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Abstract: The technological challenges faced by any industry in machining OHNS steel in the use of tools and die by conventional processing techniques point to tool wear rate and poor surface finish. To overcome these, Electrical Discharge Machine (EDM) process, an inevitable Unconventional Machining process is used in the precision and micro component manufacturing industries. Here an attempt has been made to machine OHNS material with a lately developed copper titanium diboride (Cu-TiB_2) of 16% wt of TiB2 is prepared through powder metallurgy route which enhances the shortcomings obtained in conventional techniques. The experiment models are made to optimize through statistical Response Surface Methodology (RSM). The experiments were conducted by considering the effect of pulsating direct current, pulse time ON, and pressure flushing. Then, ANOVA is executed to predict the impact of each parameter and its significance concerning the output responses of roughness (SR) and Volume of Material removed (MRR). The equation developed for each output response and then the optimum process parameters obtained in the desirability based multi-objective optimization using RSM. The minimum surface roughness and maximum material removal rates are attained at 14 A, 16(µs) and 0.6 MPa. Then the confirmation experiments were carried to validate the model and it is witnessed that the error percentage attained was within the satisfactory range.

Keywords: Electrical Discharge Machine (EDM), Roughness (SR), Volume of material removed (MRR), Response Surface Methods (RSM).

1. Introduction:

The Spark Machining was a thermo-electric material removal process thoroughly used applied unconventional machining processes to machine hard materials with complex geometry. This method involves a controlled erosion of materials that are electrically conductive exercising initial repeated electric sparks produced between the conductive work and tool electrode that are separated by a dielectric medium.

The Powdered Metallurgy (PM) process facilitated the development of the electrode tool which was acquired by the combination of cobalt (Co) and Chromium (Cr) powders which were ultimately used in the Electric Discharge Machining process (EDM).The image generated by Energy Dispersion (EDaX) had analyzed spectra which had a surface containing elements of O, Al, Cr, Fe, Co and C at its zenith. The alloying of mild steel with the electrode was established through this data[1]. Modification of the high carbon steel surface was progressed using an electrode consisting of a combination of Copper-Chromium-Nickel by the method of powdered metallurgy through EDM. This particular electrode tool produced, that was utilized in the EDM process had produced better micro hardness for the machined surfaces of the workpiece[2] .The deposition of the hard layers throughout the Electric Discharge Machining process begins accompanied by the erosion of the compact electrode tool which was produced by the process of powdered metallurgy resulting in the generation of borides and hard carbides. The zenith of Titanium, carbon, and boron make the presence of tool material affirmative[7].

Copper is one of the most widely and efficiently used earth elements attributing to its various material properties such as electrical conductivity, ductility, malleability, elasticity, and strength. Copper is also said to have very good potential for oxidation. This being included in the production of the Cu-SiC composite electrode tool by powdered metallurgy which in turn is used on a workpiece through EDM to obtain a copper matrix [8]. Selective Laser Melting (SLM), a conventional tool electrode manufacturing process was incorporated to deliver a tungsten carbide tool electrode which was depended on the volume energy density to account for the multiple varieties of microstructures. Three phases of factors namely build direction processing stage and parameter set were driven into consideration for the tool composition. As the presence of the cobalt element is minimized in the electrode, the further procedure to be undergone by the electrode for cobalt decrease is also neglected[3,6]. Electric discharge machining of oil hardening on shrinking tool steel where the fabrication of metal matrix composite electrode by combining Al_2O_3 with copper powder was operated where the Voltage and current are the established parameters in which the wear rate of the tool, removal rate of material, percentile wear rate, the roughness of surface were established as output parameters. Various examinations that were accounted for Cu-TaC(Copper tantalum) electrodes generated by the process of powdered metallurgy were conducted with two different compositions (Cu with 30% and 50% wt Tac). Using the Taguchi method to correlate the usefulness of the electrodes that were produced through the process of powdered metallurgy that is being compared to the conventional copper electrode[4,5].

