ANALYSIS OF MACHINING FOR SILICON CARBIDE ON ELECTROCHEMICAL DISCHARGE MACHINING WITH BRASS TOOL

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Abstract: The Electrochemical discharge machining (ECDM) is an incorporated machining process which has specifically used for machining of non-conducting materials. In this research work, the ECDM experimental setup was fabricated for machining of non-conducting materials. This machining process was used for machining of silicon carbide which is very brittle and hard in nature. The experiments were done with the help of Taguchi L_{27} orthogonal array method and analyzed by using MINITAB 17 software. The hole diameter and machined depth results were inspected after ECDM drilling on silicon carbide material with considering the input machining parameters such as electrolyte concentration, voltage, and rotation. The experimental observation results showed that electrolyte concentration is the major parameter for hole diameter and machining depth followed by voltage and rotation of the tool electrode.

Key words: ECDM, silicon carbide, Taguchi, Brass

1. INTRODUCTION

In modern industries, the technological growth and devolvement of harder machining materials, which discover wide application in automobile, aviation, medical, nuclear reactor, and missile. It is very difficult to find adequate strong and hard tools to machine such hard materials. Therefore, there is a necessity to develop innovative machining technologies to machine these difficult-to-machine materials more precisely [1]. Silicon carbide (SiC) is one of the hardest material in the world. The SiC is mostly applicable in automobile industries, defense, electrical and electronics technologies, aerospace technologies, and biomedical fields because of its various properties such as high hardness, wear resistance, high durability, excellent corrosion resistance, high rigidity, high specific stiffness, low conduction electricity, high strength, lightweight, extreme brittleness, poor machinability, low density, radiation resistance, high thermal conductivity, high intensity, high toughness, wide energy band gap, chemical resistance, low thermal coefficient expansion, electromagnetic response, chemical inertness and biocompatibility [2]. Due to various properties of SiC, it is very challenging to machine with the conventional machining process. Hence, electrochemical discharge machining process which can be used to machined SiC material. The electrochemical discharge machining (ECDM) technique is combinations of two manufacturing process viz. electrochemical manufacturing process (ECM) and electro-discharge manufacturing (EDM) used to machine non-conducting materials [3]. The ECDM machining technology initially discovered by Kurafuji et al. in the year 1968 which was used to drill on glass material [4]. In this process at higher electrolyte concentration and higher machining voltage conditions which can produce micro holes with maximum precision [5]. The most common actuation source for the workpiece or tool is gravity feed which means that the tool and the machined workpiece are continuously in contact which caused influences the machining performances [6]. The maximum machining depth was attained with the help of abrasive cutting tools in ECDM drilling process at the highest voltage and electrolyte concentration [7]. The most of researchers have used Tungsten carbide as cathode tool electrode material, Graphite as anode tool material and NaOH as electrolyte medium [8]. Previously, Pawar et al. investigated the tool wear rate (TWR) and material removal rate (MRR) by using the ECDM drilling process applied on Mosaic ceramic material [9]. In this research work, the fabricated gravity feed ECDM was used to machined very hard material i.e. Silicon carbide. The hole diameter and machining depth were investigated with consideration of machining input parameters such as voltage, rotation of tool electrode, and electrolyte concentration.

