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Optimization of Chromium Mixed Powder EDM parameters using Response Surface Methodology for H13 Tool steel Machining

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Abstract

In the present study, effect of chromium powder mixed in dielectric of EDM is studied during machining of H13 tool steel. Four parameters namely peak current, pulse on time, duty cycle and powder concentration are taken as input parameters and material removal rate (MRR) and tool wear rate (TWR) are considered as performance measures. Copper electrode is used as the tool. Analysis is done using Response Surface Methodology. Results revealed that pulse on time powder concentration; duty cycle and peak current are the significant factors affecting MRR while TWR is significantly affected by peak current only. Increasing the powder concentration results in increasing MRR and decreasing TWR

Keyword: *Chromium powder, MRR, TWR and Response Surface Methodology.*

1. INTRODUCTION

Development of the materials like Inconel, hot hardened steels, polycrystalline diamond, titanium, Hastalloys, carbides etc which are electrical conductive and are very difficult to machine by conventional methods lead the rise of non conventional machining processes . Electrical Discharge Machining is one of the non conventional processes that is used widely in industries to machine such materials. It is a thermal process that uses spark discharges to machine electrical conductive materials regardless their hardness. A shaped electrode or wire acts as a tool which makes cavities or holes in the work piece. Electrically conductive work piece is connected to one pole of pulsed power supply and the electrode is connected to another pole of power supply. A small gap is maintained between electrode and work piece to provide controlled electrical resistance in the gap. Since there is no contact between the tool and work piece in EDM, machining problems like mechanical stresses, chattering and vibrations does not arise during machining. In spite of advantages of EDM, there are disadvantages like low material removal rate and poor surface finish which restricts its application in industries to some extent. In order to remove these limitations, a new technique known as Powder Mixed EDM has been emerged for the enhancement of EDM process capabilities [16].

In PMEDM, a suitable powder like silicon, vanadium, titanium etc is mixed with the dielectric of EDM. Due to the applied electric field applied, the powder particles get energized and accelerated and become conductors and promote breakdown in the gap and also enhance the spark gap between the tool and the workpiece.

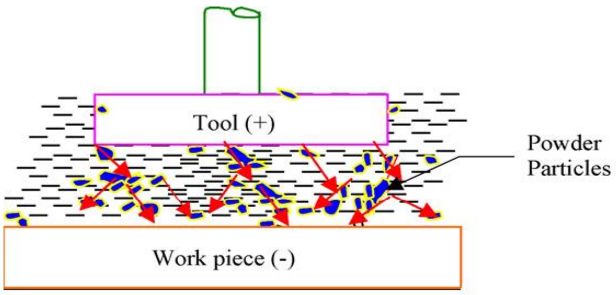

Figure 1: Principle of PMEDM

Powder particles formed the chain type structure and arrange themselves in the direction of current.

This causes the bridging gap between the electrode and workpiece, hence insulating strength of dielectric gets reduced which lead to easy short circuiting and hence early explosion in the gap takes place. It results in the series of discharges under the electrode area. Due to this, faster sparking causes the faster erosion from the workpiece and hence MRR get increased. Addition of powder in the dielectric enlarged the plasma which causes the electric density to decrease and hence uniform erosion occurs on the workpiece leading to better surface finish along with high material removal rate [7].

