International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 8, August-2014, pp: (291-303), Impact Factor: 1.252, Available online at: www.erpublications.com

Optimization of Powder Mixed Electric Discharge Machining using ASTM A-105 Steel by Response Surface Methodology

Sukhvir Singh[1], Jujhar Singh[2]

[1,2]Dept. of Mechanical Engineering, Rayat-Bahra Institute of Engineering & Bio-Technology,
Kharar, Distt. Mohali, Punjab, India

Abstract: The objective of this paper is to study the effect of the various process parameters i.e. peak current, no-load voltage, pulse on time and duty cycle on response parameters by mixing silicon powder in the dielectric fluid of the Electric Discharge Machining (EDM). Response surface methodology (RSM) is used for investigating the effect on these parameters. Central composite design (CCD) is used for the estimation of the model coefficients of five factors, which are believed to influence the material removal rate (MRR) and tool wear rate (TWR) in powder mixed EDM (PMEDM) process. Experiments are conducted by using ASTM A-105 steel. The separable influence of individual machining parameters and the interaction between these parameters are also investigated by using analysis of variance (ANOVA). It is found that powder concentration along with peak current, no-load voltage, pulse-on time and duty cycle have significant effect on MRR and TWR.

Keywords: Central Composite Design (CCD), Powder Mixed EDM (PMEDM), RSM, MRR, TWR, ASTM A-105.

Introduction

It is an essential requirement in today world to use material, which provides high strength. Some advance materials provide high strength, but these materials are very hard in nature. The problem is not only to machine these hard materials but is also to make complex shape parts from these materials. This hardness of material and complex shapes of parts reduces the machinability of these material on convectional and as well as on some advance machines. To get rid from this machining problem, Electric Discharge Machining (EDM) was invented. EDM works on the principle of spark erosion, which removes the material by eroding the work piece. The main equipments of the Electric Discharge Machine are D.C. supply unit, EDM circuit, servomechanism, dielectric unit. There is a gap between the tool (electrode) and the work piece, which is known as spark gap. To complete the circuit the current is passed through the tool and the work piece through dielectric fluid. The current tends to break the dielectric fluid into ions, which start moving from work piece to tool. The movement of ions and electrons between tool and work piece occurs at such a high speed that it seems as a spark.

This transfer of ions and electrons increases the temperature, which melts the work piece. The spark melts a small material volume on each of the electrodes. The dielectric fluid that fills the gap between the electrodes removes part of this material. The circulation of dielectric fluid and the removal of machined debris is very difficult, especially when the hole or the cavity becomes deep, which reduces the machining efficiency due to poor circulation of the dielectric fluid from working gap. This poor flushing ends up with stagnation of dielectric and builds-up machining residues which apart from low material removal rate (MRR) also lead to short circuits and arcs [1]. To improve the machining performance of EDM, a suitable metallic powder is mixed in the fluid of the Electric Discharge Machining. The addition of this metallic powder in the dielectric fluid increases the conductive strength of the fluid. This increased conductive strength tends to break the fluid into ions easily. This increases in the creation of the plasma, which helps in more rapidly eroding work piece. Fig 1 shows the mechanism of powder mixed EDM.

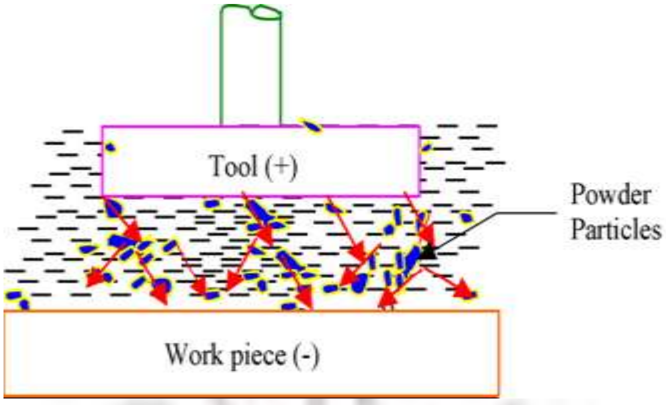

Fig.1: Mechanism of powder mixed EDM [2]

Literature Survey

Singh et al. concluded that the PMEDM (Powder Mixed Electric Discharge Machining) had significant effect on the MRR and TWR. With the addition of the powders in the dielectric, MRR had been increased to a extent and the TWR had been reduced. TiC gives better results in terms of MRR and TWR Al_2O_3 powder [3]. Baraskar et al. used mathematical models for relating the, MRR and TWR to machining parameters. It was concluded that central composite design was a powerful tool for providing experimental diagrams and statistical-mathematical models [4]. Pardhan and Biswas used Response surface methodology to investigate the relationships and parametric interactions between the three controllable variables on the material removal rate. It was found that discharge current, pulse duration, and pulse off time significant effect on the MRR [5]. Mir et al. studied the parametric optimization of Surface Roughness on the PMEDM of H11 steel. It was concluded that the factors peak current and powder concentration were most influential parameters affecting SR [6].

Goyal and Singh concluded that the Grain size of aluminum powder and concentration of aluminum powder mixed with EDM oil had a great influence on MRR and Surface finish. Too low and too high Grain size of aluminum powder in EDM oil gives lower MRR and lower Surface finish[7]. Tomadi et al. studied the influence of operating parameters of tungsten carbide on the machining characteristics. It was concluded that in order to obtain low values of TWR, high values of the pulse off time and low values peak current should be used [8]. Ali et al. concluded that addition of SiC powder at 10 g/l in dielectric fluid significantly reduced Ra surface roughness. However, higher concentration of SiC powder (above 20 g/l) tends to increase the surface roughness [9]. Kubade and Jadhav concluded that the MRR mainly influenced by peak current; where as other factors had very less effect on material removal rate. TWR was mainly influenced by peak current and pulse on time, duty cycle and gap voltage had very less effect on TWR [10]. Prajapati and Prajapati concluded that peak current and Pulse on time were having more influence to material removal rate. Surface roughness was mainly affected by the current and pulse on time [11].

