Diametral overcut and surface roughness analyze of Cu-TiB_2 powder metallurgy electrode in EDM of Monel 400^{TM}

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Abstract

Electrical discharge machine is one of the essential machine in the precision machining industry. While saying precision it is mandatory to measure the overcut and surface roughness of the machined surface. In this current study focus on evaluating diameteral over cut and surface roughness of Monel 400^{TM} with selected parameter such as discharge current, titanium di boride percentage, pulse on time, flushing pressure. The experiment was designed by using the central composite design approach. A second order regression model was developed for the response variable using response surface. An ANOVA technique was used to test the significance of the model. In the further study the influence of each parameter on response also addressed. It noted that impact of the discharge current and pulse on time play a significant role in diametral overcut and surface roughness. Finally, surface characteristics of machined surface are examined by using scanning electron microscope images.

Keywords: Electrical discharge machining (EDM), Design of experiments (DOE), Diametral overcut (DOC), surface roughness (SR), Powder metallurgy, Response surface methodology, ANOVA

1. INTRODUCTION

Electric discharge machining plays a major role in the die making industry. It can cut any hard conductive material, regardless of its hardness because material removal depends on the electrical properties of metal not mechanical properties [1,2] .Generally conventional electrode copper, brass, graphite are used in EDM industries. Here an approach to be made to machine the material with composite electrode which made through powder metallurgy route[3,4].The advantage of making electrode in powder metallurgy is desirable properties can be achieved by mixing various powder. In die making industry, major emphasis is given in dimensional accuracy and surface roughness of the machined component [5,6].Parveen Goyal has performed the experiments with cn-mn powder metallurgy electrode to analyze diametral overcut, surface roughness, material removal rate, tool wear rate. Pulse current, pulse on time and pulse off time has considered as process parameter [7]. Chinmaya P. Mohanty et al studied the effect of open circuit voltage, discharge current, pulse-on-time, duty factor, flushing pressure and electrode material on material removal rate, tool wear rate, surface roughness and radial overcut [8]. Reza Teimouri and Hamid Baseri reported the influence of process parameters such as pulse current, pulse on time and pulse off time on electrode wear rate and overcut [9]. Vikas et al have addressed the effect of the various input parameters like Pulse on time, discharge current, Pulse OFF time, and gap voltage over the diametral over-cut for an EN41 material using Taguchi method [10]. From the literature, it found that only few researchers have addressed the diametral over cut and surface roughness using powder metallurgy electrode. But no author yet tried with Cu-TiB2 powder metallurgy electrode to analyse diametral overcut and surface roughness. So here an attempt has been made to analyse the performance of Cu-TiB_2 electrode with discharge current,TiB_2 (%), pulse on time and flushing pressure on monel 400^{TM} material.

2. MATERIALS AND METHODS

2.1. Work piece Material

Monel material is used as a work piece. The material having higher corrosive resistance and it find major application in marine industries. The chemical properties of the material is shown in table 1.the material initially sliced into the cross section of 20 X 20. The thickness of the work piece is about 5 mm.

Table : 1 Chemical composition of Monel 400^{Tm}

Component	Ni	Cu	Fe	Mn
Weight Percentage	63	28-34	2.5	2

2.2. Tool Electrode Material

Powder metallurgy based composite electrode is used as tool material. The electrode was prepared by mixing various percentages of titanium di boride and copper powder. The mixing was done on v blender for about 5 hours to get uniform mixture. The mixer was uni axialy compacted in a hydraulic press with pressure of 14 ton. The size of the compacted pellet is about 12 mm diameter and 5 mm thickness. The green compacted electrode is strengthened by a sintering process using tubular furnace with a temperature of 800^{0}C. Finally sintered composite electrode is brazed at the end of copper rod for holding purpose.

2.3. Dielectric Fluid

Commercial grade EDM oil is used dielectric medium. The dielectric medium plays a major role in removing debris between tool and work piece. The presence of more debris between work piece and tool lead to short circuit in EDM. It also act as coolant to remove the heat from the working surface. The side flushing method was employed for removing the debris.