2. BASIC WORKING PRINCIPLE AND EXPERIMENTAL SETUP OF ECDM

Figure 1 represents the basic working principle of the ECDM process. In this process cathode, anode and workpiece material are immersed inside an aqueous electrolyte medium. When D.C. voltage approximately 20 to 30 V applied between cathode and anode tool electrode then electrolysis ensued. Then, hydrogen gas bubbles and oxygen bubbles are developed at the cathode and anode tool electrodes. When the voltage is raised, the current rises and a large number of bubbles formed a bubble layer around the cathode and anode. The bubbles coalesce into a gas film at the round surface of the cathode when voltage utmost than the critical voltage. At that time light emission is seeing and electrical discharges take place. The fabricated ECDM machining setup is shown in Figure 2. In this setup X, Y and Z axis movement was controlled manually. The workpiece was holding on fixture and fixture was positioned on ECDM electrolyte cell. The ECDM cell fixed on the X-Y axis compound slide table which was mounting on the machine table. The cathode electrode was coupled to the Z axis. The gravity feeding mechanism was used to move the workpiece in an upward direction during the machining process. The cathode tool electrode was attached to stepper motor spindle and its speed is controlled with Arduino Uno board through the computer. The D.C. voltage was given between the cathode tool and anode tool electrodes [10]. The conical shaped cathode electrode (Brass) having tool tip diameter 1mm and increased up to 3mm diameter was utilized. The stainless steel 416 was taken as the anode electrode having 15 mm diameter. For the experimentation, NaOH electrolyte was used and machining time is set to be 25 min for each experiment.

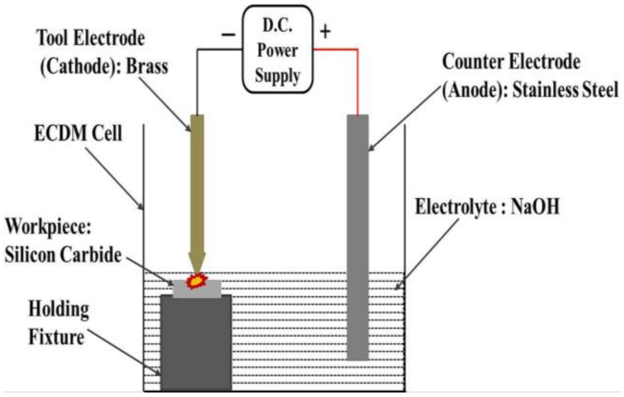


Fig. 1. Schematic diagram of ECDM process

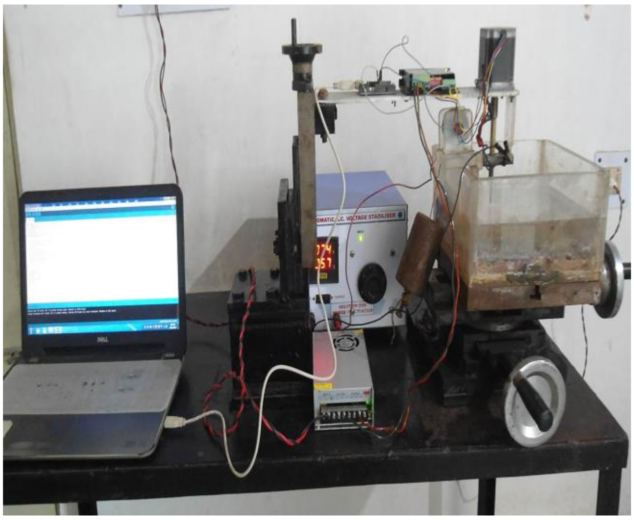


Fig. 2. Experimental Setup of ECDM

3. EXPERIMENTAL CONDITIONS

The micro-hole was drilled on 150×150×10 mm^3 silicon carbide material by using the ECDM process. The Taguchi L_{27} orthogonal array method was used for experimentation on silicon carbide material. In this experimental work choosing three factors with three levels and their two-way interactions taking into consideration therefore, the total degree of freedom is 18. Thus, for experimental work L_{27} orthogonal array was used which partakes 26 degrees of freedom. In this experimental work voltage, rotation and electrolyte concentrations were taken as input machining factors and output responses are hole diameter and machining depth. Table 1 indicates that input process parameters and their individual levels [11].

Table 1. Process Parameters and Their Levels

Factor	Parameters	Unit	Levels		
			1	2	3
A	Voltage	V	70	80	90
B	Rotation speed	rpm	0	10	50
C	Electrolyte Concentration	%	10	15	20

The signal to noise (S/N) ratio is selected based on the earlier research work information; accordingly, it must be carefully taken. The signal designates the effect of each factor on the response, whereas noise is the measure of the effect of deviation as of average responses. The S/N ratio is selected based on the previous research work information and expertise.