Another challenging parameter of the spark machining is the Volume of Material Removed (MRR). The electrode formed by the powdered metallurgy will have a different composition of the copper with chromium and molybdenum to replicate a fair volume of material removed. Both the electrode tool upon being fused onto the workpiece has ascertained material deposits onto the workpiece[9].

To further improvise the surface hardness and the abrasive wear resistance of the workpiece, an electrode tool using the combination of copper powder and boron carbide powder is manufactured by the process of powder metallurgy. Only through this process, the weight percentage of the boron carbide powder (B_4C) is about 20% in composition with the copper powder electrode. The workpiece being EDMed using this particular electrode and analyzed produced hardness 4 times better than the other workpiece, and colossal reduction up to 65% - 78% in the abrasion wear [10]. In this paper the focus on the Copper- Titanium diboride of 16% wt electrode–prepared through Powder Metallurgy route effects on the OHNS in EDM machine was studied.

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2. Experimental procedure:

The material used for this investigation is an OHNS material of 25×25×5mm with a chemical composition listed in Table1.

Table 1. Chemical composition of High OHNS Steel (wt %)

Element	C	Mn	Cr	V	Ni	Mo	Iron
Composition	0.95	1.15	0.49	0.19	0.05	0.13	Balance

It is widely used in tool and dies material, milling cutters, and gauging tools. The Copper-Titanium diboride electrode is prepared in the different composition of 4, 8, 12, 16, 18 % wt is prepared using powder metallurgy route by mixing copper powder (44 µm) and titanium diboride (44 µm) in a V-Blender for a time period of 10 hours then the blended powder of 2.5g is transferred to the die contains 12mm in diameter and pressed using a hydraulic pressing machine with a force of about 14000kg. The prepared powder metallurgy tool is then sintered using a tubular furnace at a temperature of 1100°C in a closed environment, in continuous of that brazing is performed to mount to the Sparking Machine. It is found that the 16%wt produces an optimum wear rate of tool which is significant in roughness [11]. Present investigation, focus on tool electrode of TiB_2 –Cu is used as shown in Figure.1

Figure 1. Copper –Titanium diboride electrode

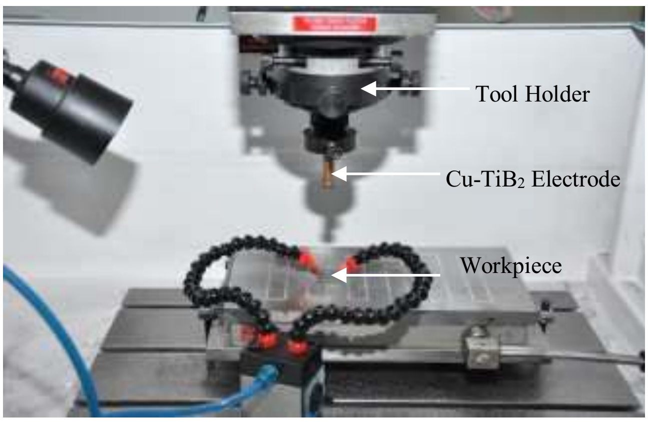

Figure 2. Set up for EDM Experiments.

Table 2. EDM operating condition

Working condition	**Description.**
Electrode material	Copper –titanium diboride
Spark Gap	0.1mm
Dielectric fluid	EDM oil
Specimen material	OHNS Steel Material
Voltage	50 Volts
Pulse Off time	20 µs

Twenty experiments are carried out using an Electra 5535 EDM machine set up as shown in Figure. 2 and its operating condition are shown in Table 2. The input parameters like Pulse Direct current (Ip) Pulse time ON (T_n), and Pressure flushing (Fp) at three levels are considered as shown in Table 3. The specimens are machined using EDM in which EDM oil is used as a dielectric medium. The roughness (SR) is measured using Roughness tester SJ-210 Mitutuyo as shown in Figure.3 three readings of each specimen were noted on various points on the surface undergone spark machining. Also, Volume of Material removed (MRR) is intended by the mass loss of the workpiece by a digital weighing scale with 0.001g accuracy and the time is taken by each trial to a depth of 1mm.

$$MRR = \frac{(Wi-Wf)}{t} \text{ g/min} \quad (1)$$

Where Wi –weight of the Work in g before Machining ,Wf- weight of the work in g after machining , t-time taken to complete machining in minutes.

