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Response surface Methodology and Desirability Approach to Optimize EDM Parameters

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Abstract

In the present work, Electrical discharge machining (EDM) was employed along with silicon abrasive powders mixed in dielectric fluid to machine AISI 52100 tool steel workpiece with copper electrode by adopting centered central composite (CCD) design of response surface methodology. To realize the process performance of material removal rate and surface roughness variables such as Pulse on time, duty cycle, peak current and the Silicon powder concentration with particle concentration and size of 2.5–2.8 g/L and 45–50μm, respectively, have been added into the kerosene dielectric liquid of a die-sinking electrical discharge machine. Analysis of variance (ANOVA) has been applied to study the influence of process parameters and their interactions. In addition a mathematical model has been formulated in order to estimate the process performance. Further, the parameters were optimized for maximizing MRR and minimizing SR using desirability function approach. The optimum settings of parameters are pulse on time 200μs, duty cycle 0.81, peak current 11A, concentration 4 g/l, for maximizing MRR and minimizing SR.The recommended optimal process conditions have been verified by conducting confirmation experiments. The obtained optimal settings are experimentally verified showing +5.2% and -4.65% as the relative errors for MRR and SR respectively.

Keywords: *Powder mixed EDM; RSM, Material removal rate MRR, Surface roughness SR*

1. Introduction

With the development of technology and industrial growth there is a growing trend to use light, slim and compact mechanical components in recent years; hence there has been an increased interest in the advance materials. The modern manufacturing industries are encountering difficulties from these advanced materials (super alloys, ceramics, and composites) that are hard, difficult to machine, requiring greater precision and surface finish which increases cost of machining.EDM has been a pillared manufacturing process providing peculiar capabilities to work “difficult to machine” raw materials with desired shape, size and dimensional accuracy. However, the drawbacks of the process include low surface quality and poor material removal rate [1]. Since the practical inception of EDM in the early 1940s, many efforts have been made towards improvising its efficiency, stability, and productivity [2]. To improve EDM process performance, stability and accuracy the use of planetary EDM[3], vibro-rotary EDM[4], rotation of work piece, combination of EDM with ultrasonic machining and magnetic force[5,6] are some typically implemented techniques. In the recent times, the powder mixed EDM (PMEDM) is emerged as one of the advanced techniques in the view of the enhancement of the performance of EDM process. In this process, a material in fine powdered form (Aluminum, copper, graphite or silicon carbide etc.) is added into the dielectric fluid of EDM [7-9].

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2. Literature Review.

Erden and Bilgin first studied the process of PMEDM[10] in 1980. They observed the effects of copper, aluminum, iron and carbon powder additives in dielectric fluid and reported decrease in ignition delay times and increase in removal rates due to the powder concentration in gap space and decrease in the insulating strength of dielectric. Thereafter, Jeswani [8] found that by adding of 4 g/L of graphite powder in kerosene oil will increase material removal rate (MRR) by 60%. Ming and He [11] examined the effects of few kinds of conductive and inorganic oxide solid particles and lipophilic surface agents mixed in dielectric fluid on MRR and the quality of EDMed surface components. The conditions of getting near mirror finish in PMEDM using C, Si, Al, SiC, MoS_2, and crushed glass as powder additives in dielectric under controlled machining states was studied by Wong et al. [12] . Chow et al. [13] experimented on micro-slit machining of Ti alloy with Al and SiC powder mixed in kerosene. They suggested that SiC powder can reach more metal removal rate than Al powder mixed to the kerosene. The effects of different powder characteristics on the efficiency of EDM on mould steel SKD-11 work pieces studied by Tzeng and Lee [14]. They stated that 70–80 nm powders showed the higher MRR, followed by 10–15μm, with 100μm producing the lower MRR.Kansal et al. [15] studied the effect of silicon powder added into the dielectric fluid of EDM on machining parameters of AISI D2 die steel. Concentration of powder and peak current were found to be most substantial characteristics for material removal. High MRR was accomplished at high concentration of 4 g/l and high Peak current of 10Amps. Ojha et al. [16] experimentally discovered MRR and EWR in PMEDM process with Chromium powder suspended dielectric. It was resolved that MRR showed an increasing tendency for increase in powder concentration.

The literature survey finds many applications to increase metal removal rate and surface finish, but very few researchers have reported on the use of silicon powder mixed in dielectric of EDM machining. To understand more consistently, its beneficial effects and proper selection of PMEDM parameters, this paper exhibits a different approach utilizing RSM and desirability approach.