In current experimental work, hole diameter was considered as nominal is best because average hole diameter results were taken into consideration and targeted nominal hole diameter is set for 3.25mm. In case of machining depth larger-the-better criteria has been preferred. The S/N ratio is evaluated by utilizing the following formula shown in Eq. 1 and Eq. 2 [12].

For larger is better

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (1)$$

For nominal is best

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\sigma^2\right) \quad (2)$$

Table 2 shows that sparking intensities of each experimental conditions during machining of silicon carbide. The sparking intensity was increased when the increase in voltage and electrolyte concentration which causes an increase in hole diameter and machined depth.

Table 2. Sparking during machining of Silicon carbide material using Brass tool material

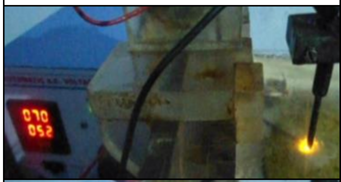
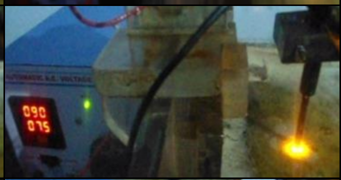
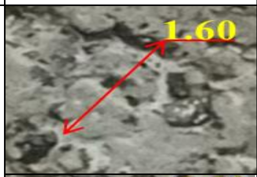
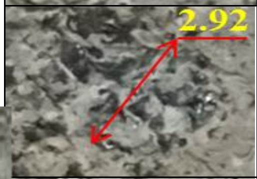
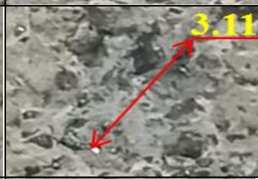
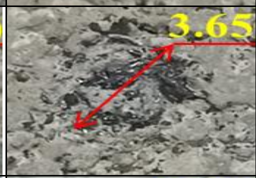
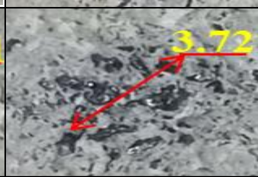
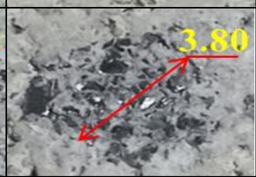
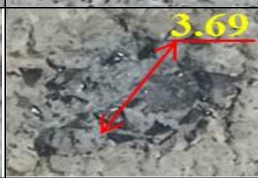
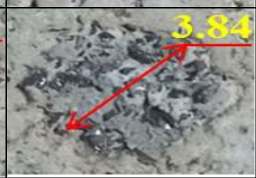
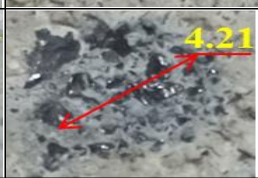
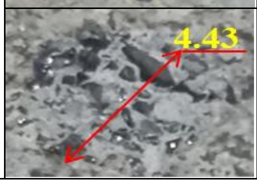
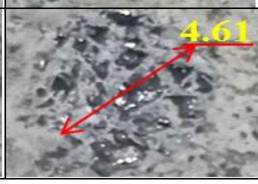
Sprking intensity during each experiment				
Rotation (rpm)			Vol-tage	Concen-tration
0	20	50	(V)	(%)
			70	10
			80	
			90	
			70	15
			80	
			90	
			70	20
			80	
			90	

Table 3 shows that microscopic images of machined silicon carbide material using a brass tool. The images were taken by using an optical microscope. Table 4 shows that experimental results obtained after machining of silicon carbide material. It shows that experimental results which include input process parameters and output responses. The microscopic images of machined silicon carbide indicates low machined depth and hole diameter at low input parameters. Due to high hardness of SiC, the output machined surface becomes coarse structure.

