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Optimization and comparative analysis of silicon and chromium powder-mixed EDM process by TOPSIS technique

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Abstract

Powder mixed electric discharge machining (PMEDM) is an advancement in electric discharge machining (EDM) to overcome the problem of low material removal rate and surface finish in the conventional EDM process. In the PMEDM process, metallic or non-metallic powders such as silicon, aluminum, graphite, etc. are mixed in the dielectric fluid. In the present work, Response surface methodology (RSM), in combination with Technique for the order of preference by similarity to ideal solution (TOPSIS) is adopted to effectively optimize the multi-performance characteristics for PMEDM of AISI D2 steel. The electrode used for the study is copper while the powders mixed in the dielectric fluid is silicon and chromium. The effect of input parameters such as current, pulse on time, and powder concentration on material removal rate, tool wear rate and electrode wear ratio is investigated. Analysis of variance (ANOVA) and the main effect plots are generated to determine the significant parameters. For silicon powder-mixed dielectric fluid, the optimum values of current are 8A, pulse on time is 150 µs and powder concentration is 2 g/l while for chromium powder-mixed dielectric fluid, the optimum values of current are 10A, pulse-on time is 200 µs and powder concentration is 2 g/l. The silicon powder-mixed and chromium powder-mixed processes are compared by considering the electrode wear ratio as the response variable. The minimum and average electrode wear ratio for the silicon powder-mixed process is 0.0050 and 0.0093 respectively while for chromium powder-mixed process, the minimum and average values are 0.0025 and 0.0070 respectively. From the comparison, it is evident that the electrode wear ratio is lower for the chromium powder-mixed process.

Keywords: Powder mixed EDM, Material removal rate, Tool wear rate, Electrode wear ratio, Response surface methodology, TOPSIS technique

1. Introduction

Electric discharge machining is an efficient machining technique. In this technique, the tool and workpiece are kept at a certain gap from each other and a stream of electric pulses is passed between them. The material is removed by the spark generated between the two. The tool shape is directly mirrored on the work-piece surface. It proves to be advantageous when machining complex shapes and difficult-to-machine materials. The materials like AISI M2 steel which has a very high hardness in the range of 60 HRc is machined using copper electrode [1] and also in some cases, advanced electrode materials are used such as tungsten-thorium electrode [2]. It also provides accuracy in machining and hence micro-drilling, etc. can be done. But it has a major drawback of low productivity and low surface finish [3]. Hence to deal with these problems, many elevations are carried out in a conventional EDM process. Some of them are – Rotary type EDM, Ultrasonic EDM, Powder Mixed EDM, Cryogenic EDM, etc [4]. In the Rotary type EDM process, the tool is rotated instead of a stationary tool in conventional EDM [5]. It improves the material removal rate and surface finish but it has a restriction of machining symmetrical and circular work such as drilling, etc. In Ultrasonic EDM, ultrasonic pulses are passed between the tool and workpiece which improves the material removal rate [6]. In the cryogenically cooled EDM process, the tool is constantly cooled using cryogenic fluids. Due to the cooling of the tool, higher current and pulse on time can be implemented as there is less amount of carbon deposition. Due to the high current and pulse on time, material removal rate increases and also tool wear is low [7]. But these techniques need major upgradation in the setup while the powder-mixed EDM process is easier to implement.

1.1 Powder-mixed EDM process

In the Powder mixed EDM process, various micro-sized powders such as silicon, chromium, aluminum, graphite, etc. are mixed in the dielectric fluid. The ions formed by powders increase the material removal rate and also improves the surface finish [8-10]. The process of powder mixed EDM process is shown schematically in Figure 1. When a voltage is applied between the tool and the workpiece, a very high electric field in the range of million-volt/m is created. The gap is filled with powder particles and the distance between tool and workpiece becomes double. The powder particles in the gap get energized and they move in a zigzag manner as shown in Figure 1. The

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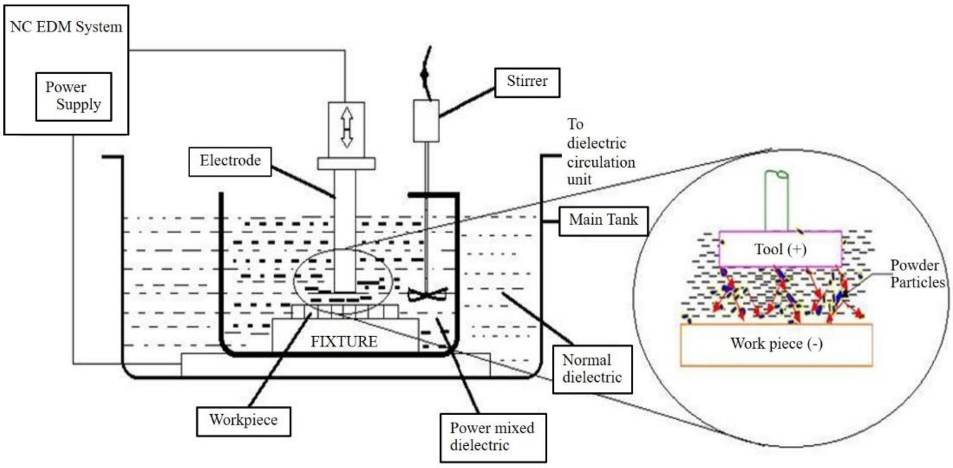