Table 3. Level of EDM Machining Parameters

Factors	**Variables**	**Units**	**Levels**				
			-1.68	**-1**	**0**	**1**	**1.68**
A	Pulse Direct Current (I)	Amperes	2	5	10	15	18
B	Pulse Time ON- T_n	Microseconds	10	14	20	25	28
C	Pressure Flushing (F)	Mpa	0.3	0.6	1	1.4	1.7

Figure 3. Surface roughness tester

3. Experimental design:

Statistical response surface methods using rotatable centred central composite approach is utilized in design of experiments. The location of the optimum is unknown pair to running the experiment, it make sense to use a design that provides equal precision of estimation in all directions. A central composite is made rotatable by the choice of α.

3.1 Developing the design Matrix:

Pulse Direct current (I) Pulse time ON (T_n), and flushing Pressure (F) are considered as the influencing inputs in the machining of OHNS Steel. The Design of experiments is a noteworthy statistical tool that describes the series of steps to perform experiments Sequentially. It is designed based on three input parameters at three levels which contains ten star points (+1,-1), Axial points and centre Points of six each with 20 trials with a value of α =1.68 are carried out based on the run order and output responses obtained is shown in Table 4.

3.2. Development of mathematical models:

Using the experimental result which is obtained from the central composite rotatable DoE and applying regression analysis, the modelling of the selected response with a small quantity of independent input process parameter can be gained. The response surface exists expressed as follows.

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

In the above equation,

y – Surface Roughness (response parameter)

x_i and x_j - input variables

a_i, a_{ii}, and a_{ij} – Coefficient of the linear terms, quadratic terms and interaction effects respectively.

Table 4. Design of experiments and its results

Run	Pulse Direct Current (I)	Pulse time ON (T_n)	Pressure Flushing (F_p)	SR (µm)	MRR (g/Min)
1	10	28	1	8.08	0.108
2	2	20	1	4.758	0.021
3	10	10	1	3.78	0.035
4	10	20	1	7.192	0.134
5	10	20	1	8.177	0.162
6	15	25	0.6	8.237	0.216
7	15	25	1.4	8.57	0.22
8	10	20	1	7.5	0.127
9	5	14	0.6	5.251	0.072
10	5	25	1.4	6.596	0.036
11	15	14	0.6	6.026	0.134
12	10	20	1	7.166	0.126
13	15	14	1.4	10.019	0.225
14	18	20	1	10.21	0.225
15	10	20	1	6.457	0.124
16	10	20	1	7.239	0.106
17	10	20	1.6	6.208	0.149
18	5	14	1.4	5.129	0.031
19	5	25	0.6	7.269	0.039
20	10	2	0.3	6.208	0.149

4. Statistical Analysis:

Statistical analysis is performed using ANOVA to know about the influencing parameters of selected process and their output responses. Table 5 and 6 shows the ANOVA result of roughness parameter and volume of material removed with 95% confidence level.

Table 5. Analysis of Variance for Surface Roughness.

Source	Sum of Squares	df	Mean Square	F-value	p-value	Status
Model	43.47	9	4.83	6.39	0.0039	significant
A-Pulse Current (I_p)	23.14	1	23.14	30.62	0.0002	
B-Pulse On(T_{on})	9.65	1	9.65	12.77	0.0051	
C-Flushing pressure(F_p)	0.9129	1	0.9129	1.21	0.2975	
AB	0.9268	1	0.9268	1.23	0.294	
AC	3.28	1	3.28	4.34	0.0639	
BC	2.22	1	2.22	2.93	0.1176	
A^2	0.603	1	0.603	0.7979	0.3927	
B^2	1.71	1	1.71	2.27	0.163	
C^2	0.8762	1	0.8762	1.16	0.3069	
Residual	7.56	10	0.7558			
Lack of Fit	6.01	5	1.2	3.87	0.082	not significant
Pure Error	1.55	5	0.3105			
Cor Total	51.02	19				

