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MATHEMATICAL MODELLING OF SURFACE ROUGHNESS ON MACHINING OF AA6061-BORONCARBIDE COMPOSITE IN EDM THROUGH RSM

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ABSTRACT

The aim of present study is to investigate the machinability evaluation of AA6061- wt.5% B_4Cp metal matrix composite in EDM. For machining of composite, three machining parameters were considered such as current, pulse ontime and pulse offtime. After experimentation, a mathematical model for surface roughness was developed to correlate the influences of these machining parameters and surface roughness (Ra). The experiments were planned as per DOE method. From the obtained results, it was evidenced that the surface roughness is influenced more by current and pulse on time. The best surface finish was obtained at minimum of pulse off time value. The optimum machining parameters in favour of good surface roughness were estimated and verified with proposed optimized results.

Keywords: AA6061 – wt.5%B_4Cp, Surface roughness, Design of experiment, Response surface methodology.

NOMENCLATURE

EDM	electrical discharge machining
MRR	material removal rate (gram/min)
TWR	tool wear rate (gram/min)
Ra	surface roughness (µm)
MMC	metal matrix composite
DOE	design of experiment
RSM	response surface methodology
SEM	scanning electron microscope
ANOVA	analysis of variance

1. INTRODUCTION

Metal matrix composite is combination of two constituents in which one being a metal and other l may be as reinforcement or ceramic. These composites are used in automobiles and aircraft for their appreciable properties (Garg et al., 2010). Electrical discharge machining is a proven non-traditional machining process for machining of intricate, composite and hard material parts (Ho and Newman, 2003). Kalaiselvan et al. (2011) were reported the fabrication procedure of AA6061 and boron carbide powder particulate through stir casting route and analyzed the micro structure and mechanical properties. The hybrid composite were developed through stir casting technique and it was machined in electric discharge machining to analyze its machinability (Ahamed et al., 2009). Al-Si matrix composites were developed through stir casting technique reinforced with aluminium nitride particles and found out that AIN particles contributed to the increase of hardness of the matrix (Wahab et al., 2009). Singh et al. (2004) have studied the effect of machining parameters during machining of as-cast Al-MMC with 10% SiCp reinforcement in EDM. Karthikeyan et al. (1999) have identified the influencing effects volume percentage of SiCp, current and pulse on time on MRR, TWR, taper and Ra.The author was developed mathematical models were developed for MRR, EWR and Ra in the machining of Al/SiC composite through response surface methodology (Habib, 2009). Dhar et al. (2007) were evaluated the effect of machining parameters on MRR, TWR, Radial overcut on electric discharge machining of Al-4Cu-6Si alloy-10wt.% SiCp composites. The effect of machining parameters on MRR, TWR and Ra were studied while machining tungsten carbide by Luis et al. (2005). The optimized model for material removal rate was developed during machining of Ti6Al4Vin EDM through DOE and RSM technique by Rahman et al. (2010). Ali et al. (2011) were reported the influence of SiC powder concentration in dielectric fluid and electrical energy in micro electric discharge machining of titanium alloy and three EDM output responses such as MRR, EWR and *Ra* were also investigated by using Design Expert software methodology. Iqbal et al. (2010) have developed mathematical models for MRR, EWR and Ra were developed during machining of stainless steel AISI 304 in EDM milling through response surface.

The aim of present paper is to develop a mathematical model for surface roughness in machining of AA6061-wt.5% B_4C_p MMC prepared through stir casting technique. For experimentation, three machining parameters viz current, pulse on time and pulse off time were considered for machining of composite in electric discharge machining. The optimized machining parameters were obtained through RSM technique. The adequacy of the developed model has been checked through analysis of variance (ANOVA). Finally, the optimum machining parameters were found out for getting better surface roughness.

2. MATERIAL AND METHODOLOGY

AA6061–wt.5%B_4Cp MMC was machined using ELECTRA PLUS EDM machine. Figure 1 shows the microstructure of specimen before machining and dispersion of boron carbide particle in the aluminium matrix.

Table 1 Experimental setting.