Figure 1 Schematic diagram of the powder-mixed EDM process

Figure 2 Experimental setup

particles get arranged in a chain-like structure which produces a bridging phenomenon. The bridging phenomenon decreases the insulating strength of dielectric fluid which leads to early short-circuit in the gap. Hence the frequency of spark increases and the material removal rate increases. Also, a wide plasma channel is produced thereby decreasing the electric density and hence uniform distribution of spark takes place. Due to uniform distribution, the surface finish improves.

Chromium powder-mixed in dielectric fluid improves the material removal rate, tool wear rate and also enhances the surface finish of machined work-piece [11]. Mixing of silicon and aluminum powder in the dielectric fluid improves the material removal rate, tool wear rate, and surface properties such as roughness and crack density [12]. There is a lot more evidence that proves that mixing of powder in the dielectric fluid enhances the output responses like productivity and surface integrity.

The Silicon powder-mixed EDM process has been explored in the previous studies but chromium powder mixed EDM technique is still in the incubation state. The data regarding various ranges of current, pulse on time and other input parameters for the chromium powder-mixed process are unavailable. Hence, Chromium powder-mixed process is studied in this paper in detail and also comparative analysis is carried out with silicon powder-mixed process which has been studied in-depth in the previous studies and therefore comparison with the well-known technique provides a clear idea about advantages and drawbacks of Chromium powder-mixed process over silicon powder-mixed process. In this present work, silicon and chromium powder are mixed in dielectric fluid with a concentration of 2, 4, and 6g/l. The process parameters considered are current, pulse on time and powder concentration. The response variables are material removal rate and tool wear rate. Two designs of experiments are generated-one for each powder using response surface methodology. A total of 40 experiments are conducted.

2. Materials and methods

2.1 Experimental setup

The experiments are conducted on Electra Plus PS50 ZNC machine which is manufactured by Electronica India Pvt. Ltd. It is a die-sinking electric discharge machine. It has a mounting surface of 550mm*350mm with a maximum height of 250mm. The process parameters which the machine can achieve are - current from 3-50A, pulse on-time range is 10-2000 µs with gap voltage of 40-100V. It works with positive as well as negative polarity. The experimental setup is as shown in Figure 2.

The experiments are carried out using a copper tool of the circular cross-section of 10mm diameter and the workpiece material is AISI D2 steel. AISI D2 steel is used to manufacture dies, knives, rollers, etc. The machining is done in the presence of specialized EDM oil which has properties such as low viscosity, less aromatic compounds, and hence low odor which improves safety to users as well as the environment, long-lasting transparency, non-corrosive and most importantly high dielectric strength which provides precision and control sparking. The EDM oil capacity of the machine is 220 liters which are reduced

Table 1 Design of experiments for silicon/chromium powder

Process parameters	Level 1	Level 2	Level 3
Current (A)	6	8	10
Pulse on time (µs)	100	150	200
Powder concentration-Si, Cr (g/l)	2	4	6

to 15 liters by necessary setup change as shown in Figure 2. Silicon and chromium powder with a grain size of 350 mesh or 40 microns are mixed in the dielectric fluid. The machining is done for 10 minutes as it provides an adequate depth of machined surface for measuring the material removal rate and tool wear rate.

2.2 Process parameters

Electric discharge machining has several process parameters including current, pulse on time, pulse off time, duty cycle, gap voltage, flushing pressure, polarity. There are certain other process parameters such as workpiece material, tool material, dielectric fluid, etc [13]. There are also some special-purpose process parameters including powder type, powder concentration, and size, ultrasonic frequency, cryogenic fluid flow. From the literature, it is revealed that current and pulse on time are the most significant parameters as they are the energy generators which help in the removal of material [14]. In this study, the process parameters taken into consideration are current, pulse on time, and powder concentration. The design of the experiment for both silicon and chromium powder is as mentioned in Table 1.

2.3 Response variables

The response variables which are considered in electric discharge machining include material removal rate, tool wear rate, electrode wear ratio, surface roughness, surface hardness, recast layer, radial overcut. The response variables which are analyzed in this study are material removal rate, tool wear rate, and electrode wear ratio.

2.3.1 Material removal rate

Material removal rate [15] is the ratio of the difference in weight of the workpiece before and after machining to the time of machining. In this work, the duration of machining is ten minutes. In some cases, the volume difference is also considered to calculate the material removal rate.