Experimentation

The experiments are conducted using the Elektra EMS 5535 model die sinking Ram EDM. The experiments are conducted by mixing silicon powder in the dielectric fluid of the EDM. This powder is mixed in a separate container. A water-circulating pump is installed in the container to circulate the dielectric fluid. The experimental setup of PMEDM is shown in fig.2. The material of work piece used for experimentation is ASTM A 105 steel. The chemical composition of the material is shown in Table 1. ASTM A 105 steel is used for forged carbon steel piping components that is flanges, fittings, valves, and similar parts, for use in pressure systems at ambient and higher-temperature service conditions. The diameter of the work piece is 16 mm and the height of the work piece is 20 mm. The copper electrode is used for the experimentation. The main reasons for using copper electrode is its easy availability and lower de-burr. The diameter of used copper electrode is 10mm.

Fig.2: Experimental setup of PMEDM

Table 1: Chemical composition of work piece (ASTM A-105)

Element	**Carbon**	**Manganese**	**Silicon**	**Sulphur**	**Phosphorus**
Percentage(Standard)	0.35 MAX	0.60 - 1.05	0.35 MAX	0.050 MAX	0.040 MAX
Percentage(Tested)	0.223	0.607	0.159	0.0490	0.0308

The process parameters, their levels, response parameters and methodology adopted for this experimentation are described below:

- Process parameters

The process parameters uses in this experimentation are powder concentration, peak current no-load voltage, pulse on- time and duty cycle. The selection of these parameters is based on their importance in die sink EDM.

- Response Parameters

The response parameters are material removal rate (MRR) and tool wear rate (TWR). These are the two basic parameters to calculate the erosion of work piece and tool within a certain period. These are measured in mm^3/min. The values of MRR and TWR are obtained by using equation 1 and equation 2 respectively.

$$MRR = \frac{(M_1 - M_2)}{\rho M_t} \times 10^3 \quad .....1$$

$$TWR = \frac{(M_1 - M_2)}{\rho M_t} X 10^3 \quad .....2$$

- Factorial Design Employed

Experiments are designed on the basis of design of experiments (DoE). The design finally chosen is a factorial design 2^4 with six central points, consequently carrying out a total of 32 experiments. Based on the CCD, experiments are conducted to develop empirical models for MRR and TWR in terms of the five input variables: powder concentration, peak current, no-load voltage, pulse-on time and duty cycle. Each input variable (factor) is varied over five levels: ±1, 0 and ±α. Table 2 shows the relationship between the machining parameters and their corresponding selected variation levels, taking into account the entire range of machine parameters. The experimental data as shown in Table 2 is utilized to obtain the relation between the EDM process parameters and the output MRR and TWR. RSM utilizes statistical design of experiment technique and least-square fitting method in the model generation phase. An equation consisting of values of a dependent response variable and independent variables is derived for MRR and TWR characteristics.

Table 2: Process Parameters and their Levels

Sr. No.	Parameters	Levels					
		(-2)	(-1)	(0)	(+1)	(+2)	Coded values
1	Powder Concentration (gm/ltr)	0.4	0.8	1.2	1.6	2	Real Values
2	Peak Current (A)	20	25	30	35	40	
3	No- Load voltage (V)	75	100	125	150	175	
4	Pulse-On Time (µs)	100	150	200	250	500	
5	Duty Cycle (%)	66.67	75.00	83.34	91.97	100	

Regression equations are found out using software for statistical analysis called "Design Expert (DX-8)". ANOVA and Fisher's statistical test (F-test) is performed to check the adequacy of the model as well as significance of individual parameters.

Response Surface Methodology

Response surface methodology is a collection of mathematical and statistical techniques that are useful for modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize the response. Response Surface Method adopts both mathematical and statistical techniques [12,13]. RSM helps in analyzing the influence of the independent variables on a specific dependent variable (response) by quantifying the relationships amongst one or more measured responses and the vital input factors. The first step in RSM is to find a suitable approximation for the true functional relationship between response of interest 'y' and a set of controllable variables {x1, x2, ……xn}. Usually when the response function is not known or non-linear, a second order model is utilized [14] in the form:

$$Y = b_{\circ} + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{i<j=2}^{2} b_{ij} x_i x_j \pm e_r \qquad \ldots.3$$

Where, ε represents the noise or error observed in the response y such that the expected response is (y -ε) and b's are the regression coefficients to be estimated. The least square technique is being used to fit a model equation containing the input variables by minimizing the residual error measured by the sum of square deviations between the actual and estimated responses. The calculated coefficients or the model equations however need to be tested for statistical significance and thus the test is performed.

- **Significance Test of the Regression Model**

Analysis of Variance (ANOVA) is used to check the adequacy of the model for the responses in the experimentation. ANOVA calculates the F-ratio, which is the ratio between the regression mean square and the mean square error. The F-ratio, also called the variance ratio, is the ratio of variance due to the effect of a factor (the model) and variance due to the error term. This ratio is used to measure the significance of the model under investigation with respect to the variance of all the terms included in the error term at the desired significance level (α). If the calculated value of F-ratio is higher than the tabulated value of F-ratio for roughness, then the model is adequate at desired α level to represent the relationship between machining response and the machining parameters.

Experimental Results

Table 3 shows the design matrix developed for the proposed model as well as the machining characteristics values obtained in the experiments for MRR and TWR.

