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Optimization Of Process Parameters Of EDM Using ANOVA Method

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ABSTRACT

The objective of this paper is to investigate the optimum process parameters for a particular work piece-tool material combination on Fuzzy Logic Control based Electrical Discharge Machine. In this experiment, two levels of current, tools material and spark gap are kept as the main variables. The work piece material was taken as S.S.304, and tool material changed at various levels of the performance as copper and brass. The DEF-92 was used as the dielectric fluid. The Design of experiment is used to design the E.D.M experiments. The various tools of D.O.E are used to analyze the final results of the experiment with the help of graphs in this paper. The analysis is being done with the help of Minitab-15 software. The analysis of variance (ANOVA) is also performed to indentify the statistical significance of parameters. The result of the experiments are the optimimum values of MRR (material removal rate), TWR (tool wear ratio), and surface finish with the help of ANOVA. The conclusions arrived are discussed at the end.

Keywords: ANOVA, DOE, MRR, Sum of Square (SS), TWR.

1 INTRODUCTION

The electric discharge machine provides an effective solution for machining hard conductive materials and reproducing complex shapes. EDM involves the phenomena such as: spark initiation, dielectric breakdown, and thermo-mechanical erosion of metals. Metal removal process in EDM is characterized by nonlinear, stochastic and time varying characteristics. Many regression techniques have been used for modeling the EDM process. Unlike milling and drilling operations, operating speeds in EDM are very low. Large electric current discharge can enhance speeds but reduces the dimensional quality of machined surface. Similarly the material removal rate is also affected by other process parameters [1].

2 LITERATURE REVIEW

Kuriakose and Shunmugam [1] used Genetic Algorithms for solving a multi-objective problem in wire EDM process. Kansal et al. [2] adopted the response surface optimization scheme to select the parameters in powder mixed EDM process. Keskin et al [3] used design of experiments (DOE) for the determination of the best machining parameters in EDM**.** Tzeng and Chen [4] employed a Taguchi fuzzy-based approach for solving the multi-objective optimization problems in high-speed EDM process. Mandal et al [5] have shown the modeling procedure of EDM using neural networks and solution methodology using GA. More recently Yuan et al. [6] illustrated the optimization process of high-speed wire EDM process using regression methods. Rathod et al. [7] used the Taguchi method to optimize the process parameters of S.S 304 using three different tools. In the present work, the design of experiment (DOE) and ANOVA method is used for optimization of process parameters. The main objectives of optimization are to (i) maximize the material removal rate (MRR), (ii) minimize the surface roughness value and (iii) maximize the tool wear ratio (TWR).

3 EXPERIMETAL PROCEDURES

The experiments were carried out on Electrical discharge machine to optimize the material removal rate, tool wear and surface finish of the component. In these experiments, the SS 304 (6 mm in thickness) work piece material was selected and its composition is Cr 18, Ni 8, Mn 2, N0.10, S 0.03, C 0.08, Si 0.75, P 0.045 % by weight. The two different tools material viz, Copper and Brass with 15 mm diameter are prepared on CNC lathe machine. The chosen levels of three variable factors viz. Tool material, Current and Spark gap voltage and their levels are shown in table 1.The experiments constant parameters are shown in table 2. Blind hole of 2 mm depth of cut was carried out in the component in each experiment. The degree of influence of main factors such as tool material, peak current, spark gap voltage and interaction among them, are studied to evaluate the tool wear, metal removal rate, and surface finish. The full factorial design matrix in actual values of factors was considered and these experiments are performed two times and the mean values of each output were subsequently used for analyzing the results. Tables 3 shows experiment readings of E.D.M process and also the calculation of metal removal rate, tool wear rate and surface finish. The figure1 shows the tool materials used in experiments and Figure 2 shows the work piece material of S.S 304 used for machining.