2.3.2 Tool wear rate

Tool wear rate is the ratio of the difference in weight of the tool before and after machining to the time of machining. The measuring of tool weight is a crucial task as tool wear is very low in case of electric discharge machining. Hence, the weighing machine of lower least count and higher accuracy must be used.

2.3.3 Electrode wear ratio

The electrode wear ratio [15] is the ratio of tool wear rate to the material removal rate or it is simply the ratio of the volume of material lost from the tool to the volume of material removed from the workpiece.

Material removal rate and tool wear rate are analyzed and optimized while the electrode wear ratio is considered for comparative study.

2.4 Design methodology

For the design of experiments, various techniques are used such as Full Factorial design, Fractional Factorial design, Taguchi design, and Response Surface Methodology. The Full Factorial Design consists of experiments given by equation 1.

$$N = m^n \quad (1)$$

Where, N = number of experiments
m = number of levels
n = number of parameters

The full factorial design gives good results but it proves to be hectic if the number of parameters or levels increase. So, the Fractional Factorial Design is used which reduces the number of experiments to half, quarter, etc.

Taguchi design is a good technique for the design of experiments. Taguchi design is based on the orthogonal array. Based on the number of levels and parameters, L_4, L_8, L_9, L_{16}, L_{18}, L_{27}, etc. arrays are used for the design of experiments. Signal-to-noise ratio and main effect plots are plotted which provide the optimum condition of the machining parameter.

Response Surface Methodology (RSM) [16] is a bunch of statistical & mathematical techniques that are used to model and analyze the responses which are affected by the number of variables and its objective is to optimize the response variables. The experiments are conducted and regression analysis is applied. A model is generated which defines the response to some process variables. By investigating the model, an optimal point can be deduced. RSM is used for single-objective optimization of process variables. The RSM deduces the optimum point by equation 2.

$$Y=f(X1,X2,X3,\ldots\ldots\ldots.Xn)\pm\epsilon \quad (2)$$

Where, Y= response variable,
X1, X2, X3,…….Xn = independent process variables
∈ = experimental error

In RSM, the expected response Y is plotted against the independent process variables. If the plot is linear, the results are far from optimum. Hence, to move towards the optimum condition rapidly, the first-order differential equation is used. The first-order differential equation is as mentioned in equation 3.

$$Y= C0+C1\ X1+C2\ X2\ldots\ldots\ldots+Cn\pm\epsilon \quad (3)$$

If the curvature is found in the plot, the results are near optimum condition and hence very fine movement is needed. Therefore, a second-order differential equation is used. The equation is as mentioned in equation 4.

$$Y = C_0 + \sum_{i=1}^{n} C_i X_n + \sum_{i=1}^{n} d_i X_n^2 \quad (4)$$

Therefore, RSM is not only used to investigate the response variables but also to deduce the optimum condition.

In the present work, the runs are designed using the RSM of face-centered composite design. The design is done using MINITAB 19.0 software. The designs are analyzed by Analysis of Variance (ANOVA) table and main effect plots. The Analysis of Variance for only two response variables- material removal rate and tool wear rate- are studied for both the powders.

Table 2 Results for silicon and chromium powder mixed EDM process

Run Order	Current 'I_P' (A)	Pulse on time 'T_{on}' (μs)	Powder Conc. 'C' (g/l)	Silicon powder mixed EDM		Chromium powder mixed EDM	
				MRR (g/min)	TWR (g/min)	MRR (g/min)	TWR (g/min)
1	6	200	2	0.03	0.0003	0.03	0.0001
2	8	150	2	0.06	0.0003	0.04	0.0002
3	10	200	2	0.07	0.0006	0.06	0.0002
4	10	100	2	0.06	0.0005	0.04	0.0012
5	6	100	2	0.02	0.0002	0.06	0.0003
6	8	150	4	0.06	0.0005	0.04	0.0002
7	8	100	4	0.06	0.0004	0.03	0.0003
8	8	150	4	0.05	0.0006	0.03	0.0002
9	10	150	4	0.08	0.0007	0.05	0.0006
10	8	150	4	0.06	0.0006	0.03	0.0001
11	6	150	4	0.04	0.0004	0.04	0.0002
12	8	150	4	0.06	0.0005	0.05	0.0002
13	8	200	4	0.07	0.0007	0.03	0.0002
14	8	150	4	0.05	0.0005	0.03	0.0002
15	8	150	4	0.06	0.0007	0.04	0.0001
16	10	200	6	0.08	0.0008	0.06	0.0002
17	6	100	6	0.04	0.0002	0.03	0.0002
18	8	150	6	0.05	0.0007	0.04	0.0004
19	6	200	6	0.04	0.0004	0.02	0.0001
20	10	100	6	0.06	0.0006	0.03	0.0002