Table 3: Experimental conditions and results

		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Response 1	Response 2
Std	**Run**	**Powder Concentration (gm/ltr)**	**Peak Current (A)**	**No-Load Voltage (V)**	**Pulse-On Time (µs)**	**Duty Cycle (%)**	**MRR (mm^3/min.)**	**TWR (mm^3/min.)**
1	2	0.80	30.00	100.00	150.00	91.67	30.5	2.94
2	31	1.60	30.00	100.00	150.00	75.00	33.12	6.53
3	21	0.80	40.00	100.00	150.00	75.00	13.62	4.61
4	13	1.60	40.00	100.00	150.00	91.67	18.5	6.02
5	12	0.80	30.00	150.00	150.00	75.00	20.12	6.92
6	30	1.60	30.00	150.00	150.00	91.67	38	4.43
7	18	0.80	40.00	150.00	150.00	91.67	18.62	5.12
8	11	1.60	40.00	150.00	150.00	75.00	26.25	1.67
9	4	0.80	30.00	100.00	250.00	75.00	26.68	2.3
10	19	1.60	30.00	100.00	250.00	91.67	27.5	2.05
11	20	0.80	40.00	100.00	250.00	91.67	15.13	0.769
12	23	1.60	40.00	100.00	250.00	75.00	29.33	4.1
13	5	0.80	30.00	150.00	250.00	91.67	26.75	7.56
14	3	1.60	30.00	150.00	250.00	75.00	24.25	3.33
15	15	0.80	40.00	150.00	250.00	75.00	22	4.69
16	16	1.60	40.00	150.00	250.00	91.67	36.5	9.43
17	6	0.40	35.00	125.00	200.00	83.34	18.75	6.02
18	22	2.00	35.00	125.00	200.00	83.34	34.75	6.71
19	24	1.20	25.00	125.00	200.00	83.34	25.25	5.65
20	28	1.20	20.00	125.00	200.00	83.34	24	0.64
21	27	1.20	35.00	75.00	200.00	83.34	23.25	1.66
22	26	1.20	35.00	175.00	200.00	83.34	29.12	5.38
23	1	1.20	35.00	125.00	100.00	83.34	30.87	6.15
24	10	1.20	35.00	125.00	300.00	83.34	35.37	5.89
25	25	1.20	35.00	125.00	200.00	66.67	18	4.35
26	29	1.20	35.00	125.00	200.00	100.00	24.37	5.25
27	14	1.20	35.00	125.00	200.00	83.34	33.56	6.41
28	8	1.20	35.00	125.00	200.00	83.34	27.87	5.64
29	17	1.20	35.00	125.00	200.00	83.34	35.25	4.23
30	32	1.20	35.00	125.00	200.00	83.34	30.25	4.1
31	9	1.20	35.00	125.00	200.00	83.34	30.87	3.15
32	7	1.20	35.00	125.00	200.00	83.34	30.05	6.15

- **Model Adequacy Test for MRR**

The ANOVA and Fisher‘s statistical test (F- test) were performed to check the adequacy of the model as well as the significance of individual parameters. Table 4 shows the ANOVA model summary statistics for MRR. It can be seen that standard deviation of quadratic model is 2.31, which is much better as compared with lower order model for R-squared. Hence, the quadratic model suggested is most appropriate. The ANOVA table includes Sum of Squares (SS), Degrees of Freedom (DF), Mean Square (MS), F-value and P-value. The MS is obtained by dividing the SS of each of the sources of variation by the respective DF. The P-value is the smallest level of significance at which the data are significant. The F-value is the ratio of MS of the model terms to the MS of the residual. In this analysis, insignificant model terms were eliminated to adjust the fitted mathematical model. As seen from Table 5, the P-value for developed model of MRR is less than 0.05, which indicates that model is significant. It was noted that MS of the model (61.42) is larger than MS of the residual (5.33), thus the computed F-value of the model (F=61.42/5.33) of 11.52 implies that the model is significant. The R-Squared is defined as the ratio of variability explained by the model to the total variability in the actual data and is used as a measure of the goodness of fit. The more R^2 approaches unity, the better the model fits the experimental data. A negative "Pred R-Squared" implies that the overall mean is a better predictor of your response than the current model."Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 13.229 indicates an adequate signal. This model can be used to navigate the design space. Table 5 shows the variance analysis results of the proposed model of MRR

Table 4: Selection of Adequate Model for Material Removal Rate

Model Summary Statistics						
Source	**Std. Dev.**	**R-Squared**	**Adjusted R-Squared**	**Predicted R-Squared**	**PRESS**	
Linear	5.56	0.3754	0.2552	0.0235	1256.86	
2FI	5.24	0.6588	0.3389	-2.5948	4626.74	
Quadratic	2.31	0.9544	0.8716	0.7254	353.48	Suggested
Cubic	2.66	0.9726	0.8298		+	Aliased