2. LITERATURE REVIEW

Kansal et al., [8] performed the experiments on H-11 steel using copper electrode. Peak current, pulse duration, duty cycle and silicon powder concentration were taken as input parameters while the MRR and surface roughness were taken as performance measures. Taguchi method was used to analyze the result. It was found that pulse duration, powder concentration and peak current affect the MRR and surface roughness significantly. **Jaswani et al.,** [6] concluded that there is an increase in MRR by 60% and TWR by 15% by adding graphite powder in the dielectric fluid of EDM. **Furutani et al.,** [3] found that there is deposition of titanium carbide layer on carbon steel with copper electrode using titanium powder mixed dielectric. **Wu KL., et al., [**25] studied the problem of powder settling by adding a surfactant with aluminium powder in dielectric fluid and observed that a surface roughness (Ra value) of less than 0.2μm. This is because of more apparent discharge distribution. It was also reported that negative polarity of the tool resulted in better hardness of the surface. **Kansal et al.,** [9] found that PMEDM technology is used in industry at very slow pace. It may be due to large powder consumption, difficulty in operation of dielectric interchange and higher initial cost. **Singh et al.,** [18] conducted an experiment on ZNC EDM machine to study the effect of aluminium powder mixed dielectric on machining characteristics of Hastealloy. Copper electrode was used as a tool. Concentration and grain size of the powder were taken as input parameters. Addition of powder resulted in lowering TWR and improves surface finish as well as MRR of the Hastealloy. Very small and large size of powder particle resulted in reducing the MRR but increasing the surface roughness of Hastealloy. %WR decreases by using small size particles and vice versa. **Prihandana et al.,** [19] presented a new method that consists of suspending micro-MoS_2 that consists of suspending micro-MoS_2 powder in dielectric fluid and using ultrasonic vibration during μ-EDM processes. Taguchi method was used to optimize process parameters which were concentration of micro-powder, tool electrode material, ultrasonic vibration of the dielectric fluid and workpiece material, to increase the MRR. It was observed that the introduction of MoS_2 micro-powder in dielectric fluid and using ultrasonic vibration significantly increase the MRR and improves the surface quality. **Goyal et al**., [4] used the alumimium powder mixed dielectric to study the performance characteristics of AISI 1045 steel. Electrical parameters namely current, voltage, pulse on time and duty cycle remains constant while grain size and concentration of powder were varied. Taguchi method was employed to optimize the results. Grain size and concentration have the significant effect on MRR and surface roughness. **Y S Wong et al.,** [27] studied the near mirror finish phenomena in EDM when fine powder is mixed with dielectric during machining of various types of steels using different types of powder suspension at the peak current of 1ampere. Mirror finish condition is significantly influenced by the various factors like right combination of workpiece material and powder characteristics, setting of electrode polarity and pulse parameters. It was found that the main condition required for mirror finish is the negative electrode polarity. **Singh et al.,** [5] carried out a study on H 13 steel by mixing aluminium powder of particle size 325 μmm in the dielectric. Solid copper electrode of 8mm diameter was used as the tool. Experimental design was based on L18 orthogonal array. Polarity, peak current, pulse on time, duty cycle, gap voltage and powder concentration were input parameters. ANOVA analysis was used to find the significant factors affecting the surface roughness of H13 steel. It was found all the input parameters affect the surface roughness. Higher peak currents produce rougher surface in EDM process**. Chow et al.,** [2] concluded that addition of SiC powder in the pure water resulted in larger expanding slit and electrode wear during micro slit EDM of titanium alloy than those of pure water used as dielectric for EDM. **Sharma et al.,** [20] found that addition of graphite powder in the dielectric and the use of cold treated electrode are the favorable conditions for reducing the electrode wear rate. **Singh P. et al.,** [21] investigate the Concentrations of aluminium powder and grain size of powder mixed in dielectric fluid strongly affects the machining performance of EDM process. **Sharma et al.,** [22] studied the effect of adding aluminium powder in the dielectric of EDM on the performance measures namely MRR, TWR. Powder characteristics found to be significantly affecting the MRR and TWR. **Klocke et al.,** [19] figured out that addition of aluminium and silicon powder in the dielectric during machining of Inconel 718 alloy using tungsten electrode resulted in causing the greater expansion of plasma channel as compared to powder free dielectric and also changed the thermal material removal mechanism. **Tzeng et al., [**23] studied the effect of various powder characteristics by using SKD 11 steel. **Ojha et al.,** [17] used the chromium powder mixed dielectric for machining EN-8 steel and found that MRR shows increasing trend for increase in powder concentration. TWR increases with lower range of powder concentration but then decrease. **Aggrawal A et al.,** [1] found that addition of powder in dielectric resulted in decreasing the wear of the electrode. **Muniu et al.,** [15] investigated the effect of adding copper, diatomite and aluminium on MRR of mild steel using graphite electrode. MRR increases with increase in powder concentration but then decreases with further increase in powder concentration. **Kolahan et al.,** [11] used the genetic algorithm approach to optimize the MRR and TWR of aluminium powder mixed dielectric EDM. **Kumar S et**