Table 3 Analysis of variance for MRR of silicon powder mixed EDM process

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Significance %
Model	9	0.004025	0.000447	9.43	0.001	99.9
Linear	3	0.003580	0.001193	25.15	0.000	100
I_P	1	0.003240	0.003240	68.28	0.000	100
T_{on}	1	0.000250	0.000250	5.27	0.045	95.5
C	1	0.000090	0.000090	1.90	0.199	80.1
Square	3	0.000345	0.000115	2.43	0.126	87.4
$I_P * I_P$	1	0.000020	0.000020	0.43	0.526	47.4
$T_{on}*T_{on}$	1	0.000014	0.000014	0.30	0.596	40.4
C*C	1	0.000164	0.000164	3.46	0.092	90.8
Interaction	3	0.000100	0.000033	0.70	0.572	42.8
$I_P * T_{on}$	1	0.000050	0.000050	1.05	0.329	67.1
I_P*C	1	0.000050	0.000050	1.05	0.329	67.1
$T_{on}*C$	1	0.000000	0.000000	0.00	1.000	0.0
Error	10	0.000475	0.000047			
Lack-of-Fit	5	0.000341	0.000068	2.56	0.163	
Pure Error	5	0.000133	0.000027			
Total	19	0.004500				

2.5 Multi-objective optimization

Single objective optimization can be done by RSM or Taguchi technique but multiple response variables-in this case, multi-objective optimization-must be carried out to acquire the optimum condition of various process parameters when response variables provide optimum results. There are various optimization techniques which are implemented by researchers including grey relational analysis, TOPSIS technique, grey fuzzy algorithm. In this present study, the TOPSIS technique is implemented for both the powders by considering material removal rate and tool wear rate as response variables.

3. Results and discussions

The experiments are designed based on the RSM technique. The experiments are conducted and the results for both silicon and chromium powders are as mentioned in Table 2.

3.1 Analysis of silicon powder mixed EDM process

The results of the silicon powder mixed EDM process are analyzed and Analysis of Variance (ANOVA) is generated using MINITAB 19 software. ANOVA gives the idea about the significance of the input parameters and the output responses such as material removal rate and tool wear rate. The ANOVA table for material removal rate and tool wear rate for silicon powder mixed EDM process is as mentioned in Table 3 and 4.

From the Analysis of Variance, current and pulse on time are the most significant parameters. Powder concentration has a high significance that means silicon powder also takes part in the variation of material removal rate and tool wear rate. The p-value for the model in both MRR and TWR is less than 0.05 which means the model is significant. The lack-of-fit is not significant. The square and interaction terms for MRR and TWR are non-significant.

The value of R-square for MRR and TWR is 89.45% and 88.77% respectively which means that the regression model provides a good correlation between the input variables i.e. current, pulse on time, and powder concentration and the output responses i.e. MRR and TWR respectively.

Table 4 Analysis of variance for TWR of silicon powder mixed EDM process

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Significance %
Model	9	0.000000	0.000000	8.78	0.001	99.9
Linear	3	0.000000	0.000000	22.79	0.000	100
I_P	1	0.000000	0.000000	47.17	0.000	100
T_{on}	1	0.000000	0.000000	13.22	0.005	99.5
C	1	0.000000	0.000000	8.00	0.018	98.2
Square	3	0.000000	0.000000	3.00	0.081	91.9
$I_P * I_P$	1	0.000000	0.000000	0.75	0.406	59.4
$T_{on}*T_{on}$	1	0.000000	0.000000	0.75	0.406	59.4
C*C	1	0.000000	0.000000	0.75	0.406	59.4
Interaction	3	0.000000	0.000000	0.54	0.663	33.7
$I_P * T_{on}$	1	0.000000	0.000000	0.00	1.000	0.0
I_P*C	1	0.000000	0.000000	0.82	0.388	61.2
T_{on}*C	1	0.000000	0.000000	0.82	0.388	61.2
Error	10	0.000000	0.000000			
Lack-of-Fit	5	0.000000	0.000000	0.84	0.574	
Pure Error	5	0.000000	0.000000			
Total	19	0.000001				