3. Powder Mixed EDM Process

The line diagram of an experimental setup for PMEDM is shown in Figure 1. A special tank was fabricated and placed inside the main tank so that the silicon powder does not enter into main dielectric sump which may otherwise block the filtration system. The tank is attached with a stirrer to maintain uniform concentration and also to prevent the settling of powder throughout the experimentation. The dielectric tank is also equipped with a circulation pump for proper flushing. The modified circulation and stirring system are designed in such a way that, it can be employed at the commercial level. In this system the pump and the stirrer are employed in the same tank within which machining is

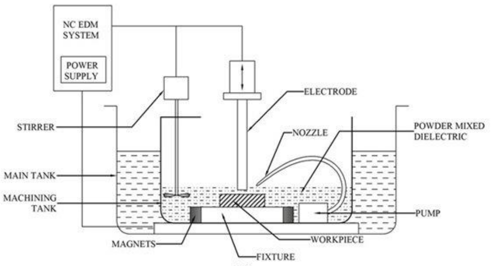

Figure1. Schematic diagram of experimental setup

performed. Powder mixed electrical discharge machining (PMEDM) is one among the new invention for the enhancement of credentials of electric discharge machining process [1].

4. Experimental detail

EZNC die sinking EDM machine manufactured by Electronic machine tools ltd. India was used to conduct experiments. The dielectric fluid selected for usage is kerosene. Silicon fine abrasive powders with size between 45-50µm were added into the kerosene dielectric of a die-sinking electrical discharge machine. Each machining run is performed for duration of 50 min. The experiment has been performed with positive polarity as recommended in [1]. In this study, AISI 52100 tool steel was selected as the work piece Copper electrode with diameter 25 mm has been used to machine the workpiece.

5. Powder mixed EDM process parameters.

The preliminary experiments are conducted by using one variable at a time approach, which means that the values of one parameter are varied at a time and other kept constant. Based on number of preliminary experiments performed, the values and ranges of these four parameters were chosen. They are: Pulse on time, *A*; Duty cycle, *B*; Peak current, *C*; Concentration of the added silicon powder, D. The levels of various parameters and their respective designations are given in Table 1. The response parameter in the current study was MRR and surface roughness (SR).

Table 1:Design scheme of process parameters and their levels.

Factor		Levels	Levels
Symbol	Parameter	Low(-1)	High(+1)
A	Pulse on time, Ton(µs)	100	200
B	Duty cycle, DC	0.7	0.9
C	Peak current, Ip(A)	5	11
D	Concentration, Conc(g/l)	0	4

6. Response surface methodology

Response Surface Method (RSM) is a collection of mathematical and statistical tools which are useful for the modeling and analysis of problems in which an output response of interest is influenced by several input variables and our objective is to optimize the response [18].RSM provides significant information relatively from a small number of experiments and has been effectively applied to study and optimize the process. Adding to that, it is possible to measure the interaction effect of the independent input parameters on the output responses. Furthermore, the empirical model is used to obtain information about the responses in relation to independent variables. In the EDM process, as several machining factors are associated, therefore, RSM can be an appropriate approach to analyze the process and its performance.
For n number of measurable input variables, the response surface can be given as

$$Y = f(X_1, X_2, X_3, X_4 \dots X_n) + \varepsilon \qquad (1)$$

Where X_1, $X_2 \dots X_n$ are the independent input parameters and ε is the random error. Y is the output or response variable which has to be optimized and f is the response function. By plotting the expected response of Y, a surface known as response surface is obtained. The form of *f* is unknown and is very complicated. Thus, RSM aims at approximating the response function by a suitable lower ordered polynomial in some region of the independent process variables. However, if a curvature appears in the system, then a higher order polynomial such as the quadratic model may be used as follows

$$Y = C_0 + \sum_{i=1}^{n} C_i X_n + \sum_{i=1}^{n} d_i X_i^2 \pm \varepsilon \qquad (2)$$

In general, a second-order polynomial response surface mathematical model is used to analyze the parametric influences of the parameters on the various response criteria when the response function is not known or non-linear. The quadratic model given is generally utilized in RSM problems .The objective of using RSM is not only to investigate the response over the entire factor space, but also to locate the region of interest where the response reaches its optimum or near optimal value. By studying carefully the response surface model, the combination of factors, which gives the best response, can then be established.