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2.4. Response surface modeling

Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques that are utilizable for modeling and analysis. In which response is influenced by several input variables and the objective is to find the relation between the response and the input variables. Discharge current, titanium di boride percentage, The Pulse on time (Ton), flushing pressure are the machining variable which is considered for the investigation.

$$y = a_0 + \sum_{i=1}^{n} a_i x_i + \sum_{i=1}^{n} a_{ii} x_i^2 + \sum_{i<j}^{n} a_{ij} x_i x_j + \varepsilon$$

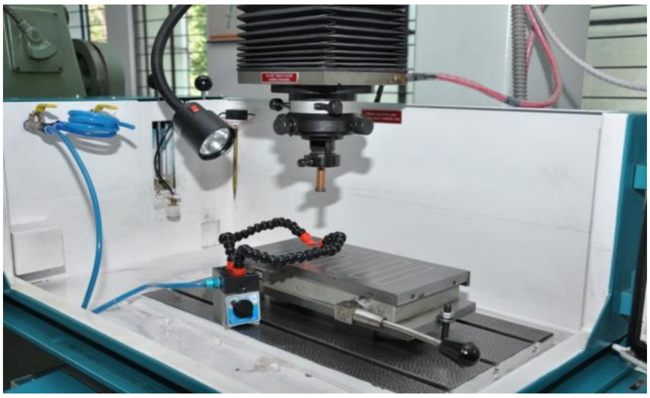

Figure. 1 EDM machine set up

3. EXPERIMENTATION

In this experimentation Electra 5535 EDM machine was used to machine monel 400 TM using Cu-TiB2 electrode with selected process parameter. Central composite design (CCD) has been selected to design the experiments. Generally CCD preferred to observe the response due to precise predictions of all responses. It's composed of the sixteen star points (+1,-1), six central points (coded level 0) and Eight axial point (+2, -2). The designed experiments with various parameters are given in Table 2. The required number of work pieces was prepared for to conduct the experiments.

Table 2: Parameters and their levels

Variables	Symbol	Levels				
		-2	-1	0	1	2
Titanium diboride, TiB_2 (wt.%)	A	4	8	12	16	20
Pulse current, (Ip) (A)	B	2	4	6	8	10
Flushing pressure,(P) (Mpa)	C	0.4	0.6	0.8	1	1.2
Pulse on-time,(Ton)	D	10	20	30	40	50

3.1. Response variable measure(DOC & SR)

Dimensional accuracy of the machined component is always emphasized in precision machining. So diameteral overcut of the machined surface can be measured by the deviation between the maximum diameter of the cavity and electrode diameter. It is calculated from equation 1.The surface roughness of the machined surface is measured using taylor and surf roughness tester. Generally EDM machined surface more crater because of discharge energy.

$$DOC = \frac{dc - dt}{2} \text{(mm)} \quad (1)$$

d_c – Maximum diameter of crater (mm)

d_t – Diameter of the tool (mm)

3.2. Modeling the response

The experiment was conducted based on central composite design and recorded values of diametral overcoat and surface roughness has shown in the table 3. The observed values are analyzed to know the effect of each parameter on DOC and surface roughness. The seconder order regression model is used to correlate the relationship between the process variable and response. The developed model for DOC has shown in the equation 2. The reduced model results indicate that the model is significant. The coefficient of variation for DOC is 4.47 and the R^2 and adjacent R^2 value is 96.7, 94.96 respectively. The insignificant terms are removed and the final response equation for DOC is given below,

DOC= +0.20-0.012*A+0.041*B-2.500E-003*C-8.333 E-003*D (2)

Design expert 7 software is used for analyze the impact of process parameter on response. In the surface roughness mathematical model insignificant terms are removed by a backward propagation method. The coefficient of variation of the SR is 2.99 and R^2 and adjacent R^2 value is 96.38, 96.44 respectively. The final response equation for surface roughness is given below,

SR = +4.62+0.22 * A+0.53 * B+0.13* C+0.21* D (3)

The developed model for the diametral overcut and surface roughness equation was used for further analysis. The adequacy of the developed model was checked by using ANOVA. The results of ANOVA are given in table 4 and 5. Checking of a goodness of fit of the model is very much required to analyze the data. The checking of model adequacy includes the test for significance of the regression model, test for significance on model coefficients, lack of fit test. This fit summary recommended that the quadratic model is more significant for analysis of diametral overcut and surface roughness.