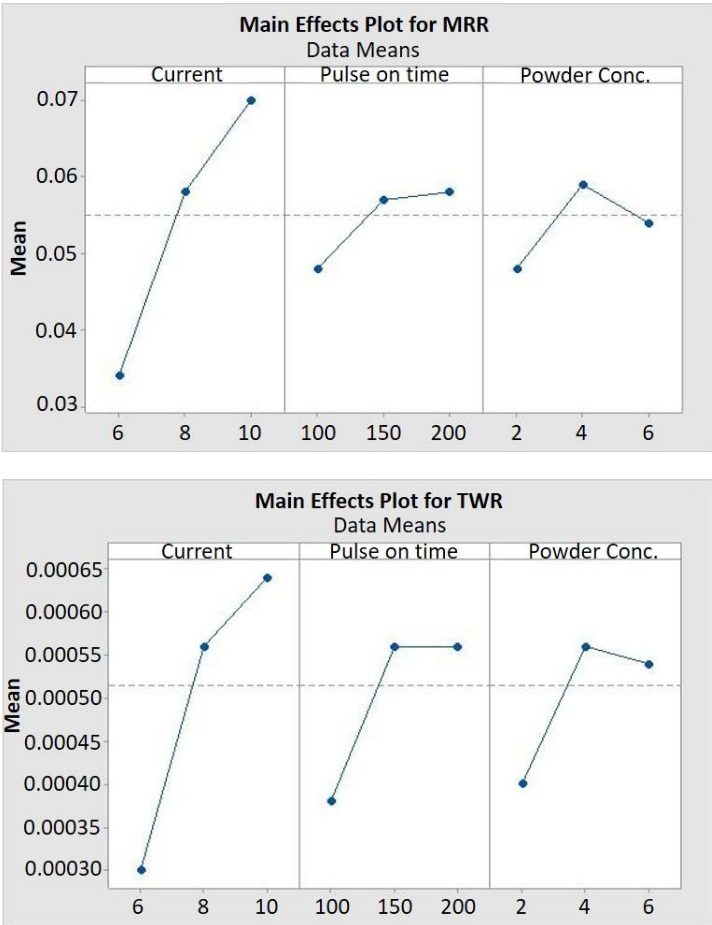


Figure 3 Main effect plots for silicon powder-mixed EDM process

The main effect plots are also generated using the software which also provides the optimum process parameters and their levels are as shown in Figure 3.

From the main effect plot of MRR and TWR, the responses show an increasing trend as current and pulse on-time increases. The material removal rate is higher at 10A current with a pulse on time of 200 µs and a silicon powder concentration of 4g/l while the tool wear rate is low at 6A current with a pulse on time of 100 µs and silicon powder concentration of 2g/l.

3.2 Analysis of chromium powder-mixed EDM process

The results of the silicon powder-mixed EDM process are analyzed using MINITAB 19 software. ANOVA gives the idea about the significance of the input parameters and the output responses such as material removal rate and tool wear rate. The ANOVA table for material removal rate and tool wear rate for chromium powder- mixed EDM process is as mentioned in Tables 5 and 6.

From the ANOVA, it is clear that the current is the most significant parameter. Pulse on time has high significance in the case of TWR but has a low influence on MRR. While powder concentration has a high significance which means chromium

Table 5 Analysis of variance for MRR of chromium powder mixed EDM process

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Significance %
Model	9	0.002118	0.000235	5.09	0.009	99.1
Linear	3	0.000729	0.000243	5.26	0.02	98
I_P	1	0.000463	0.000463	10.02	0.01	99
T_{on}	1	0.000014	0.000014	0.31	0.591	40.9
C	1	0.00025	0.00025	5.41	0.042	95.8
Square	3	0.000154	0.000051	1.11	0.39	61
$I_P * I_P$	1	0.000098	0.000098	2.12	0.176	82.4
$T_{on}*T_{on}$	1	0.000044	0.000044	0.96	0.35	65
C*C	1	0.000033	0.000033	0.71	0.42	58
Interaction	3	0.001237	0.000412	8.93	0.004	99.6
$I_P * T_{on}$	1	0.001012	0.001012	21.92	0.001	99.9
I_P*C	1	0.000113	0.000113	2.44	0.15	85
$T_{on}*C$	1	0.000113	0.000113	2.44	0.15	85
Error	10	0.000462	0.000046			
Lack-of-Fit	4	0.000079	0.00002	0.31	0.863	
Pure Error	6	0.000383	0.000064			
Total	19	0.00258				

Table 6 Analysis of variance for TWR of chromium powder mixed EDM process

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Significance %
Model	9	0.000001	0.000000	4.66	0.012	98.8
Linear	3	0.000001	0.000000	8.38	0.004	99.6
I_P	1	0.000000	0.000000	10.92	0.008	99.2
T_{on}	1	0.000000	0.000000	10.88	0.008	99.2
C	1	0.000000	0.000000	3.62	0.086	91.4
Square	3	0.000000	0.000000	1.83	0.206	79.4
$I_P * I_P$	1	0.000000	0.000000	3.95	0.075	92.5
$T_{on}*T_{on}$	1	0.000000	0.000000	1.28	0.284	71.6
C*C	1	0.000000	0.000000	0.69	0.425	57.5
Interaction	3	0.000000	0.000000	4.67	0.027	97.3
$I_P * T_{on}$	1	0.000000	0.000000	2.74	0.129	87.1
I_P*C	1	0.000000	0.000000	4.52	0.059	94.1
$T_{on}*C$	1	0.000000	0.000000	6.76	0.027	97.3
Error	10	0.000000	0.000000			
Lack-of-Fit	4	0.000000	0.000000	23.69	0.001	
Pure Error	6	0.000000	0.000000			
Total	19	0.000001				

powder also takes part in the variation of material removal rate and tool wear rate. The p-value for the model in both MRR and TWR is less than 0.05 which means the model is significant. The square terms for MRR and TWR are non-significant while interaction terms are significant for both cases.