7. Experimental plan

The PMEDM process was studied with a standard RSM design called central composite design (CCD) [19] which is an effective alternative to the factorial design. Face-centered CCD scheme, a popular variant of the central composite design involving three levels for each factor was used to plan the experiments. It is one of the most effective second-order designs capable of handling linear, quadratic and interaction terms in process modeling. The location of the axial points in a response surface central composite design with respect to the center point (the origin) is determined by alpha value. In face-centered central composite design, α = 1, which means a three-level design space, coded as −1, 0, and 1 representing low, medium, and high factor level, respectively. The factorial portion of CCD is a full factorial design with all combination of the factors at two levels (high, +1 and low, −1), and composed of eight star points, and six central points (coded level 0), which is the midpoint between the high and low levels, corresponds to α=1. The "face-centered CCD" involves 30 experimental observations at four independent input variables.The'DesignExpert 8.0.7.1 software version was used for regression and graphical analysis of the data obtained [20]. The optimum values of the selected variables were obtained by solving the regression equation and by analyzing the response surface contour plots [21].

8. Results and discussions

The machining performance criteria selected for this study were based on performance characteristics such as material removal rate (MRR) and surface roughness (SR).The material removal rate have been calculated by weight difference of the work material and the electrode before and after machining using a digital weighing scale (maximum capacity 1000g, precision .001g) MRR = $(W_i - W_f)$/(t × ρ) Where, W_i= initial weight of material.W_f = final weight of material after experiment. and t is machining time ρ = density of material = 7.8 kg/m^3.The average surface roughness value Ra (μm) was chosen to assess the surface finish quality. The 30 experiments were conducted on EDM and the average values of MRR and SR were tabulated in Table 2.

Table 2. Design of Experimental matrix and results for the PMEDM performance characteristics.

S.no	Pulse-on time T_{on} , A	Duty cycle DC, B	Peak Current I_p, C	Conc. D	MRR mm^3/min	SR (µm)
1	100	0.7	5	0	2.564	2.32
2	200	0.7	5	0	2.786	2.19
3	100	0.7	11	0	2.187	2.37
4	200	0.7	11	0	2.41	2.19
5	100	0.9	5	0	21.876	6.87
6	200	0.9	5	0	23.941	7.8
7	100	0.9	11	0	22.7	7.75
8	200	0.9	11	0	25.232	6.8
9	100	0.7	5	4	2.956	2.27
10	200	0.7	5	4	3.792	1.39
11	100	0.7	11	4	3.067	4.18
12	200	0.7	11	4	3.193	1.41
13	100	0.9	5	4	27.348	5.57
14	200	0.9	5	4	28.301	5.19
15	100	0.9	11	4	26.254	5.19
16	200	0.9	11	4	29.894	5.19
17	100	0.8	8	2	5.245	5.75
18	200	0.8	8	2	8.2	7.02
19	150	0.8	5	2	7.157	6.08
20	150	0.8	11	2	6.845	6.47
21	150	0.7	8	2	2.284	1.85
22	150	0.9	8	2	26.01	6.04
23	150	0.8	8	0	7.35	6.86
24	150	0.8	8	4	8.859	4.83
25	150	0.8	8	2	5.652	6.44
26	150	0.8	8	2	7.452	6
27	150	0.8	8	2	6.99	6.85
28	150	0.8	8	2	7.96	6.24
29	150	0.8	8	2	6.385	6.2
30	150	0.8	8	2	8.069	6.03

Probability (p values) was used to check the significance of the coefficients, which are essential to recognize the trends of the related interactions between the test variables [21]. The smaller value of the probability reveals a very significant correlation coefficient. The significance of the coefficient was tested by a t test with the confidence of 95 %. The excellence of the fit of the model equation was articulated by the coefficient of determination (R^2), and its statistical significance was checked by an F test. Regression analysis is used to build the statistical models with the variable of interest and the EDM process characteristics. These models are also used as objective functions for the optimization problems. Response surface plots were produced and are used to investigate the surfaces and locate the optimum condition and subsequently, confirmation experiments were accompanied to verify the validity of the statistical experimental strategies. Analysis of variance (ANOVA) is performed for these purposes.

8.1 Mathematical modeling and Analysis of material removal rate

Based on the quadratic model depicted in Eq.2, the results in the form of ANOVA are given in Table 3. The fit summary suggested that the model is statistically meaningful for analysis of MRR. When R^2 approaches unity, there exists less difference between the actual and predicted data. Further, the adequate precision (AP) value which relates the range of the fore casted value to the average prediction error is far greater than 4.