Table 5: ANOVA for Response Surface Quadratic Model of Material Removal Rate

Source	**Sum of Squares**	**DOF**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	1228.45	20	61.42	11.52	< 0.0001	significant
A-powder concentration	352.90	1	352.90	66.21	< 0.0001	
B-peak current	126.34	1	126.34	23.70	0.0005	
C-no load voltage	37.13	1	37.13	6.97	0.0230	
D-pulse on time	14.12	1	14.12	2.65	0.1319	
E-duty cycle	34.73	1	34.73	6.52	0.0269	
AB	31.33	1	31.33	5.88	0.0337	
AC	14.04	1	14.04	2.63	0.1328	
AD	2.24	1	2.24	0.42	0.5299	
AE	0.066	1	0.066	0.012	0.9132	
BC	78.63	1	78.63	14.75	0.0027	
BD	113.05	1	113.05	21.21	0.0008	
BE	27.64	1	27.64	5.19	0.0437	
CD	0.81	1	0.81	0.15	0.7033	
CE	92.02	1	92.02	17.26	0.0016	
DE	4.94	1	4.94	0.93	0.3564	
A^2	26.69	1	26.69	5.01	0.0469	
B^2	179.31	1	179.31	33.64	0.0001	
C^2	35.07	1	35.07	6.58	0.0263	
D^2	11.27	1	11.27	2.11	0.1738	
E^2	159.07	1	159.07	29.84	0.0002	
Residual	58.63	11	5.33			
Lack of Fit	23.31	6	3.88	0.55	0.7565	not significant
Pure Error	35.32	5	7.06			
Cor Total	1287.08	31				
R-Squared=0.9544, Adj R-Squared = 0.8716, Pred R-Squared = 0.7254, Adeq Precision = 13.229						

- **Model Adequacy Test for TWR**

The ANOVA and Fisher's statistical test (F- test) were performed to check the adequacy of the model as well as the significance of individual parameters. Table 6 shows the ANOVA model summary statistics for TWR.

Table 6: Selection of Adequate Model for Tool Wear Rate

Model Summary Statistics						
Source	**Std. Dev.**	**R-Squared**	**Adjusted R-Squared**	**Predicted R-Squared**	**PRESS**	
Linear	1.99	0.1996	0.0457	-0.3395	173.17	
2FI	1.48	0.7304	0.4777	-0.6398	211.99	
Quadratic	1.14	0.8885	0.6857	0.5140	62.83	Suggested
Cubic	1.31	0.9340	0.5910		+	Aliased

Table 7: ANOVA for Response Surface Quadratic Model of TWR

Source	**Sum of Squares**	**DOF**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	114.86	20	5.74	4.38	0.0076	significant
A-powder concentration	0.68	1	0.68	0.52	0.4873	
B-peak current	0.13	1	0.13	0.100	0.7580	
C-no-load voltage	18.85	1	18.85	14.38	0.0030	
D-pulse on-time	0.86	1	0.86	0.65	0.4363	
E-duty cycle	1.48	1	1.48	1.13	0.3100	
AB	5.54	1	5.54	4.22	0.0644	
AC	11.41	1	11.41	8.71	0.0132	
AD	1.28	1	1.28	0.98	0.3437	
AE	4.44	1	4.44	3.39	0.0927	
BC	0.57	1	0.57	0.43	0.5246	
BD	3.19	1	3.19	2.44	0.1468	
BE	4.38	1	4.38	3.34	0.0948	
CD	19.69	1	19.69	15.03	0.0026	
CE	15.39	1	15.39	11.74	0.0057	
DE	2.73	1	2.73	2.08	0.1768	
A^2	2.04	1	2.04	1.56	0.2376	
B^2	10.42	1	10.42	7.95	0.0167	
C^2	5.65	1	5.65	4.31	0.0621	
D^2	0.94	1	0.94	0.72	0.4157	
E^2	0.44	1	0.44	0.34	0.5735	
Residual	14.42	11	1.31			
Lack of Fit	5.89	6	0.98	0.58	0.7404	not significant
Pure Error	8.53	5	1.71			
Cor Total	129.28	31				
R-Squared = 0.8885, Adj R-Squared = 0.6857, Pred R-Squared = 0.5140, Adeq Precision = 9.391						

It can be seen that standard deviation of quadratic model is 1.14, which is much better as compared with lower order model for R-squared. Hence the quadratic model suggested is most appropriate. Table 7 shows the variance analysis results of the proposed model of TWR. The ANOVA table includes Sum of Squares (SS), Degrees of Freedom (DF), Mean Square (MS), F-value and P-value. The MS was obtained by dividing the SS of each of the sources of variation by the respective DF. The P-value is the smallest level of significance at which the data are significant. The F-value is the ratio of MS of the model terms to the MS of the residual. In this analysis, insignificant model terms were eliminated to adjust the fitted mathematical model. As seen from Table 7, the P-values for developed model of TWR is less than 0.05, which indicates that model is significant. It was noted that MS of the model (5.74) is larger than MS of the residual (1.31), thus the computed F-value of the model (F=5.74/1.31) of 4.38 implies that the model is significant. Table 7 shows the R-Squared (R^2) "Adjusted R-Squared (Adj. R^2)" and "Predicted R-Squared (Pred. R^2)" statistics. The R-Squared is defined as the ratio of variability explained by the model to the total variability in the actual data and is used as a measure of the goodness of fit. The more R^2 approaches unity, the better the model fits the experimental data. A negative "Pred R-Squared" implies that the overall mean is a better predictor of your response than the current model."Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 9.391 indicates an adequate signal. This model can be used to navigate the design space.

Analysis and Discussion of Results

In this study, the effect of powder concentration in support with various parameters is investigated on MRR and TWR using ASTM A 105 steel. These parameters are peak current, no-load voltage, pulse on-time and duty cycle. A set of 32 experiments made with the help of "Design Expert-9" software. The methodology adopted for this experimentation is response surface methodology (RSM).