4. RESULTS AND DISCUSSIONS

4.1. Effects of Process Parameters on DOC

Diametral overcut play important role in a precision machining. Precision and accuracy of the product represent by reduction of overcut.

Table:3 Experimental design and results for DOC and SR

	A	B	C	D	Observed Responses	
Run	Titanium diboride, (wt. %)	Pulse curren t (A)	Flushing pressure (Mpa)	Pulse on-time (µs)	Diamet ral overcut (mm)	Surfa ce rough ness, (µm)
1	1	1	-1	-1	0.25	4.915
2	1	-1	1	-1	0.17	4.43
3	0	-2	0	0	0.12	3.319
4	0	0	0	2	0.19	4.926
5	-1	-1	1	-1	0.18	3.749
6	0	0	-2	0	0.21	4.53
7	0	0	0	-2	0.22	4.1
8	-2	0	0	0	0.22	4.299
9	1	-1	1	1	0.13	4.615
10	-1	-1	-1	1	0.18	3.584
11	0	0	2	0	0.19	4.971
12	-1	-1	1	1	0.18	4.209
13	1	-1	-1	-1	0.17	4.039
14	1	-1	-1	1	0.13	4.511
15	0	0	0	0	0.21	4.638
16	0	0	0	0	0.2	4.703
17	0	0	0	0	0.2	4.708
18	0	0	0	0	0.19	4.779
19	0	0	0	0	0.19	4.789
20	0	0	0	0	0.19	4.803
21	-1	-1	-1	-1	0.18	3.45
22	2	0	0	0	0.18	4.941
23	0	2	0	0	0.27	5.65
24	-1	1	-1	-1	0.27	4.599
25	1	1	1	1	0.23	5.722
26	-1	1	-1	1	0.26	4.97
27	-1	1	1	-1	0.26	4.805
28	1	1	-1	1	0.23	5.446
29	-1	1	1	1	0.25	5.274
30	1	1	1	-1	0.25	4.996

Table. 4: ANOVA for DOC

Source	SS	df	MS	F Value	p-value	
Model	0.0459	10	0.00459	55.66	< 0.0001	Signi ficant
A-A	0.0032	1	0.00326	39.61	< 0.0001	
B-B	0.0400	1	0.04001	485.30	< 0.0001	
C-C	0.00015	1	0.00015	1.81	0.1933	
D-D	0.00166	1	0.00166	20.21	0.0002	
AB	1E-04	1	1E-04	1.21	0.2845	
AC	2.5E-05	1	2.5E-05	0.30	0.5883	
AD	0.00062	1	0.00062	7.58	0.0126	
BC	2.5E-05	1	2.5E-05	0.303	0.5883	
BD	2.5E-05	1	2.5E-05	0.303	0.5883	
Residual	0.00156	19	8.25E-05			
Lack of Fit	0.00123	14	8.809E-05	1.321	0.4048	not signi ficant
Pure Error	0.0003	5	6.666E-05			
Cor Total	0.0474	29				

Figure 2 shows the effect of TiB_2(%) and pulse current on diametral overcut.It shows that diameteral overcut increases with an increase in discharge current. While increasing the discharge current lead to increase in spark energy resulting in increase of temperature between the tool and work material. The higher temperature would produce wider and larger craters on the machined surface, increases the radial overcut. In the same plot increase in percentage of TiB2 (%) reduces the diametral overcut due to the higher melting temperature of TiB2 particles. Fig. 3 shows the variation of diametral overcut with pulse on time and flushing pressure. The plot shows the gradual increase in DOC with increase of pulse on time.While

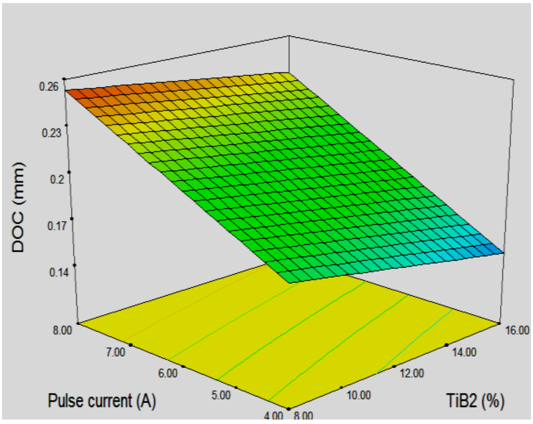

Figure.2. Response graph of DOC Vs I_P & TiB_2

increase in pulse-on-time increase the sparking time, results in an increase of the radial overcut on the machined surface due to increase in spark energy. In same plot, increase in flushing pressure lead to minimize the overcut.