Table 3. Microscopic images of machined Silicon carbide material by using Brass tool

Taguchi L_{27} orthogonal Experimental results	Brass Tool Experimental Results: Rotation (rpm) 0	20	50	Voltage (V)	Concen-tration (%)
				70	10
				80	
				90	
				70	15
				80	
				90	
				70	20
				80	
				90	

4. RESULTS AND DISCUSSION

The rotary speed of tool electrode may possibly influence the efficiency, cutting ability and quality of machining performance [13, 14]. The ANOVA statistical tool is used to analyze the significance of the input parameters. The response table for the signal to noise ratios, larger is better of machined depth is used for ranking of the input process parameter. The response table for the means for hole diameter, nominal is best for hole diameter is considered for ranking of the input process parameters. The effect on machining depth and hole diameter is explained below.

Table 4. Experimental observation of silicon carbide material by using Brass tool

Run	Electrolyte Concen-tration (%)	Voltage (V)	Rotation (rpm)	Hole diameter (mm)	Machined depth (mm)
1	10	70	0	1.60	0.10
2	10	70	20	2.65	0.10
3	10	70	50	2.80	0.10
4	10	80	0	2.92	0.15
5	10	80	20	3.11	0.20
6	10	80	50	3.20	0.29
7	10	90	0	3.03	0.18
8	10	90	20	3.30	0.23
9	10	90	50	3.65	0.30
10	15	70	0	2.93	0.15
11	15	70	20	3.10	0.20
12	15	70	50	3.21	0.24
13	15	80	0	3.38	0.20
14	15	80	20	3.45	0.31
15	15	80	50	3.50	0.35
16	15	90	0	3.41	0.20
17	15	90	20	3.72	0.35
18	15	90	50	3.80	0.43
19	20	70	0	3.32	0.21
20	20	70	20	3.69	0.30
21	20	70	50	3.84	0.37
22	20	80	0	3.91	0.48
23	20	80	20	4.21	0.60
24	20	80	50	4.37	0.58
25	20	90	0	4.43	0.54
26	20	90	20	4.61	0.63
27	20	90	50	4.88	0.69

4.1 Effect on machined depth

Table 5 shows that ANOVA table for machined depth of silicon carbide using brass tool material in which condition of larger is better. The ANOVA table shows that maximum F-value 71.4 was obtained to be for electrolyte concentration which means it is the most dominant factor compared to the other two input parameters. The machining depth increases with increasing concentration from 10 to 20%. The observed machined depth results were similar trends to previously published reports [15-17]. All input parameters are the significant effect on machined depth due to P values are less than 0.05. The electrolyte concentration is contributed 57.43, voltage is contributed 25.03%, and rotation of the tool electrode is contributed 9.48% respectively. Table 6 shows that response table for the signal to noise ratios of the machined depth of silicon carbide material using brass tool material. It shows that electrolyte concentration is the first rank followed by voltage and rotation speed of the tool.

Table 5. ANOVA table for machined depth of Silicon carbide material using Brass tool material

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage Contri-bution
Voltage (V)	2	0.1946	0.097	31.13	0.00	25.03
Electrolyte Concen. (%)	2	0.4464	0.223	71.4	0.00	57.43
Rotation Speed (rpm)	2	0.0737	0.037	11.78	0.00	9.48
Error	20	0.0626	0.0031			8.06
Total	26	0.7773				100

Table 6. Response table for Signal to Noise Ratios larger is better for machined depth Silicon carbide material using Brass tool

Level	Voltage (V)	Electrolyte Concentration (%)	Rotation Speed (rpm)
1	-15.056	-15.481	-13.455
2	-10.003	-11.839	-10.991
3	-9.015	-6.753	-9.627
Delta	6.041	8.727	3.828
Rank	2	1	3