Factor	Column	Level 1	Level 2
Tool material	A	Cu	Br
Current	B	9	17
Gap voltage	C	5	9

Table 1 Variable and their Levels

Flushing height = 10
Polarity = +1
Work piece = SS304
Depth of cut = 2mm
Voltage = 6 volts
Electrode diameter = 15mm
Pulse off time = 55
Tool diameter=15 mm

Table 2 Experimental Constants

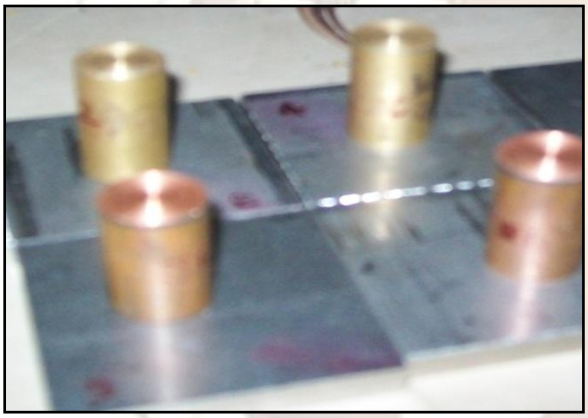

Fig.1 Tool materials

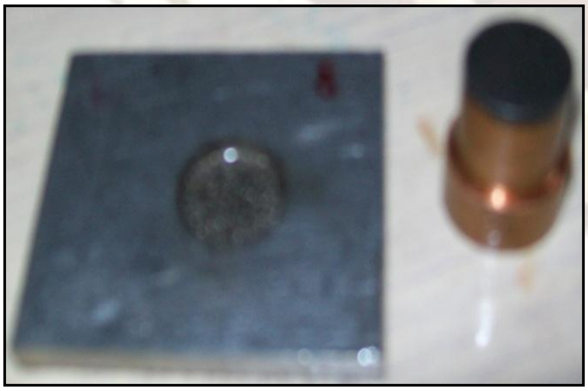

Fig.2 Work piece material SS 304

3.1 CALCULATION OF MRR

Metal removal rate is directly calculated from experimental data. The weight of the specimen is taken before and after the machining process by using a digital weighing machine.

$$MRR = \frac{(W_{tb} - W_{ta})}{D \times t}$$

Where W_{tb} = weight before machining in gm.
W_{ta}= weight after machining in gm.
D = density of work piece material in gm/mm^3.
t = time consumed for machining in minute.

In this experiment, the work piece material is S.S 304 and its density is 0.00792 gm/mm^3.

3.2 CALCULATION OF TOOL WEAR RATIO

Tool wear ratio is defined as the volume of metal removed from the work piece to the volume of the material loss from the tool.

$$\text{Tool wear ratio} = \frac{MRR}{TW}$$

Where,
MRR= Metal removal rate. TW= Tool wear.

3.3 SURFACE ROUGHNESS MEASUREMENT

Since EDM process is also used in the making of a dies of an injection molding in which surface roughness is important criteria because all the cavity formation is totally depended upon the surface finish of the die material. In present analysis surface roughness is measured on a Mitutoyo make portable digital surface finish tester (model: surf test set no: 178-923e).

4. RESULTS AND DISCUSSION

4.1 ANALYZING AND EVALUATING RESULTS OF THE EXPERIMENTS USING D.O.E TOOL

The figure 3 shows Pareto Chart of the Standardized Effects for MRR which indicates that main effect tool material (A), current (B), Spark gap voltage (C) and interaction AB, BC, ABC are significant and plays dominant role in this process. AC interaction is not significant. The figure 4 shows a main effect plot and figure 5 for the response surface plot for MRR. It can be concluded from figure 4 and 5, the maximum MRR can be achieved when tool material is copper, current is 17 amps and spark gap voltage is 5 volts.

The figure 6 indicates that tool material (A), gap voltage (C) and combination of tool material and gap voltage (AC) play dominant role in this process. It can be concluded from figure 7 and 8, the maximum TWR can be achieved when tool material is copper, current is 17 amps and spark gap voltage is 5 volts.

The figure 9 indicates that only current is significant for surface roughness. It can be concluded from the figure 10 and figure 11 indicates the minimum surface roughness can be achieved when current is 9 amps and spark gap voltage is 5 volts and tool material does not show any effect on surface roughness.