Parameters	Description
Work piece material	AA6061–wt.5%B_4Cp
Work piece size	18mm x 18mm x 84 mm
Electrode material	14mm Dia x 150 mm height
Dielectric fluid	Kerosene
Electrode polarity	Negative
Applied voltage	200 Volts.
Flushing type	Jet flushing
Flushing pressure	2.2 kg/cm^2
Machining time	20 minutes

Surface roughness (Ra) is measured after machining the work piece by using the Surftest (SJ-210 –MITUTOYO make) with a cut-off length 0.8mm over the three sampling lengths and the speed of indenter was 0.5 mm/s. The inventor type was diamond. Ra is surface roughness in µm.

2.1. Theory of the experimental design

In the present experimental study, three independent machining parameters viz current, pulse on time and pulse off time were considered for experimentation. The experiments were conducted as per Box-Behnken design (BBD).

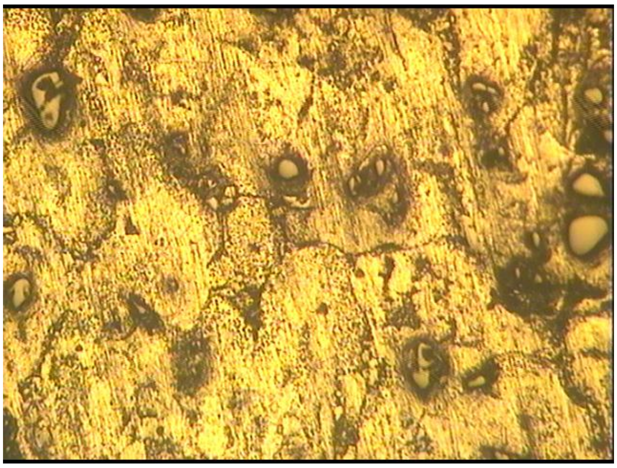

Figure 1 Microstructure of AA6061 wt.5% B_4Cp composite before machining.

The machining parameters were varied into three levels, coded as -1,0 and +1.The experimental design consists of 17 runs as given in Table 1. The levels and codification of machining parameters are given in the Table 2. And the Table 3 shows the details of Box Behnken Design matrix and its results.

Table 2 The levels and codification of machining parameters.

Machining parameter	Coding	Level -1	Level 0	Level 1
Current A	A	10	12.50	15
Pulse on- time µs	B	500	1250	2000
Pulse off -time µs	C	50	125	200

2.2. Response surface modelling

Response Surface Methodology is a technique for formulating mathematical models and analysing the influencing parameters on output performance. In the present work RSM is utilized for developing mathematical model for surface roughness in EDM process. To study the effects of the EDM parameters, a higher order polynomial quadratic equation was developed.

Table 3 Plan for Box Behnken Design matrix : Different machining parameters and results.

Exp No	Current (A) Amps	Pulse ontime µs (B)	Pulse offtime µs (C)	Ra µm
1	1	0	1	7.436
2	1	-1	0	7.231
3	0	-1	1	6.132
4	-1	1	0	5.891
5	0	-1	-1	6.112
6	0	0	0	6.543
7	-1	-1	0	5.243
8	0	0	0	6.252
9	0	0	0	6.253
10	1	0	-1	7.775
11	0	1	1	6.688
12	0	0	0	6.251
13	1	1	0	7.747
14	0	0	0	6.252
15	-1	0	1	5.546
16	-1	0	-1	5.559
17	0	1	-1	6.789

In the general form of response surface is described by the below mentioned equation.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1}^{k-1} \sum_{j=2}^{k} \beta_{ij} X_i X_j \quad (1)$$

Where, Y is surface roughness (Ra) and Xi (A, B, C) are the coded machining parameters. The term β_0,β_{ii} and β_{ij} are the second order coefficients. The response surface methodology was used to indicate the relationship between the three response variables and machining parameters as given below form.

$$Y = F (A, B, C) \quad (2)$$

Where Y is the function of three machining parameters viz current (A), pulse on time (B) and pulse offtime (C) . The equation (3) can be rewritten as follows.

$$Y = \beta O + \beta_1 A_1 + \beta_2 B_2 + \beta_3 C_3 + \beta_{12} A_1 B_2 + \beta_{13} A_1 C_3 + \beta_{23} B_2 C_3 + \beta_{11} A_1^2 + \beta_{22} B_2^2 + \beta_{33} C_3^2 \quad (3)$$

Where: A_1, B_2 and C_3 are the machining parameters current, pulse on time and pulse off time respectively. β_O is a constant value. β_1, β_2 and β_3 are co efficient value of the linear effect. β_{12}, β_{13}, β_{23} are the co efficient value of interaction effect. β_{11}, β_{22}, β_{33} are the second order coefficient value.