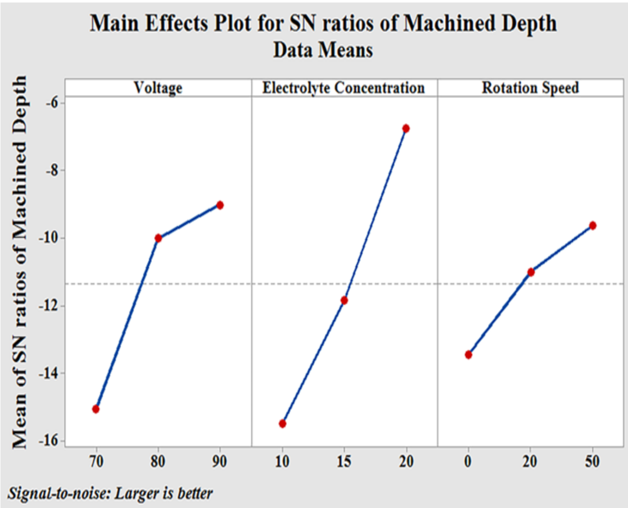


Fig. 3. Main effect plot for machined depth of Silicon carbide using Brass tool material

The main effect plot in Figure 3 states that the machined depth increases significantly with the increase in electrolyte concentration, voltage and rotation speed of the tool electrode. The maximum machined depth achieved at ECDM machining condition of voltage 90 V, electrolyte concentration 20% and the rotation speed of 50 rpm. The similar graphical results were found out to previous literature [18, 19]. The histogram for SN ratios of machined depth is presented in Figure 4 which designates that the residuals are properly distributed for all observed data of machined depth. There is no skewness and outliers exist on the graph which shows good agreement of predicted and experimental results.

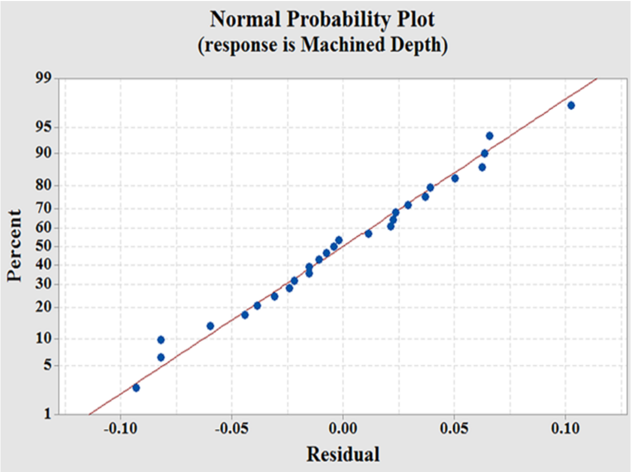


Fig. 4. Normal probability plot for machined depth of Silicon carbide using Brass tool material

Figure 5, 6 and 7 represents the 3D response surface plots for machined depth of silicon carbide material using brass tool material. It states at the higher level of each input factors shows maximum machined depth. The electrolyte concentration and voltage were mostly influenced machined depth. Hence, for achieving maximum machined depth machined then parameters to be set at the higher level.