The values obtained are as follows: R^2 = 0.9956 and AP= 76.399 for MRR. Also the values of R^2 and adjusted R^2 is over 99% which conveys that the regression model gives a fine explanation of the relationship between the independent input variables and the output responses (MRR). The respective p-value for the model is greatly less than 0.05 (i.e. $\alpha = 0.05$ or 95% confidence) which indicates that the model is measured to be statistically significant [21]. Moreover, the lack-of-fit term is non significant having a *p* value higher than 0.05 as it is desired. Further, it is seen that the individual factors A (pulse on time), C (peak current), D (concentration of silicon powder), interaction effect of factor A (pulse on time) with factor C (peak current), interaction effect of factor C (peak current) with factor D (concentration) and second order term of factor C(peak current) have significant effect. The significance of parameters are based on the *p* value, the lower the value of *p* the more is the significance of parameter. This results shows MRR is enhanced by adding powder into the dielectric fluid [1,8]. The other terms are said to be non-significant.

Table 3.ANOVA table for MRR

Source	**Sum of quares**	**DOF**	**Mean square**	**F-Value**	**Prob> F**
Model	2782.79	6	463.80	870.13	<0.0001(Significant)
A	10.20	1	10.20	19.14	0.0002
C	2364.82	1	2364.82	4436.63	<0.0001
D	28.42	1	28.42	53.32	<0.0001
AC	3.79	1	3.79	7.10	0.0138
CD	14.04	1	14.04	26.34	<0.0001
C^2	361.53	1	361.53	678.26	<0.0001
Residual	12.26	23	0.53		
Lack of fit	7.84	18	0.44	0.49	0.87739 (non- significant)
Pure error	4.42	5	0.88		
Cor. Total	2795.05	29	-------		
Std.dev	0.73		R^2	0.9956	
Mean	11.43		R^2 –adjusted	0.9945	
C.V %	6.39		R^2-predicted	0.9931	
PRESS	19.41		Adeq.Precision	76.399	

Final Equation in Terms of Coded Factors:

$$MRR = +7.18 +0.75* A +11.46 * C +1.26 * D +0.49 * A * C +0.94 * C * D +7.09* C^2 \qquad (3)$$

The discharge energy was found to be smaller for low values of peak current, hence lower MRR was associated with low discharge energy into the machining area. Opposing, the higher the peak current, higher is the discharge energy, hence deeper cavity was formed making the debris harder to expel from the machining zone This causes short-circuit disturbing the electrical discharge, resulting in low MRR. Hence optimal value of pulse current is necessary to achieve maximum MRR.

Figure 3 depicts the 3D surface of estimated MRR response with respect to peak current and pulse on time. From this figure, it shows the MRR tends to increase steadily with increase in both peak current and pulse on time. This is due to the fact that increasing both current and pulse on time results in more discharge of energy in the machining gap, causing removal of more material from the work piece within a short duration. Hence, maximum MRR is obtained at high peak current (11 A) and high pulse on time (200s). However, at low range of peak current (3–5 A), maximum MRR is obtained at 150s pulse on time.