The Design Expert 7.0 software was utilized for experimentation, modelling and optimization.

2.3 The mathematical model for Ra

As mentioned in equation 4, a mathematical model has been developed to correlate machining parameters and surface roughness.

The final equation of actual factors

$$Ra = 4.80944 - 0.25927*A + 5.33278E-004*B + 1.58278E-003*C - 1.76000E-005*A*B - 4.34667E-004*A*C - 5.37778E-007*B*C + 0.029324*A^2 + 6.13778E-008*B^2 + 1.52044E-005*C^2 \quad (4)$$

3. RESULTS AND DISCUSSION

3.1 ANOVA results for surface roughness

From the ANOVA table, as the model F value is 80.09, the model is significant. There is only 0.01 % chance that a model F-value this large could occur due to noise.Values of Prob > F less than 0.0500 indicate model terms are significant.

From the ANOVA table 4, it is understood that Current A, Pulse ontime B, A^2 are significantly affect the model. And probability values greater than 0.1000 indicate the model terms are not significant. It is aslo observed that the Lack of Fit F value of 0.36 implies the Lack of Fit is not significant relative to the pure error.There is a 78.54% chance that a Lack of Fit F value this large could occur due to noise. Non-significant lack of fit is good Table 5 shows the value of R^2 and adjusted R^2 are 99% and 99% respectively. This means that regression model of surface roughness provides perfect explanation of the relationship between the response for surface roughness and the independent variables of machining parameters. In the Table 4 shows the lack of fit term is non-significant, as it is desired.

The Predicted R-Squared of 0.9554 is in reasonable agreement with the Adjusted R-Square of 0.9780. Adequate Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. As the adequate signal ratio is 30.410 the model can be used to navigate the design space.

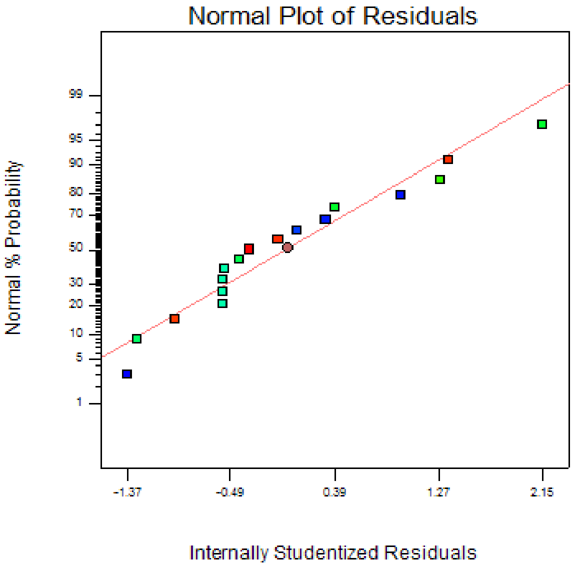

Figure 2 The normal probability plot of Ra.

Table 4 The ANOVA results of surface roughness.

Source	Sum of squares	DF	Mean square	F value	P value Prob>F
Model	8.8665	9	0.9852	80.09	< 0.0001
A-Current	7.9003	1	7.9003	642.28	< 0.0001
B-Pulse on time	0.7182	1	0.7182	58.39	0.0001
C-Pulse off time	0.0234	1	0.0234	1.91	0.21
A X B	0.0044	1	0.0044	0.35	0.5705
A X C	0.0266	1	0.0266	2.16	0.1851
B X C	0.0037	1	0.0037	0.30	0.6023
A^2	0.1414	1	0.1414	11.50	0.0116
B^2	0.0050	1	0.0050	0.41	0.5433
C^2	0.0308	1	0.0308	2.50	0.1576
Residual	0.0861	7	0.0123		
Lack of Fit	0.0184	3	0.0061	0.36	0.7854
Pure Error	0.0678	4	0.0169		
Cor Total	8.9527	16			

Table 5 R-squared values for surface roughness.