The value of R-square for MRR and TWR is 82.10% and 80.73% respectively which means that the regression model provides a good correlation between the input variables- current, pulse on time, powder concentration-and the output responses- material removal rate and tool wear rate respectively.

The main effect plots are also generated using the software which also provides the optimum process parameters and their levels are as shown in Figure 4.

From the main effect plot of MRR, the responses show an increasing trend as current and pulse on-time increases while TWR show an increasing trend for a current while has an inverse phenomenon for the pulse on time and for both MRR and TWR, chromium powder concentration show a decreasing trend. The material removal rate is higher at 10A current with a pulse on time of 200 µs and chromium powder concentration of 2g/l while the tool wear rate is low at 6A current with a pulse on time of 200 µs and chromium powder concentration of 6g/l.

3.3 TOPSIS Optimization

TOPSIS means a technique for order of preference by similarity to ideal solution. In this technique, the criteria selected must be nearest to the best positive solution and must be farthest from the best negative solution. The finest solution is one that is closest to the ideal solution [11, 17]. Material removal rate and tool wear rate for both the powders are optimized by this technique. The steps to implement the TOPSIS technique are:

Step 1- Generation of decision matrix

The decision matrix is the initial step of this technique. The matrix has n number of attributes and m number of alternatives. In this study, there are 2 response variables and 20 runs. Therefore the decision matrix is (20, 2) matrix.

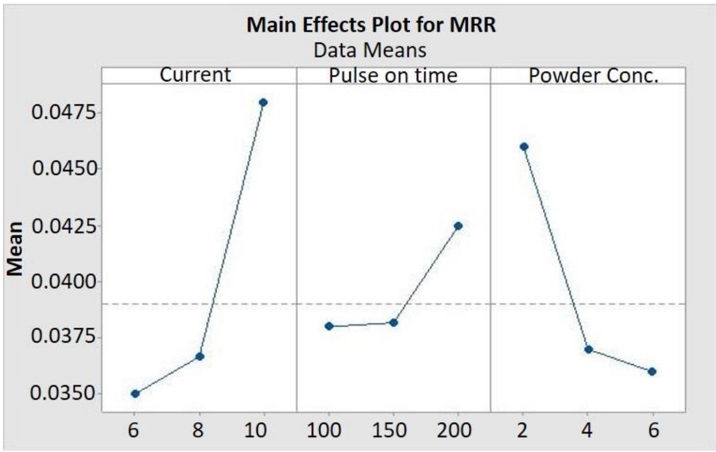
Step 2- Calculate the normalized matrix

In this step, a normalized matrix is generated. The equation to deduce the normalized matrix is as shown in equation 5.

$$\underline{X_{ij}} = X_{ij} / \left(\sqrt{\sum_{j=1}^{n} X_{ij}^2} \right) \quad (5)$$

Step 3-Calculate weighted normalized matrix (Vij)

In this step, the weightage for each variable is decided. In this work, the weightage (Wj) for both MRR and TWR is considered



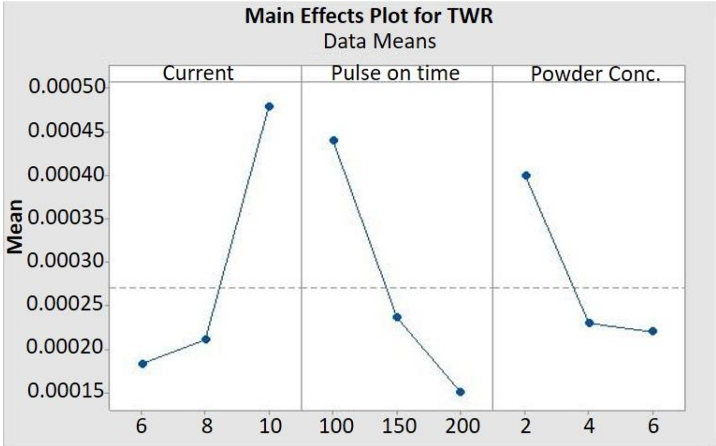


Figure 4 Main effect plots for chromium powder mixed EDM process

as 0.5 as both are equally important. The weighted normalized matrix is calculated by equation 6.

$$V_{ij} = \underline{X_{ij}} \, x \, W_j \quad (6)$$

Step 4- Calculate ideal best (V_j^+) and ideal worst solution (V_j^-)

In this step, the weighted normalized matrix is analyzed and the ideal best (V_j^+), and the ideal worst solution (V_j^-) for both the responses are calculated. The ideal best solution for MRR is the maximum value in the MRR column of the weighted normalized matrix while the minimum value in the column is the ideal worst solution. In the case of TWR, it is exactly the opposite.