al., [12] found that adding the manganese powder in the dielectric causes the micro hardness of the machined surface under the favorable conditions. **Kung et al**., (13) reported that the material removal rate and electrode wear ratio in powder mixed electrical discharge machining of cobalt-bonded tungsten carbide by suspending aluminium powder in dielectric fluid. They observed that the powder particles disperses and makes the discharging energy dispersion uniform. **Vhatkar et al.,** [24] reported that adding powder in the dielectric causes the MRR to increase and reduces the surface roughness. Silicon powder provides the best result for MRR and surface roughness. **W.S Jhao et al.,** [26] studied the surface morphology using dielectric with and without powder. It was revealed that more circular shapes with smaller diameter are produced with powder mixed dielectric as compared to without powder additives. **Kanasl et al.,** [14] tried to optimize the condition of aluminium powder mixed EDM of Al-10%SiCP metal matrix composite using response surface methodology. **Yan BH., et al.,** [28] studied the electric discharge machining with powder suspended working media and reported that the gap length become shorter regardless of a mixed powder with a decrease of the pulse duration at a duty factor of 0.5.
From the literature survey, it is concluded that most of the work is done by using Silicon, Alumimium and Zinc powder mixed dielectric to enhance and optimize the machining output parameters of various hard and tough materials. Very little literature is available on chromium powder mixed EDM. Therefore, present study is carried out to optimize the chromium powder mixed EDM parameters using RSM for H13 tool steel machining. H13 is selected as work material because of its wide applications for hot punches and dies for blanking, blending and forging, hot extrusion dies for aluminium, cores, injector pins, nozzles for tin and lead die castings etc.

3. EXPERIMENTATION

3.1 Experimental Setup and Material

Experiments are performed on ELEKTRA PS 35 die sinking EDM machine. The working tank of the machine is very large having dimensions of 850mm long 550mm wide and 300mm high. Therefore in order to prevent the mixing of powder with the whole dielectric fluid and to avoid the clogging of main filter unit of the machine, a separate tank of 300mm X 150mm X 145mm is fabricated from the mild steel sheet of 1.5mm thick. This tank is placed in the working tank of EDM and the machining is performed in this tank. Fixture is placed in the tank to hold the workpiece. Tank is filled with the EDM oil. Small circulation pump is installed in the tank for proper circulation of powder mixed dielectric at the discharge gap. Two permanent is used at the bottom of machine tank to hold the fixture during machining and to separate the debris from the fluid. Copper electrode of 16 mm is used as the cutting tool and H13 is used as working material. Specimen of H13 steel are cut into rectangle shaped blocks of 28mm X 20mm X10mm. Chemical composition of H13 steel, properties of Chromium powder and copper electrode are shown in table 1, table 2 and table 3 respectively.

Element	**Percentage (%)**
Carbon	0.40
Manganese	0.40
Silicon	1.0
Chromium	5.25
Molybdenum	1.35
Vanadium	1.0

Table 1: Composition of H13 steel.

Properties	**Value**
Density	7.19 (g/cm^3)
Thermal conductivity	0.16 (Cal/s-cm-°C)
Melting Point	1875 °C
Specific heat (25 °C)	0.11 (cal/g-°C

Table 2: Properties of Chromium Powder.

Properties	**Value**
Density	8.96 g/cm^3
Yield Strength	65 N/mm^2
Melting Point	1083°C

Table 3: Properties of Copper Electrode.

3.2 Selection of Parameters and Their Levels

Process parameters namely Peak current, Pulse on time, Duty cycle and Powder concentration are taken as input parameters and MRR and TWR are considered as output parameters for experimentation. Each input parameter has three levels. Levels for peak current, pulse on time and duty cycle are selected according to the range of the machine while powder concentration levels are based on literature survey. Table 3 shows the parameters selected and their levels.

Parameter	**Code**	**Level 1**	**Level 2**	**Level 3**
Peak current (Amp)	A	10	15	20
Duty Cycle (τ)	B	4	6	8
Pulse On Time (μs)	C	100	150	200
Powder Concentration (g/l)	D	5	10	15

Table 3: Levels of Input Parameters.

Following parameters are kept constant at fixed value during the experimentation.

- Work material – H13 steel
- Electrode – Copper of 16 diameter
- Fluid pressure- 0.5 kg/cm^2
- Peak voltage – 120 Volt DC
- Time – 10 min.

Parameters MRR and TWR are selected as output parameters which can be calculated by the following equations

MRR=$(Wjb - Wja) \div (t \times \rho)$
Wjb=Weight of the workpiece before machining.
Wja= Weight of the workpiece after machining.
t= Machining time=10 min.
ρ = Density of H13 steel= 7.80gm/cm^3
TWR= $(Wtb - Wta) \div (t \times \rho)$
Wtb = Weight of tool before machining.
Wta = Weight of tool after machining.
t= Machining time = 10 min.
ρ = Density of copper = 8.96gm/cm^3