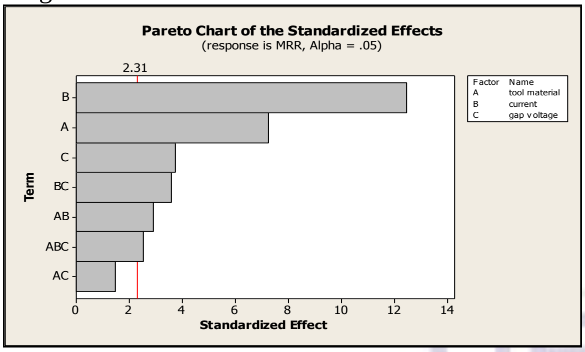

Fig.3 Pareto Chart of the Standardized Effects for MRR.

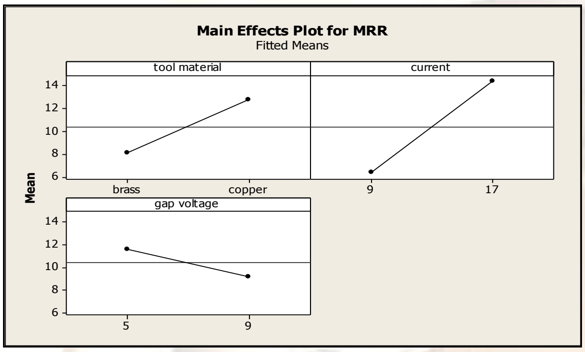

Fig.4 Main effect plot for MRR.