4.1. Developing the final model:

The Mathematical regression model was developed for the output responses of the material removal rate and was evaluated by F-test . It was found that the model F-value for the surface roughness is 6.39 and the lack of fit is 3.87 .Also ,the model f-value for Material removal rate is 15.79 and the lack of fit is 2.38 . This result implies that the mathematical model was statistically evaluated and it's proven the significance of the developed model. ANOVA was done to check the adequacy of the model. Insignificant factors are eliminated by a backward elimination method to improve the significance of the model. The developed model for SR and MRR is shown in Equation (3) and (4)

$$SR = -7.89824 + 0.01972 *A + 0.960470 *B + 5.19353 *C - 0.012377(A*B) + 0.320062(A*C) - 0.239261 (B*C) + 0.008182 A^2 - 0.011400B^2 - 1.54109 *C^2 \quad (3)$$

$$MRR = -0.127073 - 0.003361 *A + 0.024696 *B - 0.129203 C + 0.000477 A*B + 0.008687A*C - 0.002784 A*C - 0.000029 A^2 - 0.000626 B^2 + 0.052977 C^2 \quad (4)$$

Where A –Pulse Direct Current B-Pulse time ON, C- Pressure Flushing.

Table 6. Analysis of Variance for Volume of Material Removed

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	**Status**
Model	0.0807	9	0.009	15.79	< 0.0001	significant
A-Pulse Current (I_p)	0.0675	1	0.0675	118.92	< 0.0001	
B-Pulse On(T_{on})	0.0022	1	0.0022	3.81	0.0796	
C-Flushing pressure(F_p)	0.0002	1	0.0002	0.3356	0.5752	
AB	0.0014	1	0.0014	2.43	0.1502	
AC	0.0024	1	0.0024	4.26	0.0661	
BC	0.0003	1	0.0003	0.5288	0.4838	
A^2	7.39E-06	1	7.39E-06	0.013	0.9114	
B^2	0.0052	1	0.0052	9.09	0.013	
C^2	0.001	1	0.001	1.82	0.2066	
Residual	0.0057	10	0.0006			
Lack of Fit	0.004	5	0.0008	2.38	0.1811	not significant
Pure Error	0.0017	5	0.0003			
Cor Total	0.0863	19				

4.2. Consequence of input Variables on the surface roughness:

Roughness is an important influencing parameter on machining of OHNS Steel. Figure 4, 5 and 6 depicts the relationship between the roughness with three input parameters and its interactions represented in a 3D plot surface. It is observed from the Figure 4. Increase in Pulse direct current 5 A to 15 A increases in roughness occurs due to generation of large discharge energy between the tool and workpiece forms a crater wear surface on the workpiece [17] and Pulse time ON increases tends to increases the roughness. At a minimum pulse direct current (5A) and pulse time ON (14μs) produces a minimum roughness. Figure 5 represents that the increases in roughness causes the pulse direct current increasing but it has attained maximum surface roughness value at minimum Pulse direct current of 5A and 0.6 Mpa pressure flushing when compared to Figure 4.