3.3 Response Surface Methodology

Response surface methodology is a collection of mathematical and statistical techniques for empirical model building. By careful design of experiments, the objective is to optimize the response (output variable) which is influenced by several independent variables (input variables). Suppose there are two input variables having different levels influence a response variable y, the relationship between input and output variable can be shown as

$$y = f(x1, x2) + e \quad (1)$$

Where e is the error observed in response y. If we donate the expected response by E(y) = f(x1, x2) = μ then the surface represented by μ = f(x1, x2) is called response surface. In most of the RSM problems the form of relationship between the response and the independent variable is unknown. Thus the first step in RSM is to find out the suitable approximation for the true functional relationship between y and set of independent variables. If the response is well modeled by the linear function of the independent variables, then the approximation function is the first order model which is written as

$$y = \beta o + \beta 1x1 + \beta 2x2 \ldots\ldots\ldots\ldots + \beta kxk + e \quad (2)$$

For the development of regression equations related to quality characteristics of EDM process the second order response surface has been assumed as:

$$y = \beta o + \sum_{i=1}^{k} \beta ixi + \sum_{i=1}^{k} \beta iixi2 + \ldots\ldots \quad (3)$$

The method of least square is used to estimate the parameters in approximating polynomials.

3.4 Design Matrix by RSM

As there are four input parameters namely peak current, duty cycle, powder concentration and pulse on time therefore total 31 experiments will be carried out according to response surface design. Minitab software is used to design the matrix and analyze the data. Table 4 shows the design matrix of the input parameters along with their levels.

Exp No.	A: Peak Current(Amp)	B: Duty Cycle(τ)	C: Pulse on Time (µs)	D: Powder Concent-ration(g/l)
1	20	4	100	15
2	15	6	150	10
3	20	4	200	15
4	15	6	100	10
5	20	8	200	5
6	15	6	150	10
7	10	4	200	15
8	10	4	100	15
9	15	6	150	10
10	20	8	200	15
11	10	8	200	15
12	20	4	200	5
13	20	6	150	10
14	15	6	150	10
15	20	8	100	15
16	15	6	150	15
17	15	6	150	5
18	10	4	200	5
19	10	6	150	10
20	20	4	100	5
21	10	8	100	15
22	15	6	150	10
23	15	6	150	10
24	15	4	150	10
25	10	4	100	5
26	20	8	100	5
27	15	8	150	10
28	10	8	200	5
29	10	8	100	5
30	15	6	150	10
31	15	6	200	10

Table 4: Design Matrix.

After EDM process, values of both responses are calculated for each experiment. These values are given below in table:

Exp No.	MRR(mm^3/min)	TWR(mm^3/min)
1	12.5000	1.67400
2	8.9743	0.41850
3	14.4230	0.27900
4	8.3333	0.13950
5	20.5128	1.95312
6	8.3333	0.27900
7	5.6089	0.27900
8	5.1282	0.55800
9	9.2948	0.13950
10	24.1987	0.27900
11	8.6598	0.13950
12	10.7371	0.27900
13	15.8653	0.41850
14	9.7756	0.13950
15	19.7115	1.25558
16	10.2564	0.41852
17	9.1346	0.27901
18	3.3653	0.27901
19	6.5705	0.13950
20	10.7371	1.11607
21	9.4551	0.13950
22	9.4551	0.27901
23	11.6987	0.13950
24	7.0513	0.13950
25	4.0064	0.13950
26	17.7884	0.83750
27	12.1795	0.13950
28	7.2115	0.13950
29	8.6538	0.13950
30	9.6618	0.13950
31	11.3782	0.27900

Table 5: Design Matrix.

4. RESULT ANALYSIS

ANOVA tables for both responses are used to analyze the results. These will signify the effect of input parameters on responses and indicates that which parameter is significant in a particular process. It can be seen from these tables that which input parameter affects the response parameters In the present study Minitab software is used to generate ANOVA tables for each response.

4.1 Analysis for Material Removal Rate using ANOVA:

From the above table, it was noticed that at 95% level of confidence ($p< 0.05$) Peak current (A), Duty cycle (B), Pulse on time (C) and powder concentration (D) are significant factors and effect the MRR significantly.

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F ratio**	**P value**
Regression	14	674.118	674.118	48.151	56.98	0.000
Linear	4	618.235	618.235	154.559	182.90	0.000
A	1	428.409	428.409	428.409	506.96	**0.000**
B	1	166.920	166.920	166.920	197.53	**0.000**
C	1	5.315	5.315	5.315	6.29	**0.023**
D	1	17.591	17.591	17.591	20.82	**0.000**
Square	4	23.036	23.036	5.759	6.81	0.002
A*A	1	22.864	6.413	6.413	7.59	**0.014**
B*B	1	0.022	0.002	0.002	0.00	0.958
C*C	1	0.144	0.144	0.144	0.14	0.718
D*D	1	0.006	0.006	0.006	0.01	0.932
Interaction	6	32.847	32.847	5.474	6.48	0.001
A*B	1	20.122	20.122	20.122	23.81	**0.000**
A*C	1	8.312	8.312	8.312	9.84	**0.006**
A*D	1	1.852	1.852	1.852	2.19	0.158
B*C	1	0.645	0.645	0.645	0.76	0.395
B*D	1	0.057	0.057	0.057	0.07	0.798
C*D	1	1.860	1.860	1.860	2.20	0.157
Residual Error	16	13.521	13.521	0.845		
Lack of fit	10	6.971	6..971	0.697	0.64	0.747
Pure Error	6	6.549	6.549	1.092		
Total	30	687.638				