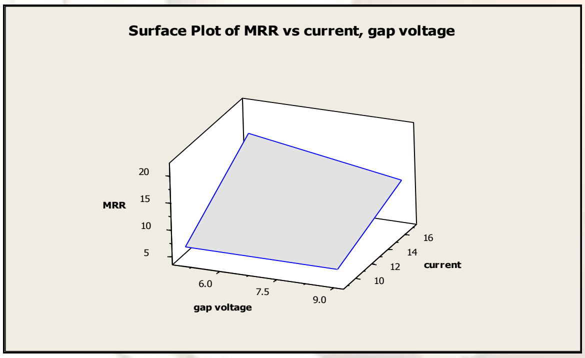

Fig.5 The response surface plot for MRR

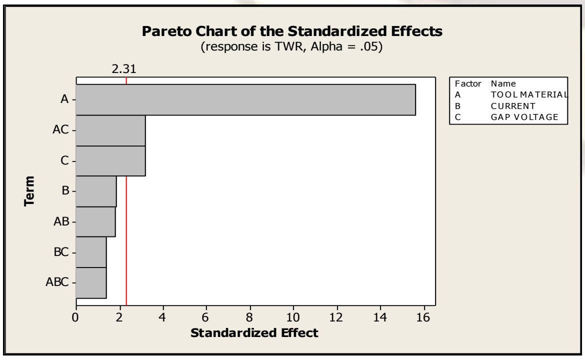

Fig.6 Pareto Chart of the Standardized Effects for TWR

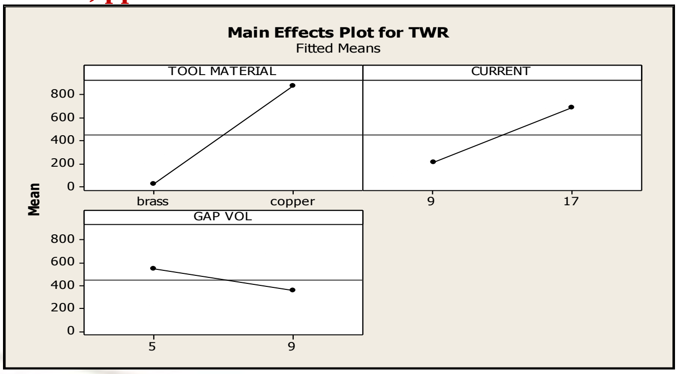

Fig.7 Main effect plot for TWR

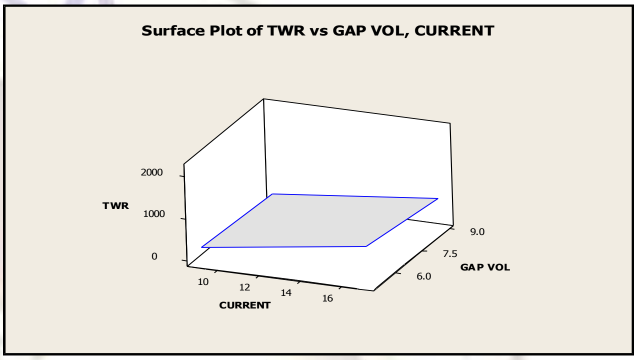

Fig. 8 The response surface plot for TWR

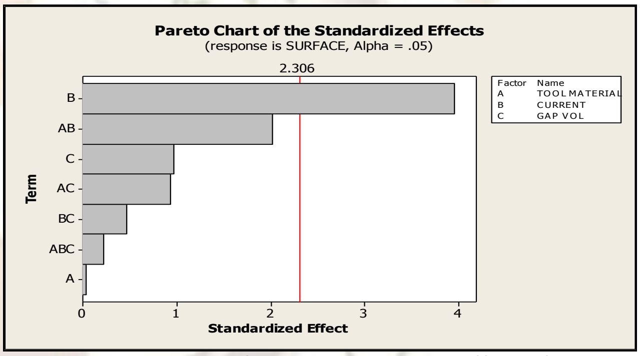

Fig.9 Pareto Chart of the Standardized Effects for SR.

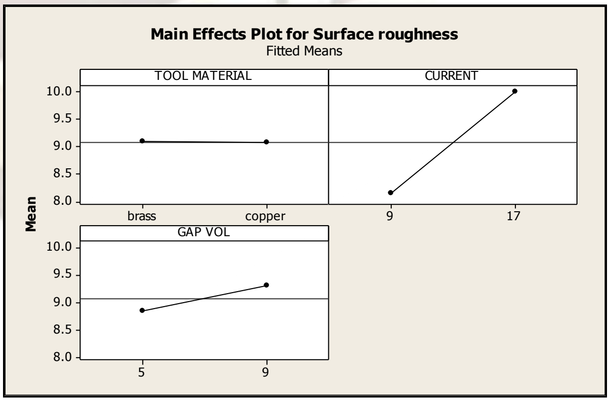

Fig.10 Main effect plot for Surface roughness.

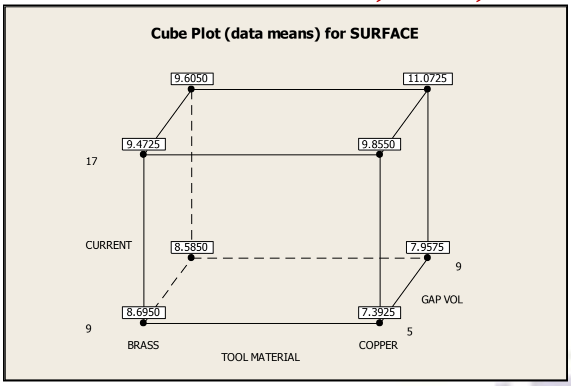

Fig.11 Cube Plot for Surface Roughness.

4.2 ANALYSIS OF VARIANCE (ANOVA)

The two set of readings of MRR, TWR, Surface Roughness and machining time are shown in table 3. The 2^3 factorial designs with treatment combination and actual values of experiments run for total MRR is shown in table 4.The table 5 summarizes the effect estimates and sums of squares for MRR. The column labeled "percent contribution (PC)" measures the percentage contribution of each model term to the total sum of squares. The percentage contribution is often a rough but effective guide to the relative importance of each model term. It is seen that the main effects tool material (A), Current (B) and Spark gap voltage (C) really dominate this process, accounting for over 87 percent of the total variability, whereas the AB and ABC interaction counts for about 3 percent whereas the BC interaction counts less than 6%. The table 6 summarizes the effect estimates and sums of squares for TWR. Note that the main effects A, C and AC really dominate this process, accounting for over 93 percent of the total variability; whereas the B and AB interaction counts for less than 2 percent. The table 7 summarizes the effect estimates and SS for Surface Roughness. It is seen that the main effect B really dominates this process accounting for over 52% of the total variability.

General Linear Model of MRR shown under section 4.3 is obtained from Minitab software. For $\alpha=0.05$, the value of F0.05, 1.8 =3.46 [10]. Now if the value of F_0 is greater than 3.46 than it shows the significant (For lower p-value). So from the section 4.3 table, we may say that the factor tool material (A),current (B), gap voltage (C) and interaction AB, BC and ABC are found significant for maximum MRR except interaction AC.