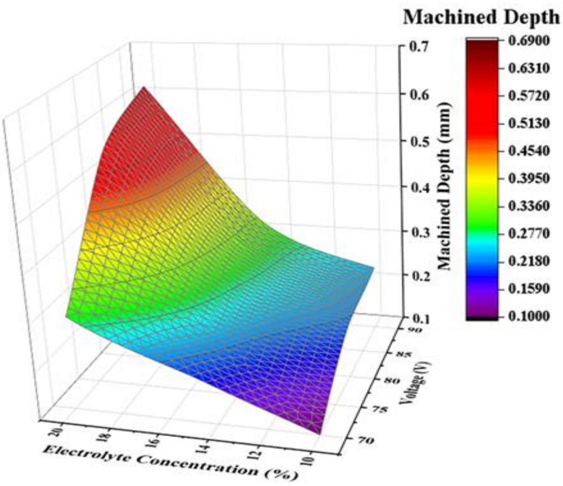


Fig. 5. Surface plot for machined depth vs. voltage, electrolyte concentration

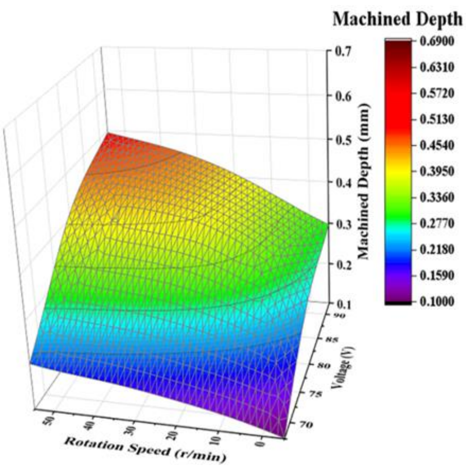


Fig. 6. Surface plot for machined depth vs. voltage rotation

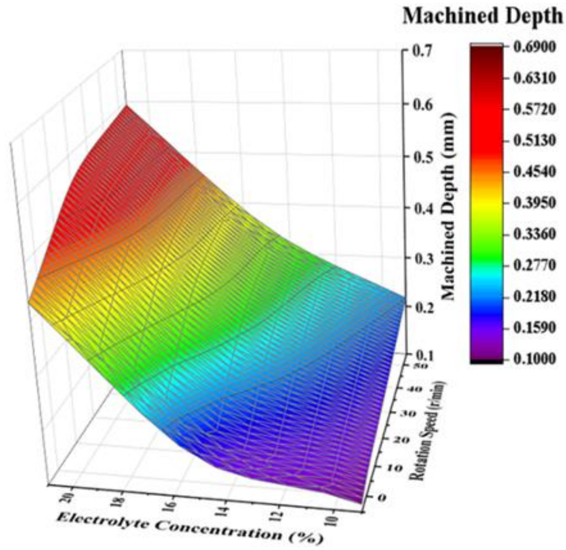


Fig. 7. Surface plot for machined depth vs. rotation, electrolyte concentration.

The mathematical model for machined is presented in Eq. 3. The correlation coefficients (R^2) of hole diameter shows that 96.27% values are very close to 1 which shows the best fit for the model.

$$Machined..Depth = -2.65 + 0.0826V - 0.1286C - 0.00292R - 0.000556V^2 + 0.002644C^2 - 0.000047R^2 - + 0.00095V*C + 0.00008V*R + 0.000088C*R \quad (3)$$

4.2 Effect on hole diameter

Table 7 shows that ANOVA table for a hole diameter of silicon carbide using brass tool material in which condition of nominal is best. It represents that the maximum F-value 93.03 obtained for electrolyte concentration which means it is a most significant factor compared to the other two input parameters. The p values show that all three input parameters are less than 0.05 which designates that all parameters are significant. The electrolyte concentration is contributed 56.86%, voltage is contributed 28.01% and rotation of the tool electrode is contributed 8.98% and respectively. The results obtained has good agreement to already published reports for hole diameter and radial overcut responses [5, 7, 16, 17, 20, 21].

Table 7. ANOVA table for hole diameter of silicon carbide using Brass tool material

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage Contri-bution
Voltage	2	3.37	1.6847	45.83	0.00	28.01
Electrolyte Concen.	2	6.84	3.4199	93.03	0.00	56.86
Rotation Speed	2	1.08	0.5392	14.67	0.00	8.98
Error	20	0.74	0.0368			6.15
Total	26	12.03				100

Table 8 shows that response table for means of hole diameter of silicon carbide using brass tool material. It shows that electrolyte concentration is the first rank followed by voltage and rotation speed of the tool.

Table 8. Response table for means of hole diameter of Silicon carbide material using Brass tool

Level	Voltage (V)	Electrolyte Concentration (%)	Rotation Speed (rpm)
1	3.016	2.918	3.214
2	3.561	3.389	3.538
3	3.870	4.140	3.694
Delta	0.854	1.222	0.480
Rank	2	1	3

The main effect plot is shown in figure 8 which states the hole diameter increases significantly with an increase in electrolyte concentration, voltage and rotation speed of tool electrode linearly. The nominal hole diameter achieved at ECDM machining condition of voltage 90 V, electrolyte concentration 20% and the rotation speed of 50rpm. The similar graphical trends were found out previous work of literature [7, 17, 22].