Table 6: ANOVA table for MRR.

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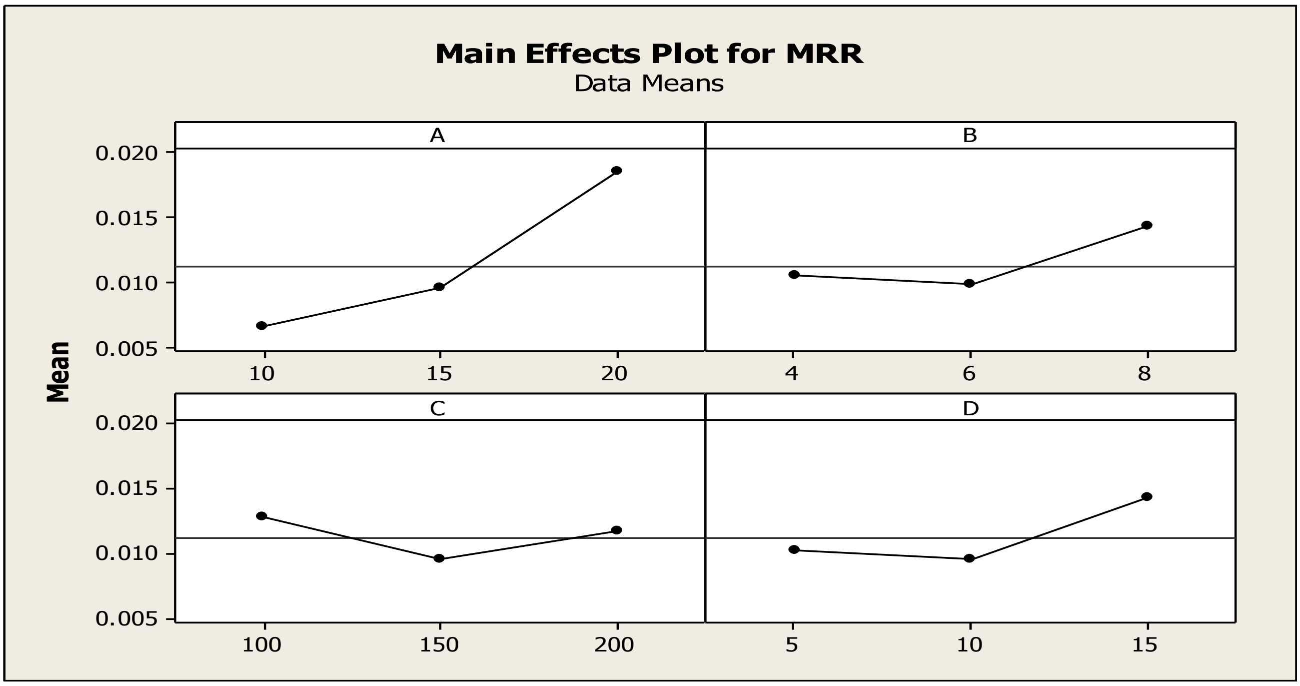
4.1.1 Main Effect Plot for MRR

Main effect plots are drawn showing the effect of various input parameters on the MRR.