Similarly from General Linear Model of TWR shown under Section 4.4, we may say that the factor A, C and interaction AC are found significant because of having lower value of p than $\alpha=0.05$. So, it can be concluded that the main effects A and C and interaction effect AC are highly significant for maximum tool wear ratio. From General Linear Model of Surface Roughness shown under Section 4.5, It is found that the only factor B is highly significant for Surface Roughness because it has lower p-value (0.004) than $\alpha=0.05$.

RUN ORDER	TOOL MATERIAL	CURRENT (amp)	GAP VOLTAGE	TIME (min)	MRR (mm^3/min)	TW (mm^3/min)	TWR	SURFACE ROUGHNESS (µm)
1	copper	9	5	45.20	07.960	0.0497	160.160	06.395
2	brass	17	9	22.56	10.130	3.5982	002.800	11.190
3	copper	17	5	17.62	21.060	0.1275	165.176	10.200
4	brass	17	5	21.92	12.670	4.0253	003.147	08.975
5	brass	9	5	47.23	05.480	2.3790	002.303	08.685
6	copper	17	9	21.92	16.010	0.0512	312.390	10.440
7	copper	9	9	54.89	06.670	0.0409	162.961	07.920
8	brass	9	9	46.08	04.110	2.2762	001.805	08.625
1	copper	9	5	38.61	07.030	0.0489	143.742	07.850
2	brass	17	9	22.02	10.030	3.6215	002.770	08.020
3	copper	17	5	17.20	21.653	0.1355	159.800	09.510
4	brass	17	5	20.43	11.740	4.0022	002.933	09.970
5	brass	9	5	51.26	05.240	2.3105	002.270	08.675
6	copper	17	9	20.93	12.060	0.0502	240.318	11.710
7	copper	9	9	55.95	09.500	0.0414	229.445	07.995
8	brass	9	9	52.22	05.080	2.2651	002.241	08.545

Table 3 Calculation of MRR, TWR and Surface Roughness

Run Order	A	B	C	Label	Tool Material	Current	Spark Gap	MRR-1	MRR-2	Total MRR
1	-	-	-	1	Brass	9	5	05.480	05.240	10.72
2	+	-	-	a	Copper	9	5	07.960	07.030	14.99
3	-	+	-	b	Brass	17	5	12.670	11.740	24.41

4	+	+	-	ab	Copper	17	5	21.060	21.650	42.71
5	-	-	+	c	Brass	9	9	04.110	05.080	09.19
6	+	-	+	ac	Copper	9	9	06.670	09.500	16.17
7	-	+	+	bc	Brass	17	9	10.130	10.030	20.16
8	+	+	+	abc	Copper	17	9	16.010	12.060	28.07
								84.09	82.33	166.42

Table 4 2^3 factorial design with treatment combination for MRR

Factor	Effect Estimate	Sum of square	PC
A	4.68	87.66	21.031
B	8.03	258.16	61.930
C	-2.40	23.16	05.550
AB	1.87	13.95	03.340
AC	-0.96	3.68	0.880
BC	-2.32	21.46	05.148
ABC	-1.64	10.74	02.576
Error		15.62	03.747
Total		432.43	100.00

PC= Percentage Contribution.

Table 5 Effect Estimate Summary for MRR

Factor	Effect Estimate	Sum of square	PC
A	194.21	150878.44	86.29
B	23.05	2125.37	01.21
C	39.39	6209.40	03.55
AB	22.29	1987.93	01.13
AC	39.65	6291.38	03.59
BC	17.40	1211.82	00.70
ABC	17.40	1211.23	00.69
Error		4956.61	02.84
Total		174872.18	100.00

DF= Degree of Freedom.

Table 6 Effect Estimated Summary for TWR

Factor	Effect Estimate	Sum of square	PC
A	-0.0825	0.0272	0.098
B	1.9181	14.710	52.725
C	0.5231	1.0946	3.923
AB	1.0093	4.0790	14.620
AC	0.5043	1.0170	3.645
BC	0.1531	0.0937	0.335
ABC	0.0393	0.0062	0.022
Error		6.8723	24.632
Total		27.9000	100.00

Table 7 Effect Estimated Summary for SR

4.3 General Linear Model: MRR versus Tool material, Current, Gap voltage

Factor	Type	Levels	Values
TOOL MATERIAL	fixed	2	brass, copper
CURRENT	fixed	2	9, 17
GAP VOLTAGE	fixed	2	5, 9