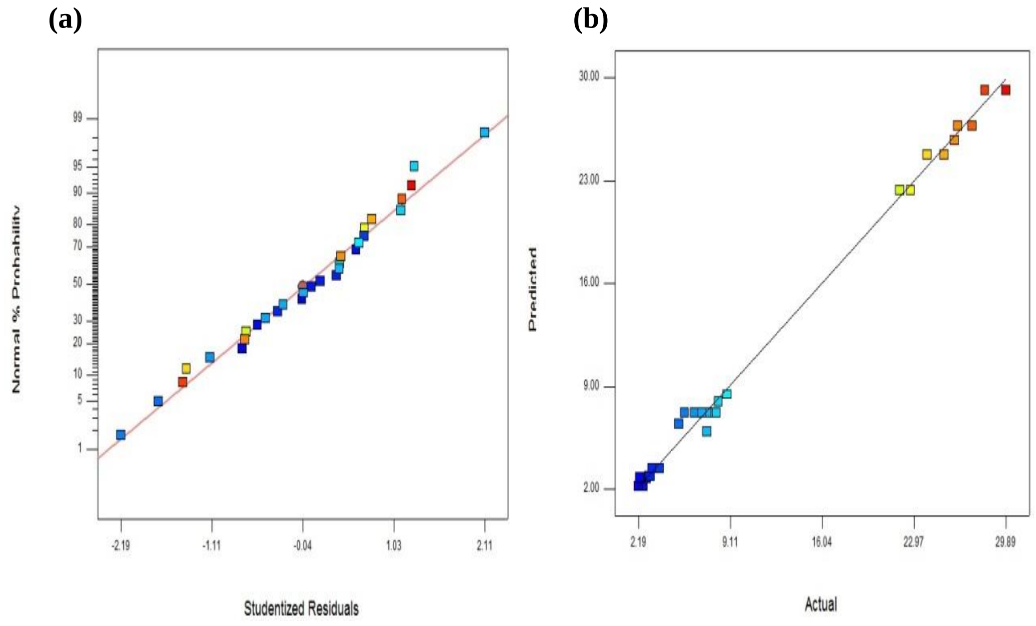

Figure 2. Plot of residuals for the MRR
(a) Normal probability plot of residuals
(b) Predicted vs observed values

The effect of peak current and concentration on MRR at constant level of pulse-on time is displayed in Figure 4. This figure shows that the value of MRR increases significantly with increase in peak current. The reason is due to their dominant control over input energy. The effect of concentration of powder added on MRR can be also represented from this figure. With increase in concentration of the powder, the MRR tends to increase. The maximum MRR is obtained at highest level of concentration of added silicon powder (4 g/l) and peak current (11 A). This is because the added additive causes bridging effect between the electrodes, facilitates the dispersion of discharge into several increments and hence increases the MRR.

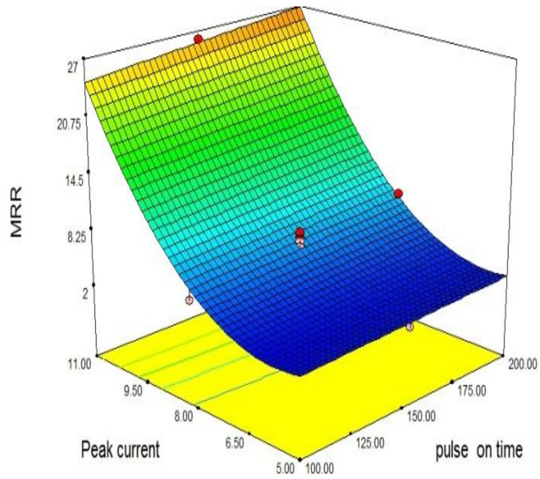

Figure 3.Effect of peak current and pulse on time on MRR

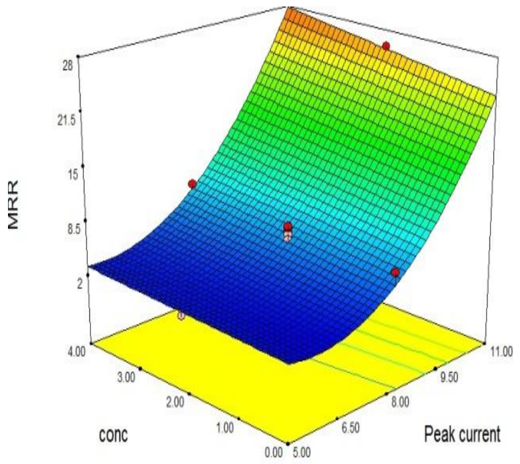

Figure 4.Effect of peak current and conc. on MRR

8.2 Mathematical modeling and Analysis of surface roughness

Based on the quadratic model depicted in Eq.3, the results in the form of ANOVA are given in Table 4. The fit summary suggested that the model is statistically meaningful for analysis of SR. The adequate precision (AP) value greater than 4 in MRR.

Table 4. ANOVA table for SR

Source	*Sum of squares*	*DOF*	*Mean square*	*F-Value*	*Prob> F*
Model	110.81	4	27.70	80.13	<0.0001
C	72.92	1	72.92	210.95	<0.0001
D	5.48	1	5.48	15.85	0.0005
CD	4.26	1	4.26	12.34	0.0017
C^2	28.14	1	28.14	81.40	<0.0001
Residual	8.64	25	0.35		
Lack of fit	8.14	20	0.41	4.09	0.062 (notsignificant)
Pure error	0.50	5	0.1		
Cor. total	119.45	29			
Std.dev	0.59		R^2	0.9276	
Mean	5.04		R^2 –adjusted	0.9161	
C.V %	11.65		R^2-predicted	0.8870	
PRES	13.50		Adeq. Precision	21.368	

The values obtained are as follows: R^2 = 0.9276 and AP= 21.368 for SR. Also the values of R^2 and adjusted R^2 is over 99% which conveys that the regression model gives a nice explanation of the relationship between the independent input variables and the output responses (SR). The respective p-value for the model is greatly less than 0.05 (i.e. α = 0.05 or 95% confidence) which indicates that the model is measured to be statistically significant [21]. Moreover, the lack-of-fit term is non significant having a *p* value higher than 0.05 as it is desired. Further, it is seen that the individual C (peak current), D (concentration of silicon powder), interaction effect of factor C (peak current) with factor D (concentration) and second order term of factor C (peak current) have significant effect. The significance of parameters are based on the *p* value, the lower the value of *p* the more is the significance of parameter. This results shows SR is enhanced by adding powder into the dielectric fluid [7]. The other terms are said to be non-significant.