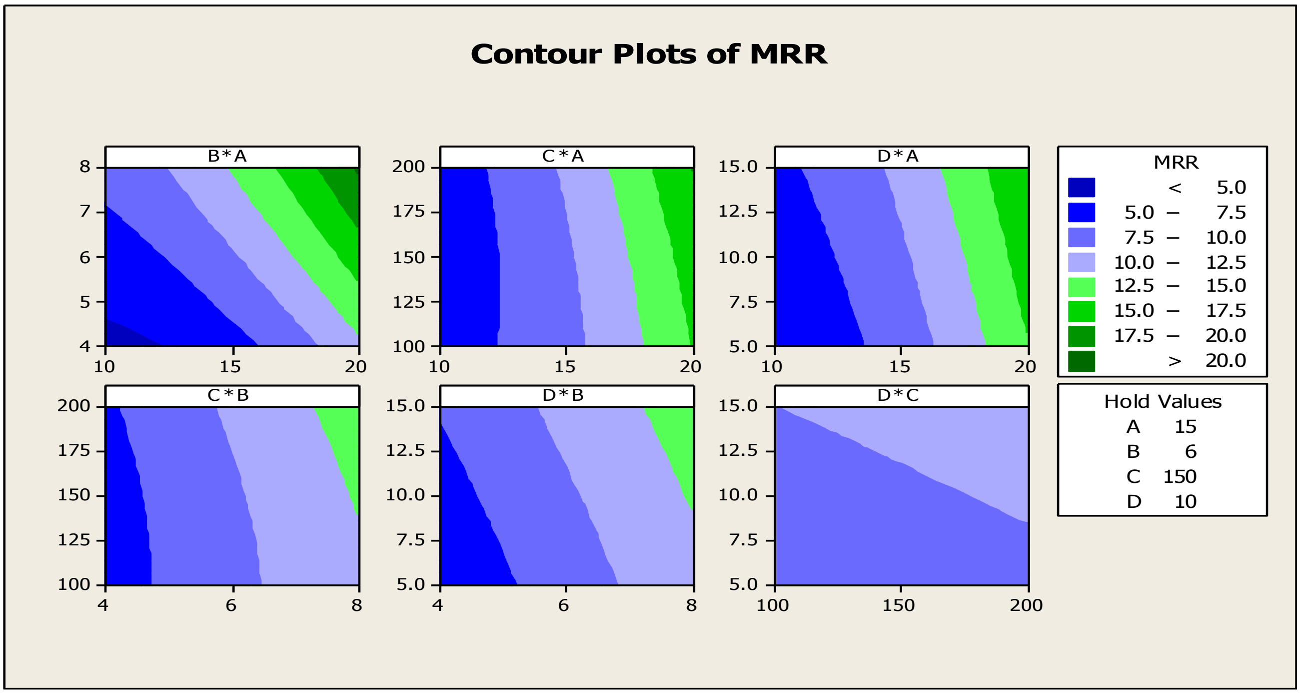
From the main effect plot for MRR, it is clear that Peak current (A), Duty cycle (B), Concentration (D) have highest inclination hence are more significant as compared to Pulse on time (C) which has less inclination and has less significant effect on MRR.



Grabh 1: Main Effect Plot for MRR.

4.1.2 Contour Plot for MRR

High Current, Duty cycle and concentration provide high MRR. Increasing Pulse on time decreases MRR.



Grabh 2: Contour Plots for MRR.