- **Selection of Adequate Model for MRR and TWR**

The Table 6.1 indicates that the quadratic model in MRR and TWR response characteristics does not show significant lack of fit, hence the adequacy of quadratic model is confirmed. Another test "model summary statistics" given in the Tables 8 and 9 confirms that the quadratic model is the best to fix as it exhibits low standard deviation, high "R-Squared" values, and a low "PRESS" (Adeq Precision), for MRR and TWR respectively. The addition of cubic terms does not significantly improve the lack of fit because these terms are aliased for Central Composite Design (CCD) (even if these were significant). The "lack of fit" test compares the residual error to the pure error from the replicated design points. By using experimental data from table 3 the regression coefficients of the second order equation are obtained for MRR and TWR. These regression equations represents the function of all the five parameters i.e. powder concentration, peak current, no-load voltage, pulse on-time and duty cycle used in experiment. The insignificant coefficients (identified from ANOVA) have been omitted from the equation 4 and 5

$$\textbf{MRR} = +30.91+3.83*A -2.73*B +1.24*C +0.77*D +1.20*E +1.40*AB +0.94*AC -0.37*AD -0.064*AE +2.22*BC +2.66*BD -1.31*BE +0.23*CD +2.40*CE -0.56*DE -0.97*A^2 -1.83*B^2 -1.11*C^2 +0.63*D^2 -2.36*E^2 \quad \ldots.4$$

Table 8: Selection of Adequate Model for Material Removal Rate

1. Sequential Model Sum of Squares						
Source	**Sum of Squares**	**DOF**	**Mean Square**	**F Value**	**p-value Prob > F**	
Mean vs Total	23029.26	1	23029.26			
Linear vs Mean	483.12	5	96.62	3.12	0.0243	
2FI vs Linear	364.78	10	36.48	1.33	0.2953	
Quadratic vs 2FI	380.55	5	76.11	14.28	0.0002	Suggested
Cubic vs Quadratic	23.31	6	3.88	0.55	0.7565	Aliased
Residual	35.32	5	7.06			
Total	24316.34	32	759.89			
2. Lack of Fit Tests						
Source	**Sum of Squares**	**DOF**	**Mean Square**	**F Value**	**p-value Prob > F**	
Linear	768.63	21	36.60	5.18	0.0382	
2FI	403.85	11	36.71	5.20	0.0408	
Quadratic	23.31	6	3.88	0.55	0.7565	Suggested
Cubic	0.000	0				Aliased
Pure Error	35.32	5	7.06			
3. Model Summary Statistics						
Source	**Std. Dev.**	**R-Squared**	**Adjusted R-Squared**	**Predicted R-Squared**	**PRESS**	
Linear	5.56	0.3754	0.2552	0.0235	1256.86	
2FI	5.24	0.6588	0.3389	-2.5948	4626.74	
Quadratic	2.31	0.9544	0.8716	0.7254	353.48	Suggested
Cubic	2.66	0.9726	0.8298		+	Aliased

$$\text{TWR} = +5.16 + 0.17A - 0.088B + 0.89C - 0.19D + 0.25E + 0.59AB - 0.84AC + 0.28AD + 0.53AE - 0.19BC + 0.45BD + 0.52BE + 1.11CD + 0.98CE + 0.41DE + 0.27A^2 - 0.44B^2 - 0.44C^2 + 0.18D^2 - 0.12E^2 \quad \ldots.5$$

Table 9: Selection of Adequate Model for Tool Wear Rate

1. Sequential Model Sum of Squares						
Source	**Sum of Squares**	**DOF**	**Mean Square**	**F Value**	**p-value Prob > F**	
Mean vs Total	701.71	1	701.71			
Linear vs Mean	25.81	5	5.16	1.30	0.2956	
2FI vs Linear	68.62	10	6.86	3.15	0.0200	
Quadratic vs 2FI	20.44	5	4.09	3.12	0.0539	Suggested
Cubic vs Quadratic	5.89	6	0.98	0.58	0.7404	Aliased
Residual	8.53	5	1.71			
Total	830.99	32	25.97			
2. Lack of Fit Tests						
Source	**Sum of Squares**	**DOF**	**Mean Square**	**F Value**	**p-value Prob > F**	
Linear	104.93	21	5.00	2.93	0.1180	
2FI	41.19	11	3.74	2.20	0.1989	
Quadratic	11.98	6	2.00	1.17	0.4408	Suggested
Cubic	0.000	0				Aliased
Pure Error	8.53	5	1.71			
3. Model Summary Statistics						
Source	**Std. Dev.**	**R-Squared**	**Adjusted R-Squared**	**Predicted R-Squared**	**PRESS**	
Linear	2.09	0.1358	-0.0304	-0.4270	187.35	
2FI	1.76	0.6213	0.2663	-2.0310	397.93	
Quadratic	1.37	0.8438	0.5597	-1.0025	262.90	Suggested
Cubic	1.31	0.9350	0.5972		+	Aliased

- **Material removal rate**

The data gathered from the experimental work is analyzed using RSM to obtain the optimal values of the process parameters. By using these optimal values of the parameters the following graphs are plotted. These graphs show parameters, which are significant for MRR observations.