For checking the quality of fit for generated SR response, a full residual analysis has been done. Figure 5(a) exposes the normal probability plot of the residuals for SR. It is evident that the residuals well distributed on a straight line, which means that the errors are evenly distributed showing a good correlation between experimental and predicted values. To check whether the regression model is fairly well fitted with the observed values, each observed value is compared with predicted value and represented in the form of a graph as shown in Figure 5(b). The final response equation for SR is given as follows:

Final Equation in Terms of Coded Factors:

$$SR = 6.23 + 2.01 * C - 0.55 * D - 0.52 * C * D - 1.98 * C^2 \qquad (4)$$

Figure 6 depicts the 3D surface of estimated SR response with respect to peak current and pulse on time. As can be deduced from this figure, the SR tends to increase significantly up to 9A peak current of nearly 9A. Above 9A, the SR is found to be decreased for any value of pulse on time. However, at low value of peak current (5 A), minimum SR is obtained at 100µs pulse on time as can be seen from figure 7.

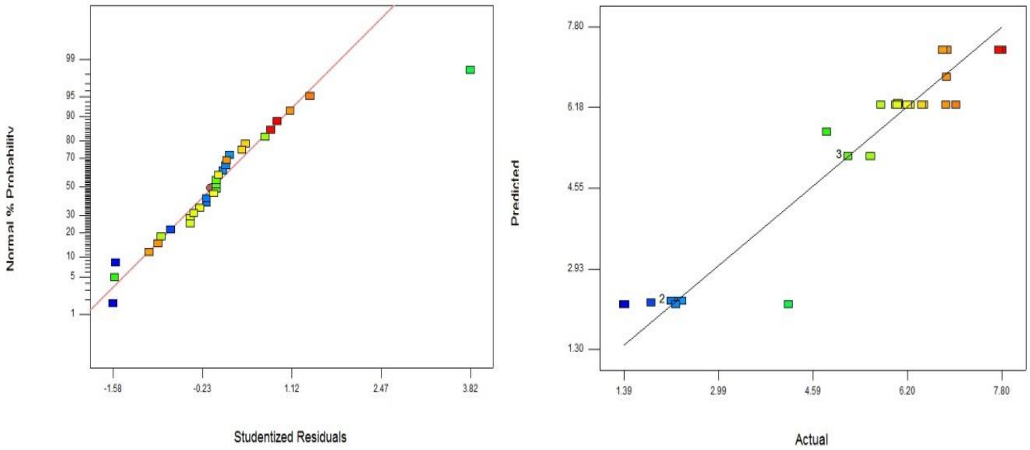

Figure 5. Plot of residuals for the SR
(a) Normal probability plot of residuals
(b) Predicted vs observed values

The effect of peak current and concentration on SR at constant level of pulse-on time is displayed in figure 7. This figure shows that the value of SR increases significantly with increase in peak current up to its maximum level. But it is found to be decreasing for increased levels of powder added showing that the good surface finish can be obtained at low values of peak current (5A) and high concentration of powder added (4g/l). The reason is due to their dominant control over input energy. The effect of concentration of powder added on SR can be also represented from this figure. With increase in concentration of the powder, the SR tends to increase. The maximum SR is obtained at highest level of concentration of added silicon powder (4 g/l) and peak current (11 A). In both the cases it is evident that more concentration of powder added into dielectric fluid is necessary for obtaining uniform surfaces. This is due to the fact that the added powder modifies the plasma channel, enlarging it producing steady and consistent sparks forming shallow craters on the work piece surface with better surface quality.