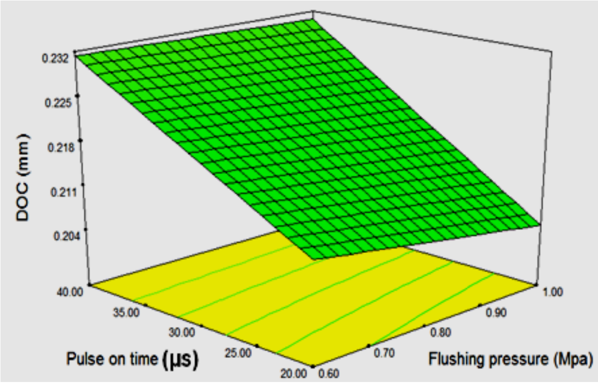

Figure.3. Response graph of DOC VS Ton & P

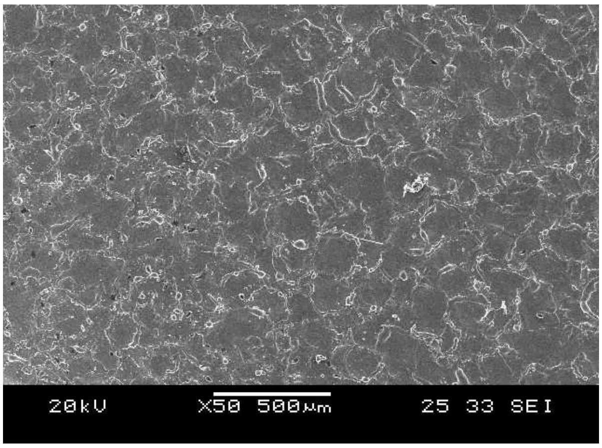

Figure. 4 SEM micrograph at a TiB_2=4% (Ip=6 A,Ton=30 µs P=0.8 Mpa)

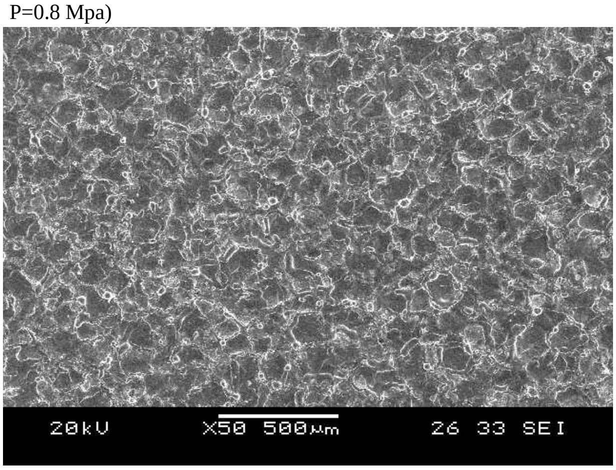

Figure. 5 SEM micrograph at TiB_2=20% (Ip=6 A,Ton=30 µs P=0.8 Mpa)

It is because removing the debris will minimize the short circuit. However, it is observed that discharge current have more influence on diametral overcut compare with other parameter. Fig. 4, 5 shows SEM micrograph comparison of the machined surface at low percentage TiB2 (4%) and a high percentage of TiB2 (20%) with setting of Ip=6 A, Ton=30 µs P=0.8 Mpa. It found that more amount of electrode material has transferred to the working surface

Table: 5 ANOVA for SR

	SS	df	MS	F Value	p-value	
Model	9.66	10	0.97	50.58	< 0.0001	Significant
A-A	1.18	1	1.18	61.71	< 0.0001	
B-B	6.83	1	6.83	357.6	< 0.0001	
C-C	0.42	1	0.42	21.9	0.0002	
D-D	1.04	1	1.04	54.55	< 0.0001	
AB	0.086	1	0.086	4.5	0.0474	
AC	0.021	1	0.021	1.11	0.3056	
AD	0.014	1	0.014	0.75	0.396	
BC	0.019	1	0.019	1	0.3305	
BD	0.045	1	0.045	2.34	0.1424	
CD	6.89E-03	1	6.89E-03	0.36	0.5552	
Residual	0.36	19	0.019			
Lack ofFit	0.34	14	0.024	5.93	0.03	Not significant
Pure Error	0.021	5	4.12E-03			
Cor Total	10.02	29				

when machining at a high percentage of TiB_2 (20%).