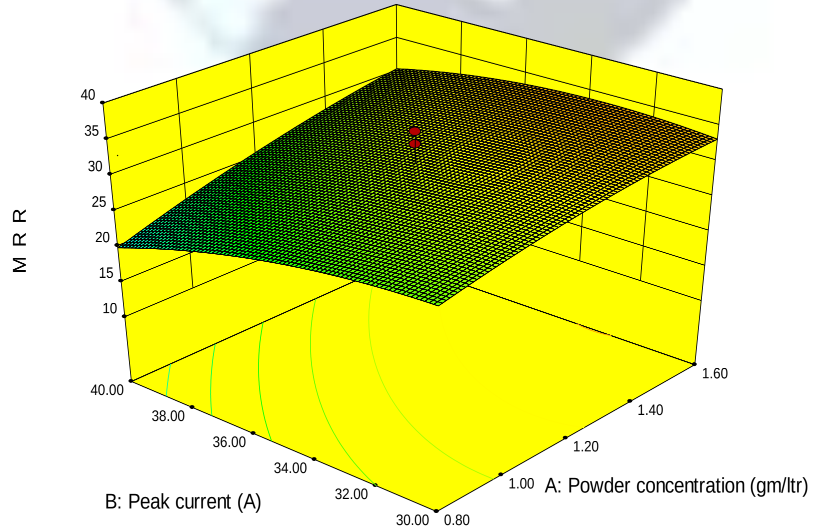

Fig 3: Combined effect of peak current and powder concentration on MRR

Fig 3 shows the combined effect of peak current and powder concentration on MRR. The value of MRR is higher at the final level of powder concentration. In addition, MRR is higher at the final values of both parameters. The final value of powder concentration and peak current is 1.6gm/ltr & 40 A respectively. At the final values of both parameters the MRR increases because, with higher powder concentration and peak current the construction of plasma channel becomes easier. This plasma erode the work piece thus MRR increases.

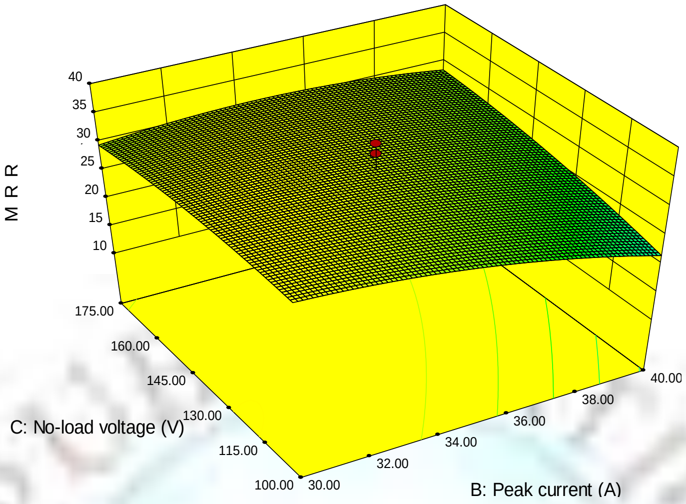

Fig 4: Combined effect of peak current and no-load voltage on MRR

Fig 4 shows the combined effect of peak current and no-load voltage on MRR. The MRR is at its higher value, when a value of peak current is at initial level (32A) and value of no-load voltage is at final level (150 V). With varying values of the current, the discharge of energy tends to melt the work piece. At the initial value of the current, the debris is in less quantity which continuously replaced by the powder, but at the final values of the peak current the debris replaces the powder concentration in the gap between the work piece and the tool which reduces the MRR.

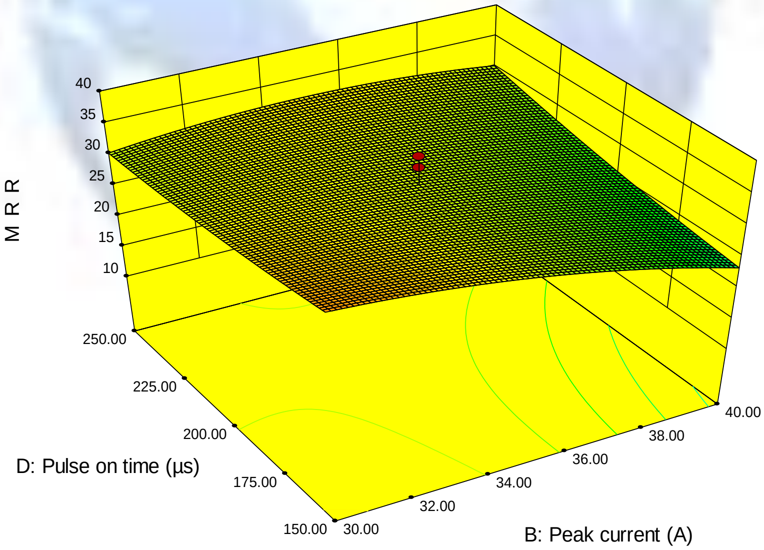

Fig 5: Combined effect of peak current and pulse on-time on MRR

Fig 5 shows the combined effect of peak current and pulse on-time on MRR. The MRR is higher at the initial values of both the parameters. Also the MRR increases at final level of peak current and pulse on-time. The reason for this behavior of MRR is that there is no interruption of debris between the tool and the work piece which result in easy generation of the plasma channel. This erodes the work piece easily. MRR rise with increase in the value of peak current with respect to higher pulse on-time. When Peak current reaches at the value of 38 A is begins to reduce as the interruption of debris between the tool and work piece increase with weakens the plasma.

Fig 6 shows the combined effect of peak current and duty cycle on MRR. The MRR is higher at the initial values of the peak current (30A) and the final value of duty cycle (91.63%) than any other values of these parameters. At the higher values of the peak current (40A) and duty cycle (91.63%) the formation of the debris are more which interrupted the plasma channel by reducing the concentration of powder in the spark gap. This reduces the MRR. At lower level of peak current and higher value of duty cycle the discharge of energy is high for a sufficient interval of time. The higher discharge of energy in sufficient time generates proper plasma which results in higher MRR.