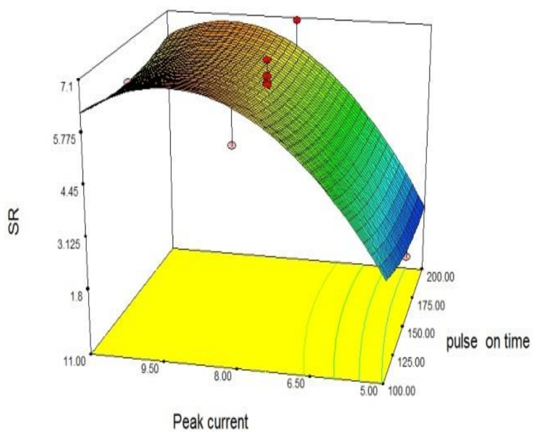

Figure 6.Effect of peak current and pulse on time on MRR

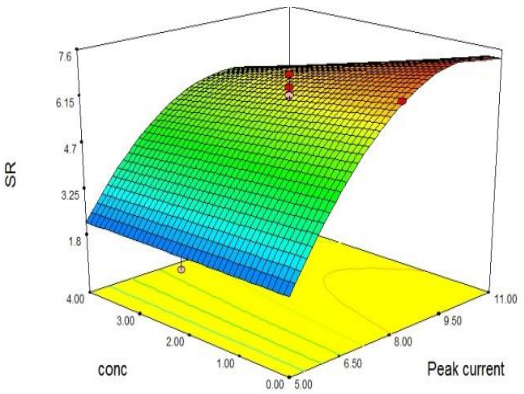

Figure 7.Effect of peak current and conc. on MRR

9. Multi Response Optimization

Derringer and Suich [22] described a useful method for optimization of multiple quality characteristic problems. An objective function D(X) called desirability function is used and the estimated response is transformed into a scale free value (d_i) called desirability ranging from 0 to 1 and completely dependent on closeness to the lower and upper limits. If the desirability value shows 1 it represents the ideal case; 0 indicates the one or more responses are being outside their acceptable limits. Depending on whether a particular response is to be maximized or minimized or assigned to a target value, various desirability functions can be used.

If the objective or target T_i for the response y_i is a maximum value, then

$$d_i = \begin{cases} 0 & y_i < L_i \\ \left(\frac{y_i - L_i}{T_i - L_i}\right)^r & L_i \leq y_i \leq T_i \\ 1 & y_i > T_i \end{cases}$$

And if the target for the response is a minimum value, then

$$d_i = \begin{cases} 1 & y_i < T_i \\ \left(\frac{U_i - y_i}{U_i - T_i}\right)^r & T_i \leq y_i \leq U_i \\ 0 & y_i > U_i \end{cases}$$

Where $L_i$and U_i represent the lower and upper limit values of the response y_i, respectively.

Composite desirability (CD) is the weighted geometric mean of the individual desirability of the responses [24] given by:

$$\text{CD} = (d_1 d_2 d_3 \ldots\ldots\ldots\ldots\ldots\ldots d_n)^{1/m}$$

The optimal parameter conditions are those with factor settings with maximum total desirability (TD).The objective function simultaneous is a geometric mean of all transformed responses. Based on composite desirability optimization technique, design expert software is used to evaluate the combination. MRR and SR have been optimized using developed models. In this Multi Response Optimization (MRO), a measure of how solution has satisfied the required aims for all the responses must be checked .The optimal solution is to evaluate the input parameters in the process range for maximizing MRR and minimizing both SR. The values of optimum parameters combination and predicted values of responses have been tabulated in tables 7 and 8 respectively.

Table 4. Range of parameters and responses for desirability

Process Parameter	**Goal**	**Lower limit**	**Upper limit**	**Importance**
Pulse on time	is in range	100	200	3
Duty cycle	is in range	0.7	0.9	3
Peak current	is in range	5	11	3
Concentration	is in range	0	4	3
MRR	Maximize	2.187	29.894	3
SR	Minimize	1.39	7.8	3

Table 5. Optimum values silicon powder mixed EDM

Process Parameter	**Goal**	**Optimum value**
Pulse on time	is in range	200
Duty cycle	is in range	0.81
Peak current	is in range	11
Concentration	is in range	4

Table 6. Predicted and observed value of PMEDM process

Response	Goal	Predicted	Observed	Error(%)
MRR	Maximize	29.160	30.676	+5.2%
SR	Minimize	5.198	4.956	-4.65%

A set of thirty optimal combination for solution is derived for the design space constraints for MRR and SR using Design Expert software. The set of conditions with the highest desirability value is considered as optimum combination for the required responses. The optimal combinations with higher desirability functions are given in Table 4.