Std. Dev.	0.110907007	R-Squared	0.990382474
Mean	6.452941176	Adjusted R-Squared	0.978017082
C.V. %	1.718704763	Predicted R-Squared	0.955371265
PRESS	0.399546375	Adequate Precision	30.41024588

Figure 2 shows the normal probability plot residulas for surface roughness. From the figure it is noticed that the residuals are falling on a straightline which means the errors are normally distributed. Further Figure 3 shows the comparision between observed value and the predicted value calcutalated from model.

3.2 Effect of current, pulse ontime and pulse offtime on Ra

Figure 4 and Figure 5 shows 3D surface model and contour effect of current and pulse ontime on surface roughnessrespectively. From the model, the surface roughness value gradually increases with increase of current and pulse ontime inwhich current influence more on roughness than pulse offtime. The best surface roughness value is obtained at minimum current and pulse ontime vaule.

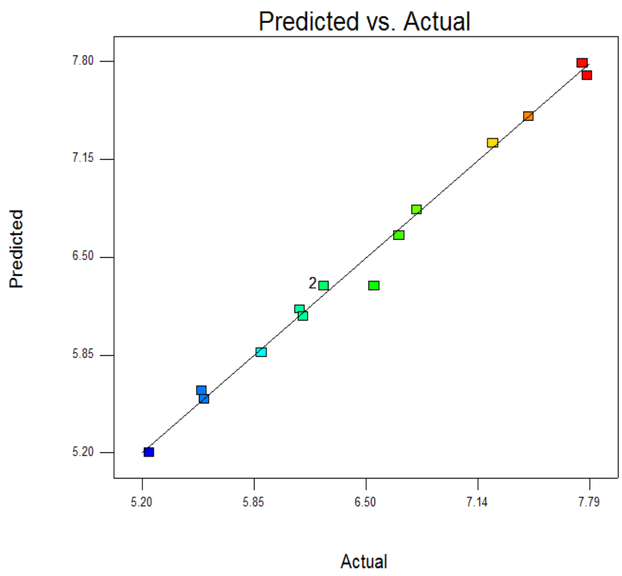

Figure 3 Predicted vs. Actual for Ra.

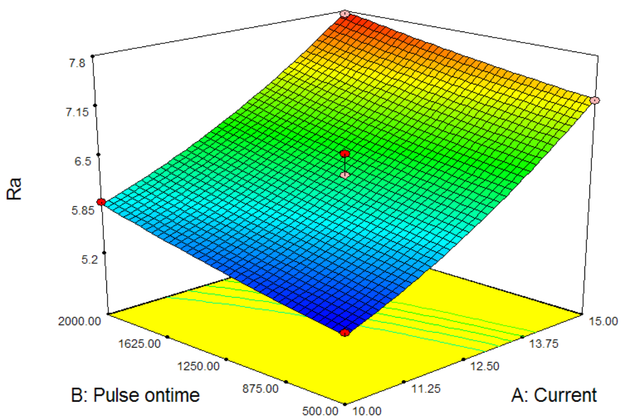

Figure 4 The 3D surface model of surface roughess with respsect to current and pulse ontime.

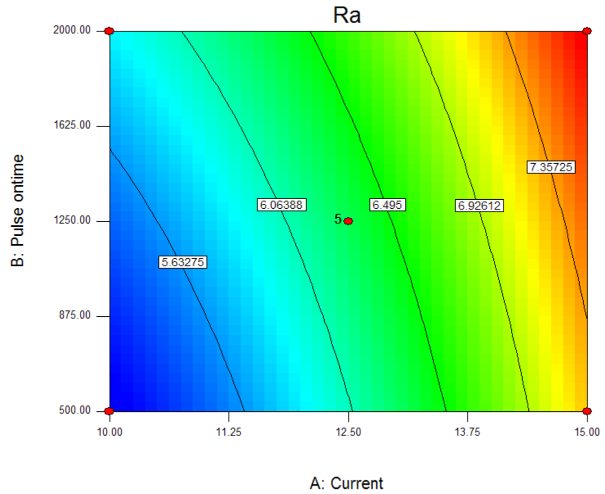

Figure 5 Contour effect of current and pulse ontime for Ra.