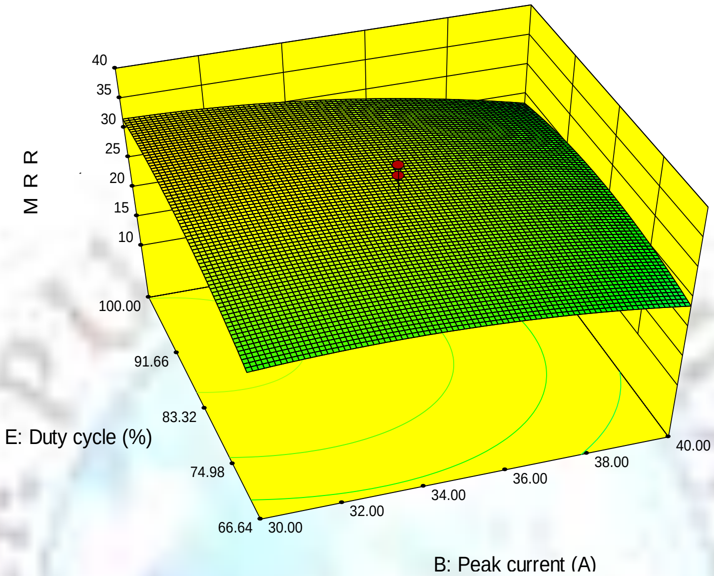

Fig 6: Combined effect of peak current and duty cycle on MRR

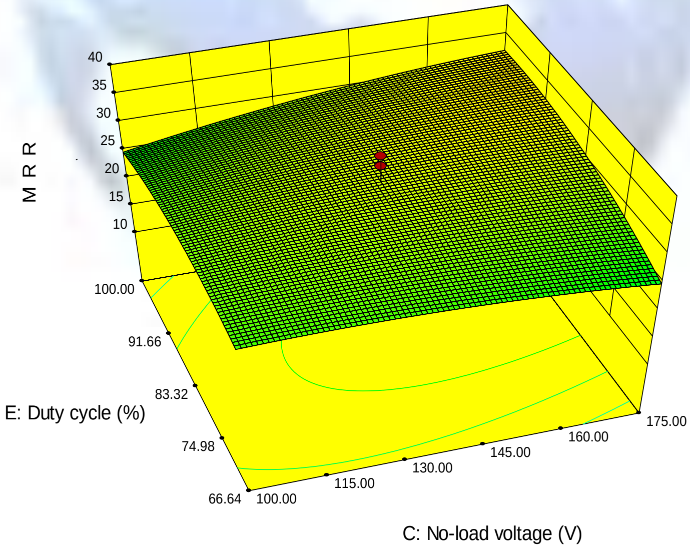

Fig 7: Combined effect of duty cycle and no-load voltage on MRR

- Tool Wear Rate

The data gathered from the experimental work is analyzed using RSM to obtain the optimal values of the process parameters. By using these optimal values of the parameters, the following graphs are plotted. These graphs show parameters, which are significant for TWR observations.

Fig 8 shows the combined effect of no-load voltage and powder concentration on TWR. The TWR is less when value of no-load voltage is 100V and value of powder concentration is 0.8 gm/ltr. At lower values the discharge of energy is less which reduces the TWR & at higher values, the debris formation in spark gap increased insulating strength which lowers TWR.

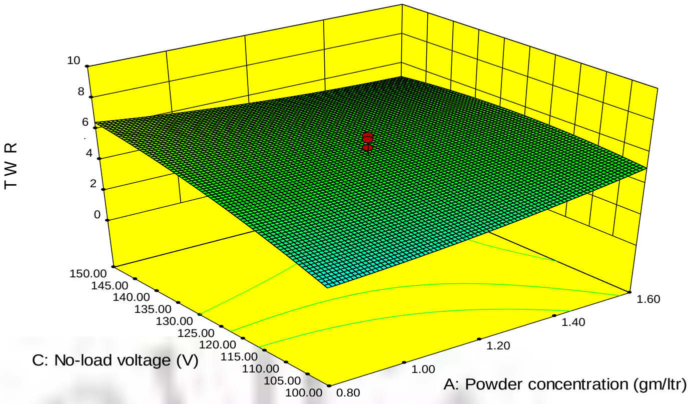

Fig 8: Combined effect of no-load voltage and powder concentration on TWR

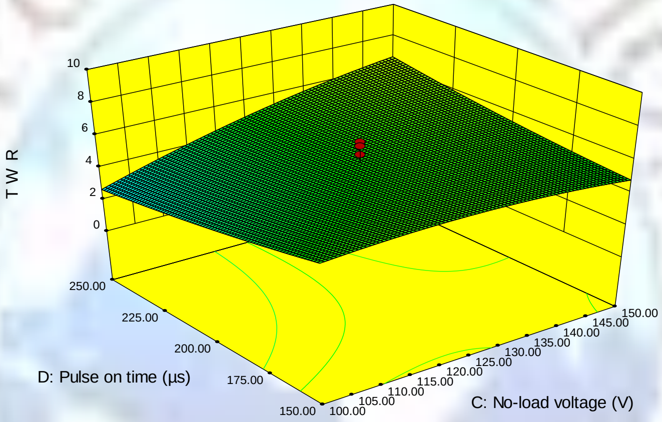

Fig 9: Combined effect of no-load voltage and pulse on-time on TWR

Fig 9 shows the combined effect of no-load voltage and pulse on-time on TWR. The TWR is less at the final value of the pulse on-time and initial value of no-load voltage. TWR increases at the final values of both parameters. At the final value of pulse on-time (250µs) and lower value of no-load voltage (4V), the generated plasma is for long time with efficient effectiveness but the interruption of debris reduces the efficiency of plasma which in turn reduces TWR. At the lower pulse on-time (150µs) and higher no-load voltage (150 V), the plasma is created for a short time interval which isn't enough to melt down the tool