Analysis of Variance (ANOVA) for MRR, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TOOL MATERIAL	1	87.724	87.724	87.724	52.64	0.000
CURRENT	1	258.320	258.320	258.320	155.02	0.000
GAP VOLTAGE	1	23.125	23.125	23.125	13.88	0.006
TOOL MATERIAL*CURRENT	1	14.024	14.024	14.024	8.42	0.020
TOOL MATERIAL*GAP VOL	1	3.671	3.671	3.671	2.20	0.176
CURRENT*GAP VOLTAGE	1	21.448	21.448	21.448	12.87	0.007
TOOL MATERIAL*CURRENT*GAP VOL	1	10.754	10.754	10.754	6.45	0.035
Error	8	13.331	13.331	1.666		
Total	15	432.396				

S = 1.29087 R-Sq = 96.92% R-Sq(adj) = 94.22%

The regression equation is

MRR = 1.55 + 1.00 current - 0.601 gap voltage ………… (1)

4.4 General Linear Model: TWR versus Tool material, Current, Gap voltage

Analysis of Variance (ANOVA) for TWR, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TOOL MATERIAL	1	150782	150782	150782	243.36	0.000
CURRENT	1	2114	2114	2114	3.41	0.102
GAP VOLTAGE	1	6190	6190	6190	9.99	0.013
TOOL MATERIAL*CURRENT	1	1999	1999	1999	3.23	0.110
TOOL MATERIAL*GAP VOL	1	6311	6311	6311	10.19	0.013
CURRENT*GAP VOLTAGE	1	1220	1220	1220	1.97	0.198
TOOL MATERIAL*CURRENT*GAP VOL	1	1203	1203	1203	1.94	0.201
Error	8	4957	4957	620		
Total	15	174776				

S = 24.8916 R-Sq = 97.16% R-Sq(adj) = 94.68%
The regression equation is
TWR = - 7 + 2.87 CURRENT + 9.8 GAP VOLTAGE ………… (2)

4.5 General Linear Model: Surface Roughness versus Tool material, Current, Gap voltage

Analysis of Variance (ANOVA) for SURFACE, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TOOL MATERIAL	1	0.0011	0.0011	0.0011	0.00	0.973
CURRENT	1	13.6530	13.6530	13.6530	15.61	0.004
GAP VOL	1	0.8281	0.8281	0.8281	0.95	0.359
TOOL MATERIAL*CURRENT	1	3.5438	3.5438	3.5438	4.05	0.079
TOOL MATERIAL*GAP VOL	1	0.7613	0.7613	0.7613	0.87	0.378
CURRENT*GAP VOL	1	0.1936	0.1936	0.1936	0.22	0.651
TOOL MATERIAL*CURRENT*GAP VOL	1	0.0452	0.0452	0.0452	0.05	0.826
Error	8	6.9950	6.9950	0.8744		
Total	15	26.0210				

S = 0.935080 R-Sq = 73.12% R-Sq(adj) = 49.60%
The regression equation is
SURFACE = 5.28 + 0.231 CURRENT + 0.114 GAP VOL ……… (3)

5 CONCLUSIONS

Through ANOVA and DOE following observations are made.
For Metal Removal Rate (MRR), the factors B (Current), A (tool material), C (Spark gap) and interactions BC, AB and ABC are statically significant except interaction AC.

The main effects really dominate MRR process, accounting for over 88.31 percent of the total variability, whereas the AB interaction accounts for less than 4 percent and BC is less than 5 percent and ABC less than 3 percent. The MRR is maximum achieved when tool material is Copper, Current is high level i.e. 17 amp and Spark gap voltage is set as low level i.e. 5 volts.

For Tool Wear Ratio (TWR), the factors A (Tool material), C (Gap voltage) and interaction AC are important for T.W.R.

The maximum T.W.R is achieved when tool material is Copper, the Current is at high level (17 amps) and spark gap voltage is at low level (5 volts).

For Surface roughness, the B (current) is only statically significant. The minimum surface roughness can be achieved when B (current) is 9 amps and spark gap voltage is 5 volts and tool material does not show any effect on surface roughness.

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