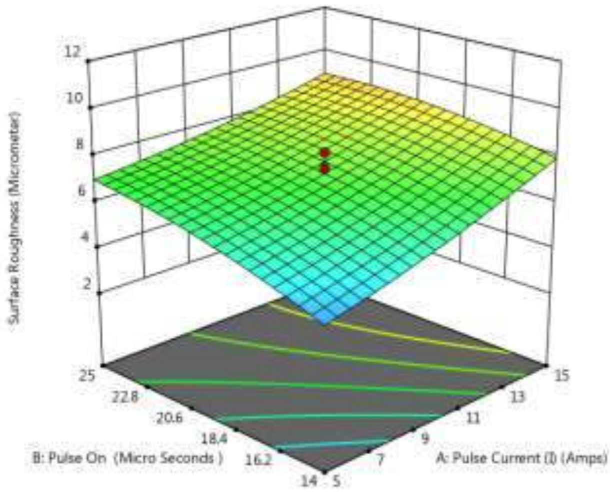

Figure 4. Effect on Roughness With Pulse Direct current and Pulse Time ON

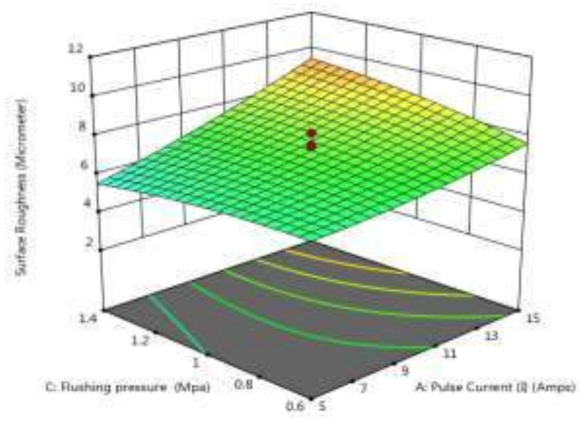

Figure 5. Effect of Roughness with Pulse Current and Pressure Flushing

Due to the increase the number of sparks with respect to time [12-13]. The pressure flushing has negligibly lesser effect on roughness. Figure.6 demonstrates the increase of pulse current increase the surface roughness that forms a stable arc in the spark gap [11,14] and increase of pressure flushing slightly increases the roughness.

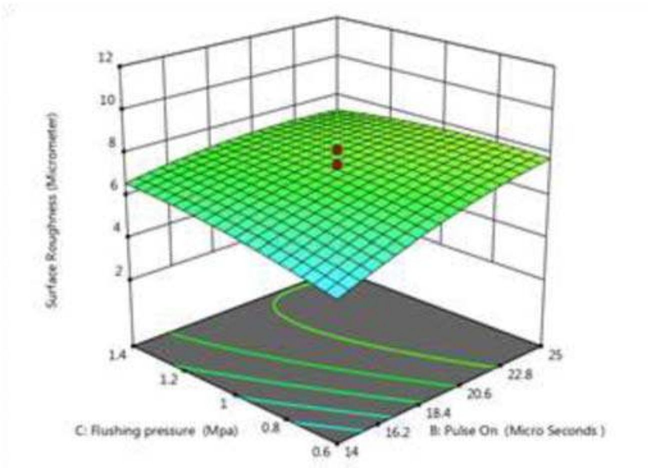

Figure 6. Effect of Roughness with Pulse time ON and Pressure Flushing

4.3 Consequence of input variables on the Volume of Material removed:

The Volume of material removed is a parameters that is to be considerably important in EDM to the three input parameters and their interaction is illustrated in 3D Plot surface as shown in Figure 7,8 and 9. Figure.7 indicates upon further increase in pulse direct current and pulse time ON the Volume of Material removed is increases it implies that higher discharge energy .When the pulse current (5A) and pulse on time (14µs) produce a maximum Volume of material removed. Figure 8. Implies that increase of pulse direct current increases the volume of material removed is slightly higher than that as discussed in Figure.7.

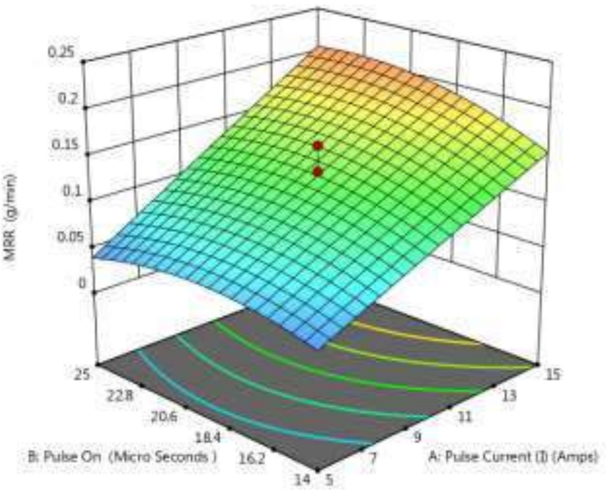

Figure .7 Effect of MRR with Pulse Direct current and Pulse time ON

The pressure flushing increases Volume of material removed increases slightly Figure.9 represents that the volume of Material removed increases on increasing the pulse time ON. From both the cases it is observed that pressure flushing have a less significant factor either it increases on MRR or decreases on SR. It has been confirmed in the ANOVA result of F-ratio of 3.81 has a lesser value compared to other two input parameters.