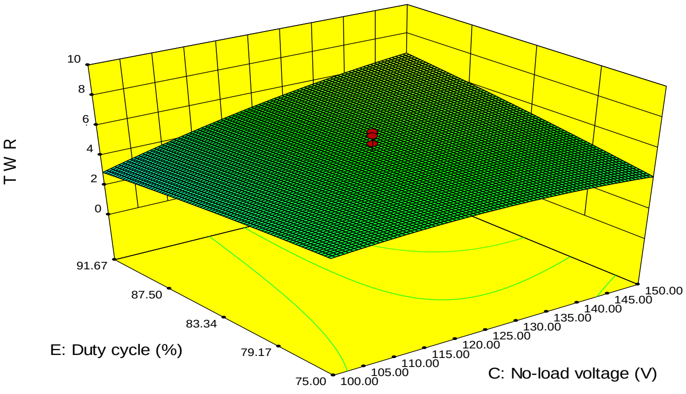

Fig 10: Combined effect of no-load voltage and duty cycle on TWR

Fig 10 shows the combined effect of no-load voltage and duty cycle on TWR. The TWR is minimum at the initial value of the no-load voltage (100 V) and final value of the duty cycle (91.63%). TWR increases with increase in the values of parameters simultaneously. At the lower level of no-load voltage (100 V) and varying value of duty cycle form 74.97% to 91.63%, the discharge of energy is less, which results in generation of less effective plasma. This results in lower TWR.

Conclusion

It is found that powder concentration along with peak current, no-load voltage, pulse-on time and duty cycle have significant effect on MRR and TWR. The experiments were conducted using ASTM A 105 steel as work piece and copper as tool. The methodology adopted is RSM.

- It is found that the concentration of Silicon powder in dielectric fluid is the most significant factor in case of MRR. The percentage contribution of powder concentration is 36.61%.
- The other significant factor is peak current. The percentage contribution of peak current in MRR is 13%
- In the case of TWR, no-load voltage proves to be the most significant factor. The percentage contribution of no-load voltage in TWR is 19.02%
- The optimal values of process parameters for the MRR and TWR is same. The predicted range of optimal MRR and TWR is Powder Concentration =1.2 gm/ltr, Peak Current = 35 A, No-Load Voltage = 5 V, Pulse On Time = 200 µs and Duty Cycle = 83.34%.

References

[1]. J. Singh, S. Singh, G. Singh, (2013) “Study Of Surface Roughness For Discontinuous Ultrasonic Vibration Assisted Electric Discharge Machining Using Rsm,” International Journal of Research in Engineering and Technology, vol. 2, 11, pp. 727-737.

[2]. J. Singh, S. Singh, G. Singh, (2013), “Advancements & Hybridization in Electric Discharge Machining – A Review”, Proceedings of International Conference on Smart Technologies for Mechanical Engineering.

[3]. S. Singh, H. Singh, J. Singh, and R. Bhatia, (2011) “Effect of Composition of Powder Mixed Dielectric Fluid on Performance of Electric Discharge Machining”, National Conference on Advancements and Futuristic Trends in Mechanical and Materials Engineering, Punjab Technical University, Jalandhar, India.

[4]. S.S. Baraskar, S.S. Banwait. and S.C. Laroiya (2011) “Mathematical Modeling of Electrical Discharge Machining Process Through Response Surface Methodology”, International Journal of Scientific & Engineering Research, vol. 2, 11, pp. 1-10.

[5]. M. K. Pradhan and C. K. Biswas (2008) “Modeling Of Machining Parameters For MRR In EDM Using Response Surface Methodology”, Proceedings of National Conference on Mechanism Science and Technology: from Theory to Application (NCMSTA’08), National Institute of Technology, Hamirpur, India, pp. 535-542.

[6]. M.J. Mir, K. Sheikh, B. Singh, and N. Malhotra, (2012) “Modeling And Analysis Of Machining Parameters For Surface Roughness In Powder Mixed EDM Using RSM Approach”,International Journal of Engineering, Science and Technology, vol. 4, 3, pp. 45-52.

[7]. S. Goyal, and R.K. Singh, (2014) “Parametric Study of Powder Mixed EDM and Optimization of MRR &Surface Roughness”, International Journal of Scientific Engineering and Technology, vol. 3, 1, pp. 56-62.

[8]. S.H. Tomadi, , M.A. Hassan, Z. Hamedon, R. Daud, and A.G. Khalid, (2009) “Analysis of the Influence of EDM Parameters on Surface Quality, Material Removal Rate and Electrode Wear of Tungsten Carbide”, Proceedings of the International Multi Conference of Engineers and Computer Scientists, vol. 2, Hong Kong.

[9]. M.Y Ali, N. Atiqah and Erniyati(2011) “Silicon Carbide Powder Mixed Micro Electro Discharge Milling Of Titanium Alloy”, International Journal of Mechanical and Materials Engineering, vol.6,3, pp. 338-342.

[10]. P. R. Kubade, and V. S.Jadhav, (2012) “An Experimental Investigation of Electrode Wear Rate (EWR), Material Removal Rate (MRR) and Radial Overcut (ROC) in EDM of High Carbon-High Chromium Steel (AISI D3)”, International Journal of Engineering and Advanced Technology, vol. 1, 5, pp. 135-140.

[11]. H. B. Prajapati, and H. R.Prajapati, (2013) “Parametric Analysis Of Material Removal Rate And Surface Roughness Of Electro Discharge Machining On EN 9”, International Journal of Research in Modern Engineering and Emerging Technology, vol. 1, 1, pp. 7-13.

[12]. D.C.Montgomery, “Design and Analysis of Experiments,” Wiley-India, 2007.

[13]. Myers, D.C. Montgomery and Anderson-Cook, “Response Surface Methodology,” John Wiley-New York, 2009.

[14]. D. C. Montgomery, “Design and analysis of experiments,” John wiley and Sons Inc., 2001.