Experiments are performed and verification should be done on the EDM above the optimal input parameter combination for MRR and SR compared with optimal response values (Table 5).From the analysis, it is observed that the error is small. Obviously, this shows perfect reproducibility of the experiment conclusions. The ramp functions graph and bar graph (Figures 8 and 9) shows the desirability for o/p responses. The dot on each ramp indicates the factor setting (or) response prediction for that response characteristic. The height of the dot reflects how much desirable it is. A linear ramp functions is created between lower value and the required value (or) the higher value and the required value as the weight for each parameter is set equal to 1. The bar graph indicates the overall desirability of the responses. The optimal region values has the overall desirability value of 0.629 indicating closeness to target response.

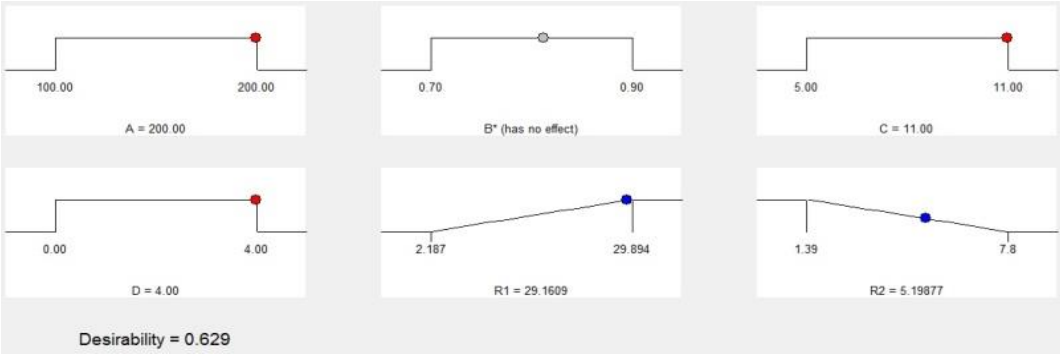

Figure 8. Ramp function graph of desirability

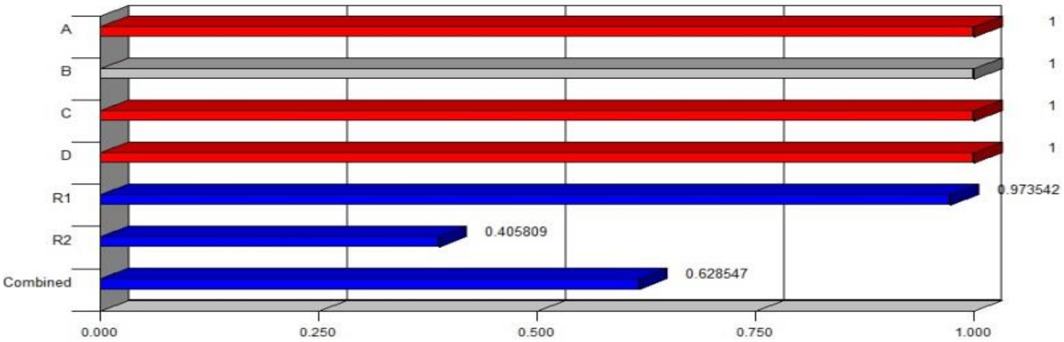

Figure 9. Bar graph of desirability

9. Conclusions

Application of response surface methodology (RSM) and desirability approach (DA) to improve the multi performance characteristics of MRR and SR in silicon PMEDM have been reported in this paper. The following are the research findings :

1. Both MRR and SR have been affected by the suspension of silicon powder in the dielectric fluid of EDM. It is found that MRR increases with increase in the concentration of the silicon powder. There is noticeable improvement in surface roughness (SR) due to the suspension of the silicon powder. As a result, more enhancements in MRR and SR is projected at still higher concentration level of silicon powder.
2. The predicted values match the experimental values reasonably well with R^2 of MRR and SR.
3. The ANOVA revealed the most influential parameters on MRR and SR are factor *C* (peak current) and factor *D* (concentration). The quadratic term of factor *C* (peak current) also have considerable effect. The factors *C* (peak current) and *D* (concentration) interact with each other. The combination of high peak current and high concentration yields more MRR and smaller SR.
4. The usage of desirability function based approach has been proved efficient in locating optimal machining conditions. The optimum settings of parameters are pulse on time 200μs, duty cycle 0.81, peak current 11A, concentration 4 g/l, for maximizing MRR and minimizing SR.
5. The obtained optimal settings are experimentally verified showing +5.2% and -4.65% as the relative errors for MRR and SR respectively.

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