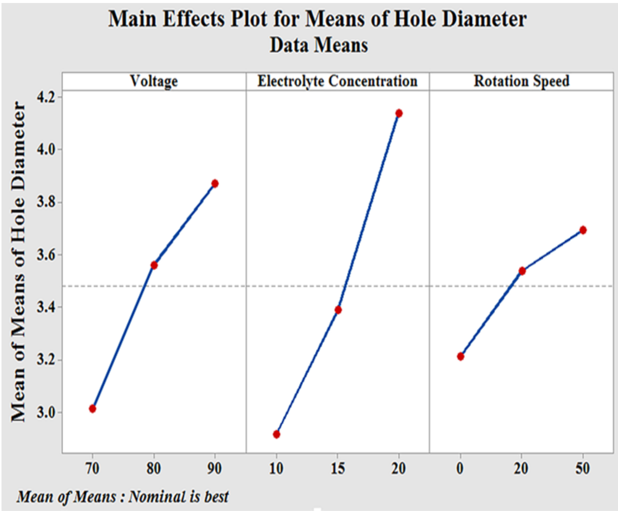


Fig. 8. Main effect plot for hole diameter of Silicon carbide using Brass tool material

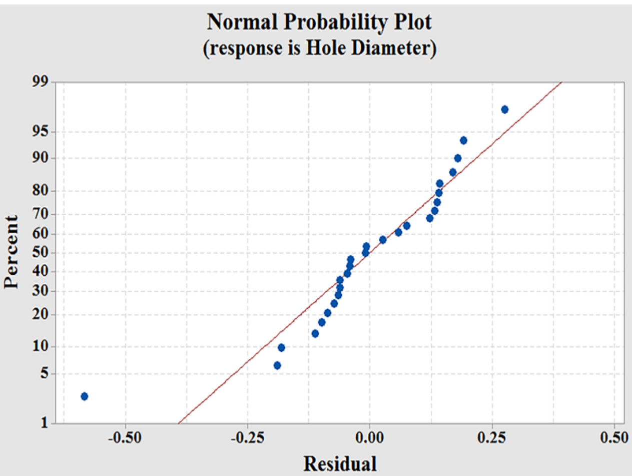


Fig. 9. Normal probability plot for hole diameter of Silicon carbide using Brass tool material

The histogram for hole diameter is shown in figure 9 which indicates that the residuals are properly distributed which means the good agreement of predicted and experimental results. Figures 10, 11 and 12 denotes the 3D response surface plots for a hole diameter of silicon carbide material using brass tool material. It states at the higher level of each input factors increases hole diameter.