4.2 Analysis of TWR using ANOVA

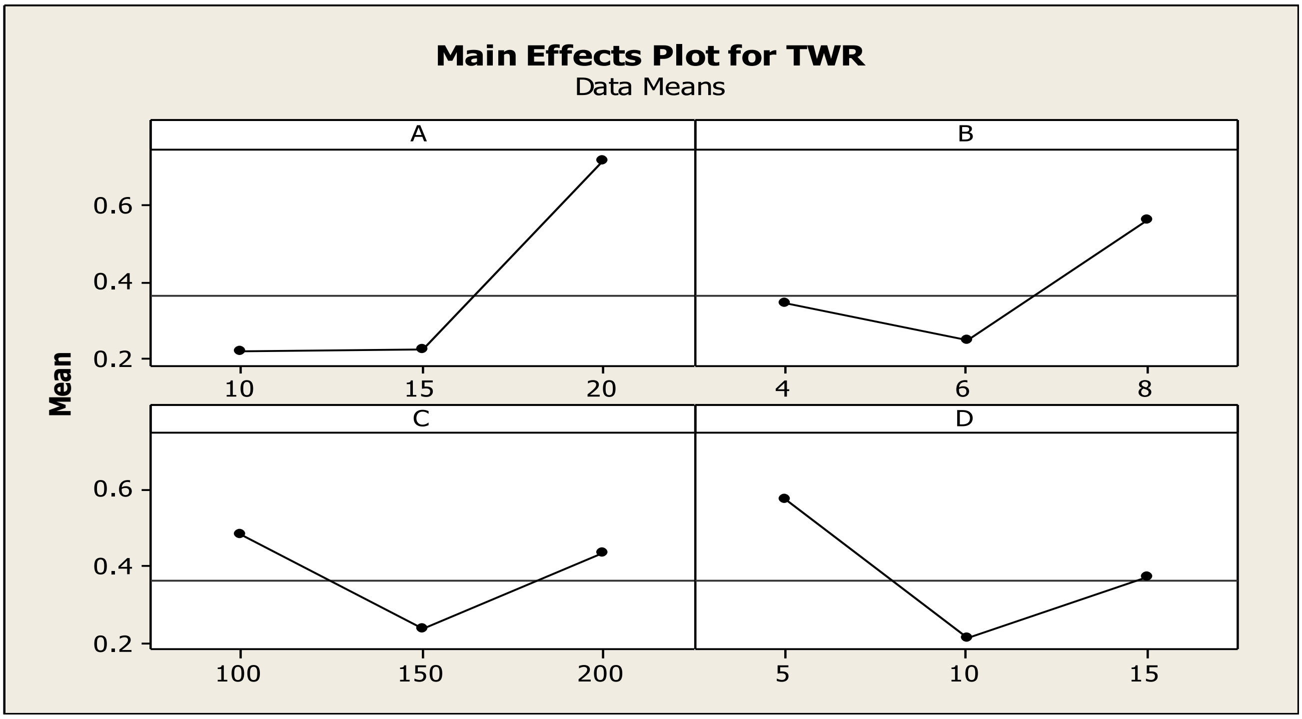
Source	DF	Seq SS	Adj SS	Adj MS	F ratio	P value
Regression	14	5.16232	5.16232	0.36874	4.41	0.003
Linear	4	5.34238	2.34238	0.58560	7.00	0.022
A	1	2.09358	2.09358	2.09358	25.03	**0.000**
B	1	0.00434	0.00434	0.00434	0.05	0.823
C	1	0.24337	0.24337	0.24337	2091	0.107
D	1	0.00109	0.00109	0.00109	0.01	0.911
Square	4	1.03425	1.03425	0.25856	3.09	0.046
A*A	1	0.83550	0.04785	0.04785	0.57	0.460
B*B	1	0.04302	0.00004	0.00004	0.00	0.984
C*C	1	0.04607	0.01132	0.01132	0.14	0.718
D*D	1	0.10965	0.10965	0.10965	1.31	0.269
Interaction	6	1.78569	1.78569	0.29762	3.56	0.020
A*B	1	0.17528	0.17528	0.17528	2.10	0.167
A*C	1	0.23852	0.23852	0.23852	2.85	0.111
A*D	1	0.07792	0.07792	0.07792	0.93	0.349
B*C	1	0.39394	0.39394	0.39394	4.71	**0.045**
B*D	1	0.31149	0.31149	0.31149	3.72	0.072
C*D	1	0.58853	0.58853	0.58853	7.04	**0.017**
Residual Error	16	1.33841	1.33841	0.08365		
Lack of fit	10	1.26613	1.26613	0.12661	10.51	0.005
Pure Error	6	0.07228	0.07228	0.01205		
Total	30	6.50073				

Table 7: ANOVA table for MRR.

From the above table, it was noticed that at 95% level of confidence (p< 0.05) Peak current (A) is the significant factor affecting the TWR.

4.2.1 Main Effect Plots for TWR

Main effect plots are drawn showing the effect of various input parameters on the TWR.