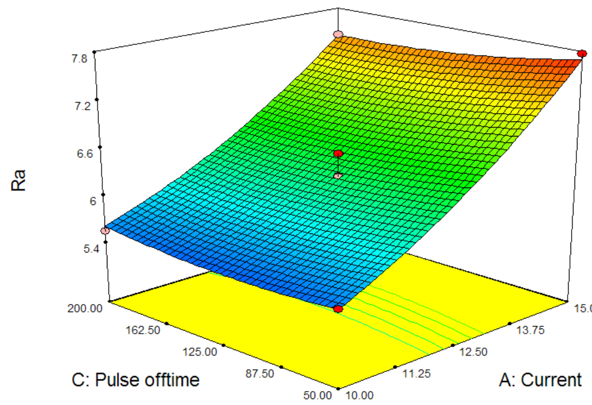

Figure 6 The 3D surface model of surface roughness with respect to current and pulse offtime.

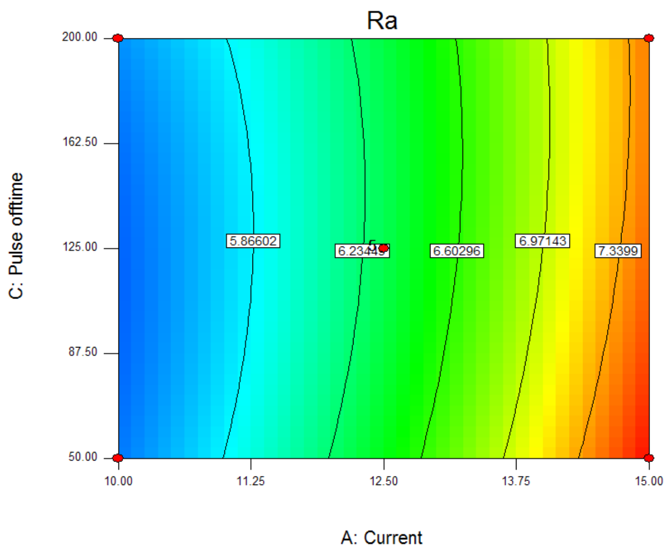

Figure 7 Contour effect of current and pulse offtime for surface roughness.

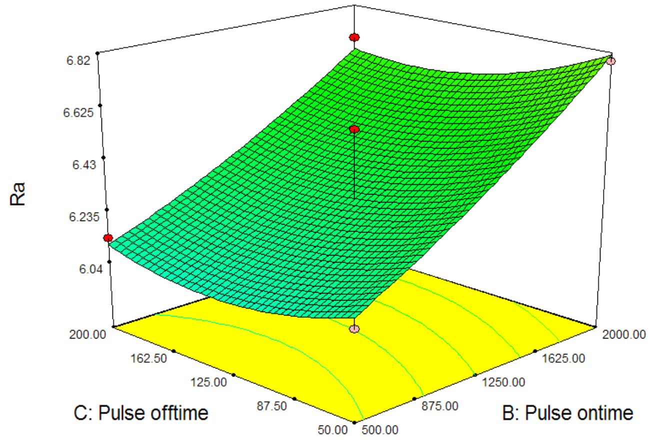

Figure 8 The 3D surface model of surface roughness with respect to pulse ontime and pulse offtime.

Figure 6 and Figure 7 shows 3D surface model and contour effect of current and pulse offtime surface roughness. It is observed from the model ,the surface roughness value gradually increases with increase of current and there is no significant effect on surface roughness value. The best surface roughness is obtained in minimum current and minimum pulse offtime. Figure 8 and Figure 9 shows 3D surface model and contour effect of pulse ontime and pulse offtime on surface roughness value.

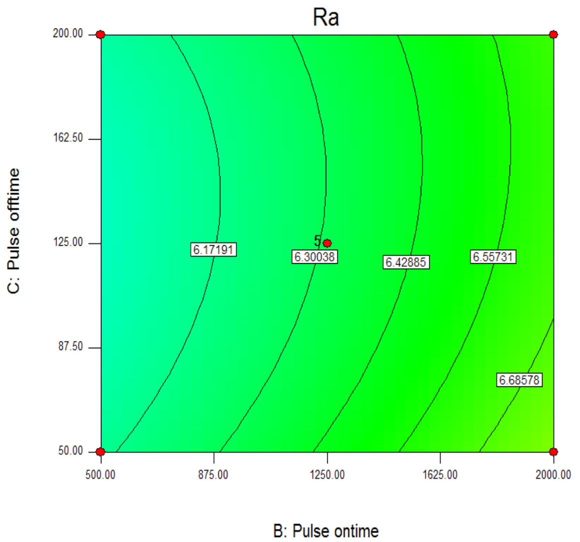

Figure 9 Contour effect of pulse ontime and pulse offtime for surface roughness.