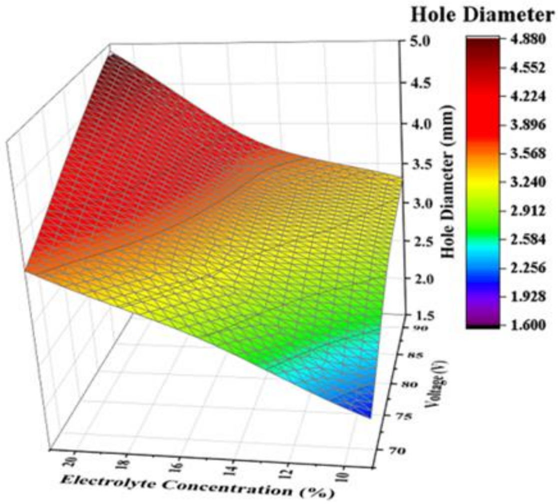


Fig. 10. Surface plot for hole diameter vs. voltage, electrolyte concentration

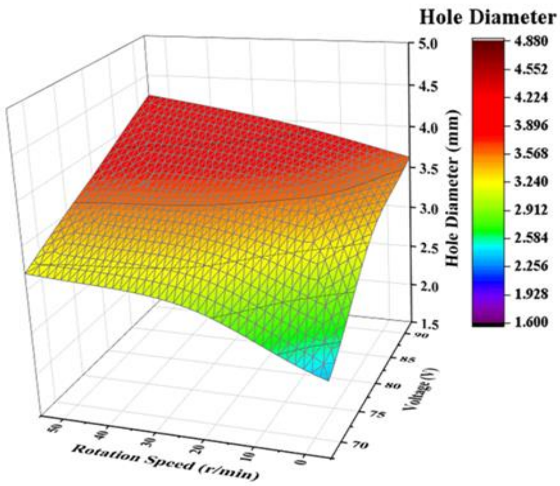


Fig. 11. Surface plot for hole diameter vs. voltage, rotation

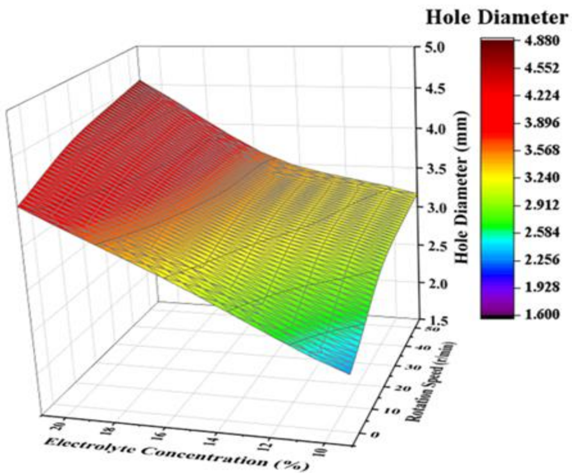


Fig. 12. Surface plot for hole diameter vs. rotation, electrolyte concentration

The regression model was assessed for silicon carbide material using responses surface methodology which is shown in Eq. (4). The correlation coefficients (R^2) of hole diameter shows that 96.32% values are very close to 1 which is the desired significance model and the best fit for the model.

$$\begin{aligned} Hole\,Diameter &= -8.51 + 0.232V - 0.055C + 0.0390R \\ &-0.001183V^2 + 0.00560C^2 - 0.000219R^2 + \\ &0.00023V*C + 0.000153V*R - 0.000412C*R \end{aligned} \quad (4)$$

5. CONFIRMATION TEST

The response surface optimization approach has been employed to scrutinize the ECDM machining parameters for the best response values. The desirability function analysis has been used in the response surface method as higher machining depth and nominal hole diameter responses. The response surface methodology optimization approach predicted results with Minitab software for machining of silicon carbide workpiece material using the brass tool is shown in Figure 13. The optimal machining parameters for desired responses are found to be at voltage 81.51, electrolyte concentration 16.16 and rotation speed of 50. Finally, to validate the optimized parameter, an experiment was executed at the same optimal value of ECDM machining parameters which are evaluated using the response surface optimization technique. The experimental results found to be machining depth of 0.44 mm and a hole diameter of 3.74. The experimental value makes a difference of 3.27% from its predicted value for machining depth and 2.74% for hole diameter. Table 9 shows that the predicted values, experimental values and percentage error between them.

Fig. 13. Response surface methodology optimization plot for machined depth and hole diameter

Table 9. Confirmation test results and comparison with predicted result

Optimum parameters			Output results	Predicted results	Experimental results	Error (%)
Voltage (V)	Concentration (%)	Rotation (rpm)				
81.51	16.16	50	Machined depth (mm)	0.4256	0.44	3.27
			Hole diameter (mm)	3.873	3.74	2.74

6. CONCLUSION

The ECDM setup was built, design and manufactured for machining of non-conducting materials. In this work, two output responses are investigated viz. machined depth and hole diameter by considering the three input factors such as voltage, electrolyte concentration, and rotation. The experimental work was carried out using the ECDM process on silicon carbide material using brass as a cathode electrode. From the current experimental observations, it can be concluded that the electrolyte concentration was the most significant factor for the machined depth and hole diameter followed by voltage and rotation. The optimum input factors combination for maximum machined depth and the nominal value for hole diameter are voltage 81.81V, electrolyte concentration 16.16%, and rotation 50rpm.

7. REFERENCES

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