Step 5- Calculate Euclidian distance from ideal solutions

In this step, the proximity of the weighted normalized matrix with the ideal solution is calculated and is given as S+ and S-. The value of S+ and S- is given by equation 7 and 8 respectively.

$$S^+ = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^+\right)^2} \quad (7)$$

$$S^- = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^-\right)^2} \quad (8)$$

Step 6- Calculate Performance score and rank

In this step, the performance score is calculated. The performance score decides the rank. Higher the performance score, the lower is the rank. It is given by equation 9.

$$P = S^- / (S^+ + S^-) \quad (9)$$

The TOPSIS optimization table for silicon and chromium powder-mixed EDM process is mentioned in Table 7.

The optimum condition for silicon powder-mixed EDM is run no. 2 where current is 8A, pulse on time is 150 µs and Si powder concentration of 2g/l.

The optimum condition for chromium powder mixed EDM is run no. 3 where the current is 10A, pulse on time is 200 µs and Cr powder concentration of 2g/l.

The confirmatory results are conducted and results are mentioned in Table 8.

From the confirmation results, the MRR of the Si PMEDM process is less or has decreased by 16.7% which is very low. The TWR for Si PMEDM and MRR for Cr PMEDM remained constant. The TWR of Cr PMEDM is decreased by 50% which is a positive case. Hence, the results confirm the optimum condition.

3.4 Comparative analysis

A comparative study is conducted for both silicon and chromium powder. The response variable considered for comparison is the electrode wear ratio as it provides a ratio between tool wear to material removal. The lower the electrode wear ratio, the better it is. The electrode wear ratio for silicon and chromium powder is mentioned in Table 9.

The graphical representation of the electrode wear ratio and the comparison of minimum and average electrode wear ratio is also provided in Figure 5. Chromium powder-mixed EDM process provides a low electrode wear ratio apart from one high peak which has an electrode wear ratio of 0.03. The minimum and average electrode wear ratio will provide a brief comparison of both powder-mixed EDM process.

The minimum electrode wear ratio for silicon and chromium powder-mixed EDM process is 0.0050 and 0.0025 respectively while the average values for silicon and chromium powder-mixed

Table 7 TOPSIS Optimization chart for silicon and chromium PMEDM process

Run Order	Si PMEDM		Cr PMEDM	
	P	Rank	P	Rank
1	1.16149	10	4.46946	10
2	3.06426	1	5.28451	5
3	1.35275	7	10.9441	1
4	1.4603	4	0.21497	20
5	1.18524	9	5.13903	8
6	1.4603	4	5.28451	5
7	2.11434	2	2.98839	17
8	0.77921	19	3.82783	14
9	1.26862	8	1.49623	19
10	1.05421	15	4.46946	9
11	1.12779	11	5.28451	7
12	1.4603	4	8.04803	3
13	1.04751	17	3.82783	11
14	1.08576	13	3.82783	14
15	0.81139	18	6.59731	4
16	1.06066	14	10.9441	1
17	1.79822	3	3.82783	11
18	0.5847	20	2.60204	18
19	1.12779	11	3.4261	16
20	1.05421	15	3.82783	11

Table 8 Confirmation results

		Optimum value	Confirmation results	Error %
Si PMEDM	MRR	0.06	0.05	16.70
	TWR	0.0003	0.0003	0.00
Cr PMEDM	MRR	0.06	0.06	0.00
	TWR	0.0002	0.0001	50.00

Table 9 Electrode wear ratio for silicon and chromium powder mixed EDM process

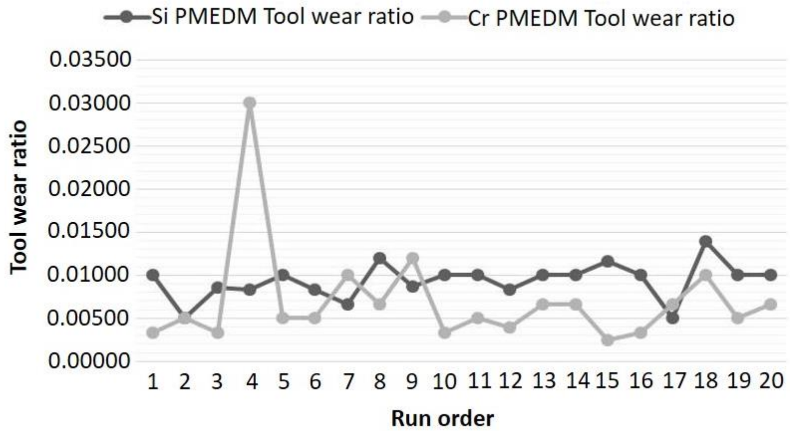
Run Order	Current (A)	Pulse on time (µs)	Powder Conc. (g/l)	Si PMEDM Electrode wear ratio	Cr PMEDM Electrode wear ratio
1	6	200	2	0.01000	0.00333
2	8	150	2	0.00500	0.00500
3	10	200	2	0.00857	0.00333
4	10	100	2	0.00833	0.03000
5	6	100	2	0.01000	0.00500
6	8	150	4	0.00833	0.00500
7	8	100	4	0.00667	0.01000
8	8	150	4	0.01200	0.00667
9	10	150	4	0.00875	0.01200
10	8	150	4	0.01000	0.00333
11	6	150	4	0.01000	0.00500
12	8	150	4	0.00833	0.00400
13	8	200	4	0.01000	0.00667
14	8	150	4	0.01000	0.00667
15	8	150	4	0.01167	0.00250
16	10	200	6	0.01000	0.00333
17	6	100	6	0.00500	0.00667
18	8	150	6	0.01400	0.01000
19	6	200	6	0.01000	0.00500
20	10	100	6	0.01000	0.00667