The surface roughness value gradually increases with increase of current. There is no significant effect on surface roughness with the parameter of pulse offtime and pulse offtime influence is smaller than pulse ontime. The best surface roughness is obtained in minimum pulse ontime and pulse offtime.

Figure 10 shows the photograph of machined composite after electric discharge machining. Figure11 depicts the SEM image of machined composite. In the SEM image, it was observed high in some place high crater size due to increase of high current and pulse on time.It is concluded that pulse on time and current has strong effect on the surface roughness value.

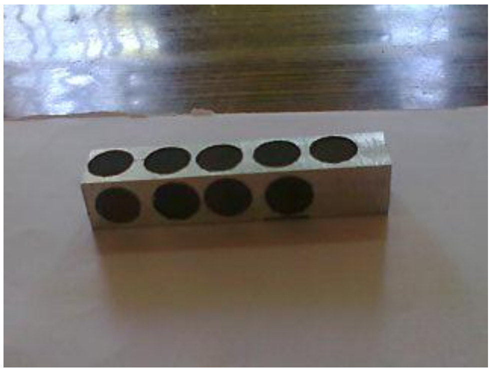

Figure 10 Photograph of machined composite.

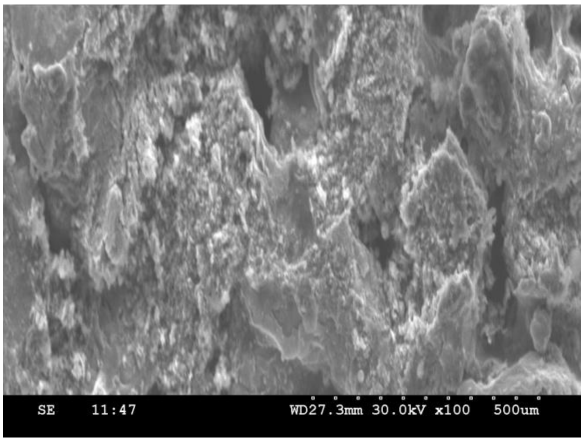

Figure 11 SEM image of machined photograph.

4. OPTIMIZATION OF MANUFACTURING CONDITIONS

The optimal manufacturing conditions for machining of AA 6061-wt. %5B_4Cp MMC with the constraints of machining parametric range is to identify the optimum values of machining parameter (y) in order to surface roughness (Ra). The optimization problem can be computed by using design of expert software 7.0.0. The aim of multi response optimization is to minimize surface roughness while machining. The constraints used during the optimization are summarized in Table 6.

Table 6 The Constraints for optimization of machining conditions.

Name	Goal	Lower limit	Upper limit
Current	in range	10	15
Pulse ontime	in range	500	2000
Pulse offtime	in range	50	200

The optimized solutions were obtained based on the desirability level by using design expert software.

Table 7 Optimization results.

Current A	Pulse on time µs	Pulse off time µs	Ra µm	Desirability
10	500	200	5.3444	0.606

5. CONFIRMATUIN OF EXPERIMENTS

To check the accuracy of mathematical model given in equation (4), two trial experiments were conducted. The details of confirmation experiments are shown in Table 8. From the table 8, it is observed that the error is less than 5%.

Table 8 the details of confirmation experiments.

Current A	Pulse on time µs	Pulse off time µs	Ra µm predicted	Ra µm Exp.	% error
10	500	200	5.3444	5.2445	1.9
10	500	200	5.3444	5.5365	3.46

6. CONCLUSION

The following conclusions were made for the mathematical modelling of surface roughness on machining of AA6061 wt.5%B_4Cp MMC.

1. The obtained results evidence that the surface roughness has influenced by current and pulse on time. But whereas it has not been significantly affected by pulse off time.
2. In the overall observation the optimized minimum surface roughness values are current10 A, pulse on time 500 µs and pulse off time 200 µs.
3. The error between the predicted values and experimental values are within 5%.
4. In mathematical model, the surface roughness of experimental values exactly fit with predicted values of these response factors with 99% confident interval.
5. The developed mathematical model can be used by the manufacturers while selecting the machining parameters.

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