4.2. Effects of Process Parameters on Surface Roughness

The surface finish is the most attributing response, particularly in die and mold making industries. So essential care is required in manufacturing. Figure 6 shows that the participation of TiB_2% and pulse on current in SR, while keeping other two parameters at central level. When increase in TiB_2 % will decrease the surface roughness. It can be attributed to the deposition of electrode material on the work piece causing a reduction in surface cracks resulting in decrease in SR. When an increase in pulse current promotes the surface roughness due to the high energy, creates a crater on the surface. At some point peak current influence is more in surface roughness though having high content of TiB_2%. The graph is plotted between flushing pressure and pulse on time to the response SR as shown in Figure 7. It is understood that increasing in flushing pressure lead to decrease in SR, because of removing of debris between the work piece and tool. While an increase in pulse on time it direct to increase in SR due to the energy concentration for longer time. Hence it is decided that pulse current played a major role than other parameter.

5. CONCLUSION

The experiments were performed to evaluate the performance of Cu-tib2 electrode in EDM Electra 5535 machine with monel 400^{TM} nickel based alloy work material .The effect of discharge current, titannium diboride percentage, pulse on time and flushing pressure on diametral overcut and surface roughness have been addressed. Using RSM based design, significant factor and interaction effect was studied. The following conclusion is made from the analyses:

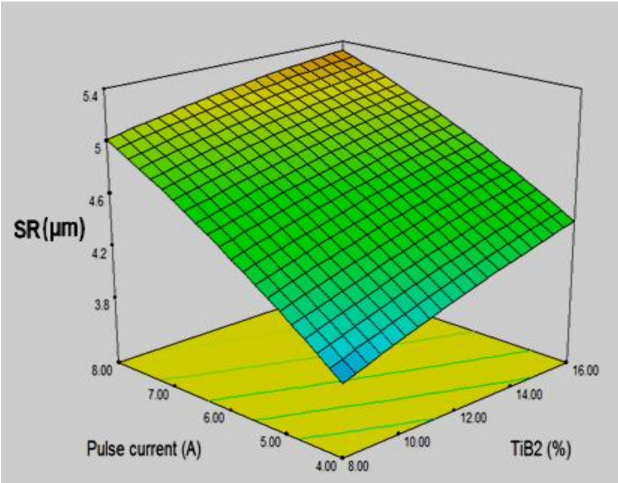

Figure.6. Response graph of SR VS I_P & TiB_2

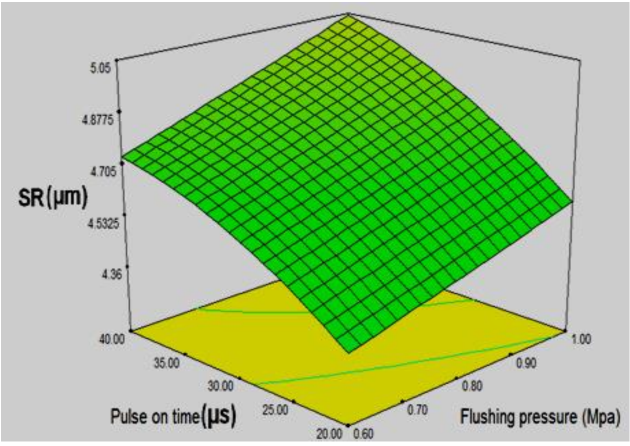

Figure.7. Response graph of SR VS Ton & P

i. The diametral over cut decrease with increase in percentage of titanium diboride but the effect is very minimum and diametral over cut increases with increase in pulse current.

ii. The diametral over cut increases with increase in pulse on time but diametral over cut dereses with increase in flushing pressure. However pulse on time has more impact when compare with flushing pressure.

iii. The surface roughness value getting increases with increase with pulse current but decreases with increase in titannium di boride percentage.

iv. The surface roughness value increases with increase in pulse on time, mean time it decreases with the increase in flushing pressure.

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