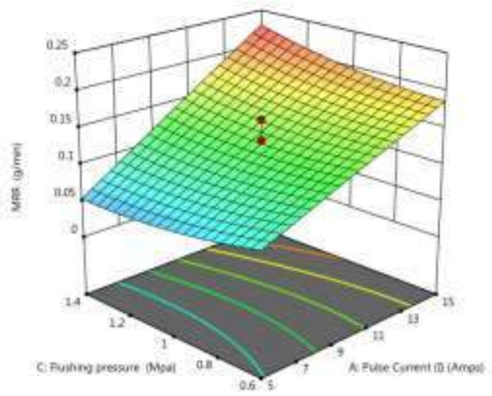

Figure. 8. MRR Vs Pulse current and pressure flushing.

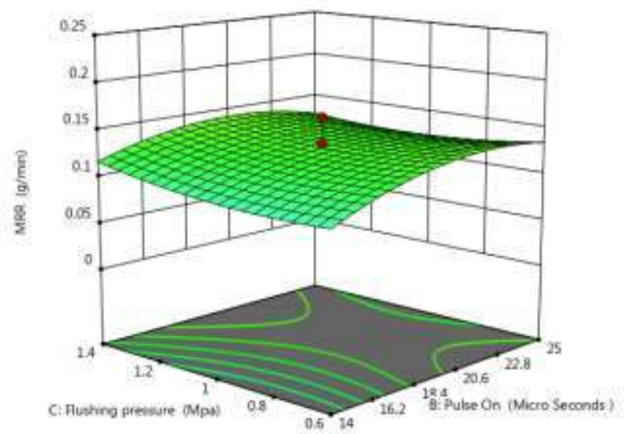

Figure. 9. MRR with Pulse time ON and pressure flushing

5. Confirmation experiments:

In order to verify the developed surface roughness and MRR regression model has been valued with the aid of Design experts 12.0. The desirability value falls between zero and one .The solution with higher desirability is considered as the optimum parameter is considered as shown in table 7. The experiments were conducted again with three trials for the conformity of experiments the same is feed into the developed equation to find the predicted value .Then experimental values are compared with the predicted value as shown in Table 8.The errors values calculated are in satisfactory level of less than 10% .

Table .7 Optimum process parameters

Parameters	Optimum Value
Pulse Current	14 A
pulse on time	15 **µs**
Flushing Pressure	0.6 Mpa

Table 8. Predicted and observed value of OHNS Steel

Output Response	Objective	Calculated Values	Obtained values	Error %
SR (µm)	Minimum	6.52968	6.828	-4.3690
MRR (g/min)	Maximum	0.147959	0.139	6.4453

6. Conclusion:

An experimental study is performed in EDM and studied the influencing input parameters in relation to Cu-TiB_2 electrode on OHNS Steel workpiece the following conclusion is observed:

i. The Pulse direct current is influenced more on roughness (SR) and Volume of material removed (MRR).
ii. Pulse time ON increases has major influence on the other two input parameters.
iii. Pressure flushing increases or decreases with pulse Direct current and pulse time ON interaction with output responses of MRR and SR has considerably less effect on both.
iv. Pulse Direct Current is the major influencing factor that is predicted using ANOVA with a F-value of 30.62 and 118.92 in Surface roughness and MRR respectively.
v. The optimum parameters obtained using face centred central composite design using RSM with high desirability value is Pulse direct current of 14 A, Pulse time ON of 15µs and Flushing pressure of 0.6 Mpa .

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