.3115) + (-9.46049+10.3115)   +
(-8.97003+10.3115)

Optimal value of SN ratio = 2.856

The formula used for calculating the theoretical optimal value of MRR is given as

$$y^2 = \frac{1}{10^{\frac{-n_{opt}}{10}}}$$

$$y_{opt} = 1.388 \ mm^3/min$$

Thus, theoretical optimal value of MRR for this experiment is 1.388 mm³/min. To verify the improvement in MRR using the optimal level of parameters, the confirmation experiments are performed and this MRRopt is compared with confirmation experiment values.

VI. RESULTS & DISCUSSION

The final step of the Taguchi method is the confirmation experiments conducted for examining the quality characteristics. The model used in the confirmation tests is defined with the total effect generated by the control factors. The confirmation experiments are performed to validate the above analysis conclusions.

Table VI Results of Confirmation Experiments

Optimal condition MRR	Predicted MRR	Experiment MRR	% Error
A3 B1 C2 D2 E3 F3 G3	1.388 mm^3/min	1.419mm^3/min	2.23

As shown in the above tables, the experimental values agree reasonably well with predictions. The maximum deviation of predicted results from experimental results is about 2.23 %. Hence, the experimental result confirms the optimization of MRR using Taguchi method and the resulting model seems to be capable of predicting MRR.

VII. CONCLUSION

Within the range of selected parameters for the present work, following conclusions are drawn:

a) The MRR and TWR are mainly affected by the current and powder.

b) With mixing of silicon carbide powder MRR can be increased by 90%

c) Current, Pulse on time, work piece material, Powder type and Flushing Pressure significantly affect MRR.

d) The maximum MRR is produced at 8 g/l of SiC powder for Flushing pressure 1.5 Kg/cm^2.

e) Duty factor shows least effect on MRR.

Finally, it has been concluded that SiC powder and Current have impact to great extent on the MRR of Tungsten Carbide (W30). This study shows future scope and potential for the improvements in the EDM field of Tungsten Carbide

Acknowledgment

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