EDM process are 0.0093 and 0.0070 respectively. The minimum electrode wear ratio and average electrode wear ratio is lower for chromium powder-mixed EDM process.

4. Conclusions

The present investigation proves that there is an increase in the material removal rate while the tool wear rate and electrode wear ratio decrease due to the addition of silicon and chromium powder to the dielectric fluid. The response variables are optimized by the variables by Response Surface Methodology and TOPSIS approach. The experiments are conducted by varying the input variables such as current, pulse on time, and powder concentration. Analysis of variance and main effect plots are generated. The result findings are as follows:

- Current and pulse on time are the most significant factors with the significance of more than 95%.
- Powder concentration has a significance of more than 80% and hence it can be inferred that silicon and chromium powder-mixed in the dielectric fluid has a major part in a variation of MRR and TWR.
- For the silicon powder mixed EDM process, MRR is higher for a current of 10A, pulse on time of 200 µs and powder concentration of 4g/l while TWR is lower at a



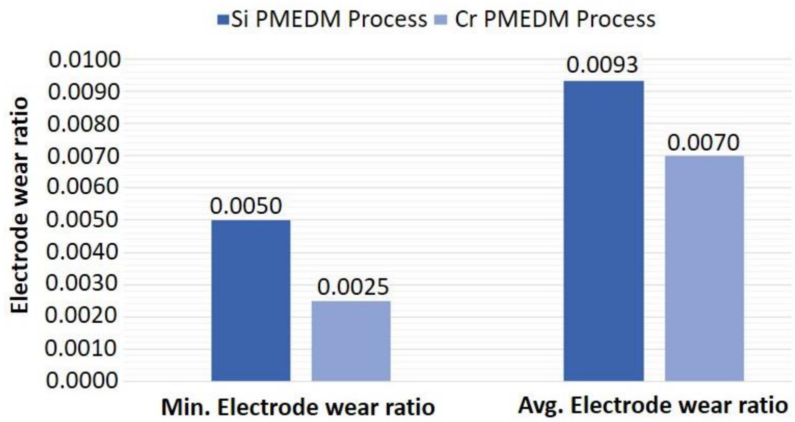


Figure 5 Electrode wear ratio for silicon and chromium powder mixed EDM process

current of 6A, Pulse on time of 100 µs and powder concentration of 2g/l.

- For chromium powder-mixed EDM process, MRR is higher for a current of 10A, pulse on time of 200 µs and powder concentration of 2g/l while TWR is lower at a current of 6A, Pulse on time of 200 µs and powder concentration of 6g/l.

The optimum values of the input variables using the TOPSIS technique are as follows:

- For the Silicon powder-mixed EDM process, run no. 2 is optimum where current is 8A, Pulse on time is 150 µs and Si powder concentration of 2g/l. The value of MRR and TWR at the optimum level is 0.06 g/min and 0.0003 g/min respectively.
- For Chromium powder-mixed EDM process, run no. 3 is optimum where current is 10A, Pulse on time is 200 µs and Si powder concentration of 2g/l. The value of MRR and TWR at the optimum level is 0.06 g/min and 0.0002 g/min respectively.
- Confirmation experiments validate the optimum values of MRR and TWR.

A comparative study is conducted by considering the electrode wear ratio as response variables. The minimum and average electrode wear ratio for silicon and chromium powder are calculated. The minimum and average values for the silicon powder-mixed process are 0.0050 and 0.0093 respectively while for chromium powder-mixed process, the minimum and average values are 0.0025 and 0.0070 respectively. The electrode wear ratio for chromium powder-mixed EDM process is lower than that of the silicon powder mixed EDM process.

From this complete study, it can be inferred that both powders play a significant role in the variation of MRR and TWR. Also, chromium powder-mixed EDM process has better effects on responses than silicon powder mixed EDM process.

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