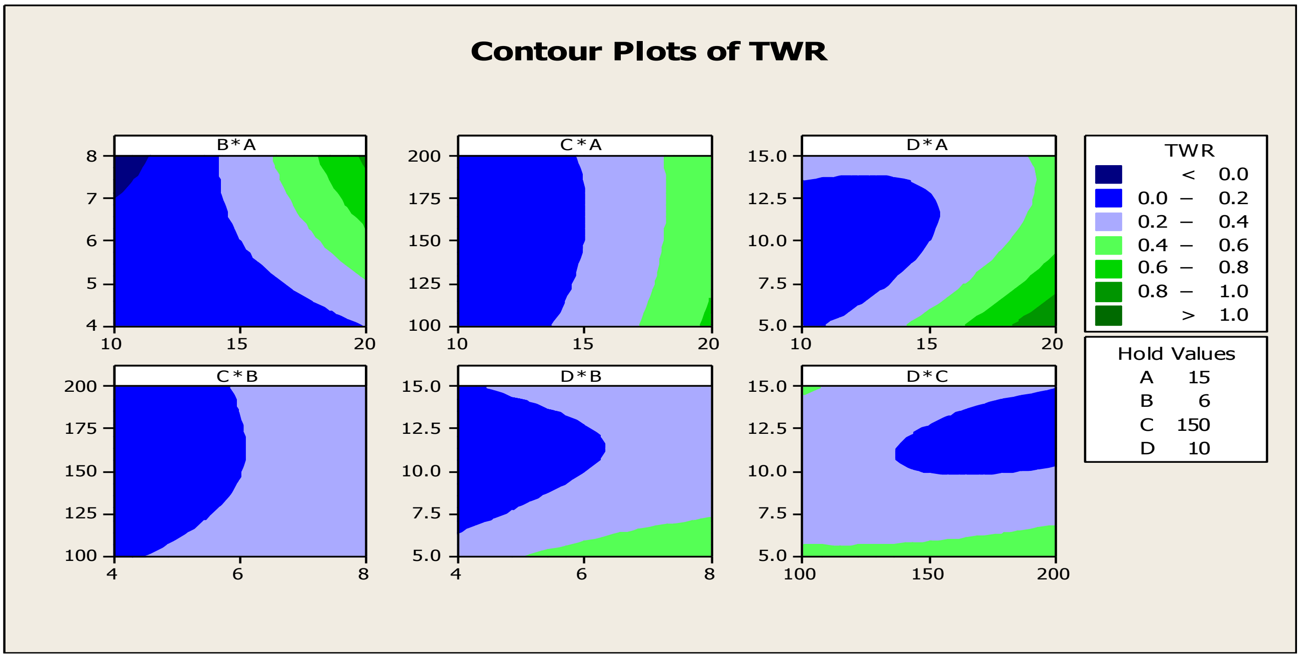


Grabh 3: Contour Plots for MRR.

From the graph it is clear that TWR is directly proportional to peak current (A). With increase duty cycle (B) and pulse on time (C) TWR first decreases then increase. Increase in powder concentration (D) reduces the TWR.

4.2.2 Contour Plot for TWR

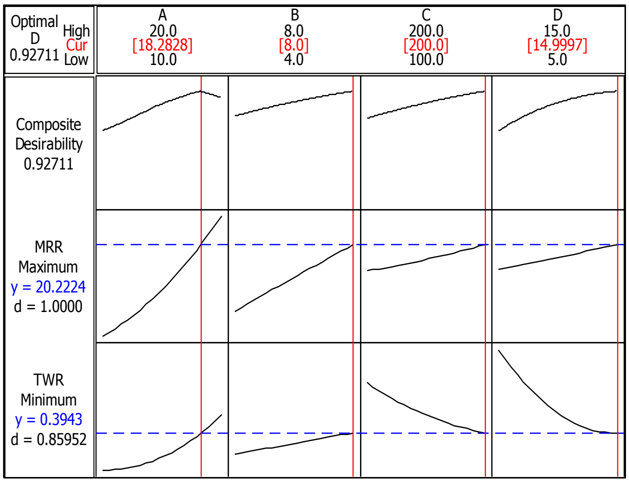
Increasing the concentration (D) and Duty cycle (B) decrease the TWR which is desired. Current (A) and pulse on time has the opposite effect on TWR



Grabh 4: Contour Plot for TWR.

5. DESIRABILITY APPROACH FOR OPTIMIZATION

In order to find out the optimal values of the input variables for maximizing the MRR and minimizing the TWR, desirability approach is used in this study.



Grabh 5: Optimization Plot for MRR and TWR.

From the above graph the following combinations of the input parameters are obtained for maximizing MRR and minimizing TWR.

MRR = 20.2224 mm^3/min
TWR = 0.03943 mm^3/min
Peak current (A) = 18.2888 ampere
Duty Cycle (B) = 8
Pulse on time = 200 μsec
Powder concentration (D) = 14.9997 g/l

Above results are obtained with the composite desirability of 0.92243.

6. REGRESSION ANALYSIS

In order to establish the relationship between process parameters and performance measures, mathematical models are developed. Method of multiple regressions is used to calculate the coefficient of mathematical models

$$MRR=20.3179-2.15212A-0.309466B-0.0834283C-0.214804D+0.0628812A^2+0.112143A*B+0.00288315A*C \quad (4)$$

$$TWR=0.932777-0.0563647A+0.00156912B*C-0.191790C*D \quad (5)$$

7. CONCLUSIONS

1 Peak current, duty cycle and powder concentration are the most significant factors affecting the MRR while pulse on time is less significant
2 Only the peak current among the considered parameters affect the TWR significantly.
3 Increasing current, duty cycle and powder concentration increase the MRR while pulse on time has less effect on MRR.
4 Higher the powder concentration in dielectric lower will be the tool wear.
5 Increase in duty cycle and peak current causes more TWR while pulse on time has very little effect on TWR.

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