INVESTIGATION OF ELECTRIC DISHARGE MACHINING PARAMETERS TO MINIMIZE SURFACE ROUGHNESS

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ABSTRACT: Surface roughness during electrical discharge machining (EDM)was determined, in which material is removed by thermo-electric process due to the occurrence of successive discharge between workpiece and electrode. Box-Behnken design (BBD) involving four parameters discharge current (I), Pulse ON time (PON), Pulse OFF time (POFF) andGap voltage, with three levels was employed to minimize the surface roughness. Other parameters such as Servo speed, Polarity and Die-electric pressurewere kept constant throughout the machining. A copper electrode toolwas used to machine the holes in AISI 1045 steel work piece. Mathematical models were developed using Response Surface Methodology (RSM), while Analysis of variance (ANOVA) was used to observe individual effect, interaction between parameters, and to check validity of models. Results revealed thatpulse on time and discharge current were two main significant parameters that statistically affected surface roughness.

Key words: ANOVA, Electric Discharge Machining, Process Parameters, and Response Surface Methodology.

INTRODUCTION

In electrical discharge machining (EDM), erosion of work part occursdue to thermo-electric energy between the electrode and work part. In this process, a series of continuous sparks isproduced between electrode and workpiece which causes electro-thermally material removal(Rao, Satyanarayana *et al*. 2008).The challenge of manufacturing industries now-a-days is the requirement of good quality product in terms of high surface finish, accuracy, better economic conditions and less environmental effects. Manufacturing consists of several processes through which raw material is converted into finishedproduct. As a result of each manufacturing process, it does not ensure proper surface finish with minimum surface roughness.Surface finish is an important characteristic that can affect the performance as well as production cost of machined parts. In EDM process, surface finish of the product depends on machining parameters *i.e.* Pulse ON time, Pulse current, Gap voltage, and Pulse OFF time(Singh and Singh 2012).To evaluate the machining parameters properly, different techniques*i.e.* full factorial and Taguchi method are used to examine the effect of processing parameters on surface roughness (Joshi and Pande 2011). In Full-Factorial Design, severalnumber of experiments need to be performed. This approach is too costly in terms of time and money, because bulk quantity of material is required to perform the experiments. Moreover,Taguchi method does not give any validated mathematical model to predict the response(Nikalje, Kumar *et al*. 2013). RSM is a statistical technique, used to develop the mathematical relationship between input parameters and output responses. RSM is a pool of scientific and mathematical techniques in which interactions between measured responses and the dynamic factors can be quantified(Çaydaş and Hasçalik 2008).

The need of study of electric discharge machining process is increasing extensively because of its use in tool and die manufacturing industry to manufacture its parts having difficult to machine profiles with high precision and accuracy(Morgan, Vallance *et al*. 2004).

RSM technique is applied to optimize the process parameters for goodsurface finish and MRR. It has been observed that SRenhances with the increase in peak current, percentage reinforcement, and Pulse ON time(Kumar, Kumar *et al*. 2013).

Little work has been reported incorporating the AISI 1045 steel for electric discharge machining using Discharge current, Pulse OFF time, Pulse ON time and Gap voltage as input variables to evaluate the surface roughness using RSM.

This study was planned to investigate the impact of process parameters on surface roughness and to find outprocess parameter which is contributing more than other three machining parameters in the increment of surface roughness.

MATERIALS AND METHODS

Die sinking EDM machine, model Neu-ar M-30 Die Sinking NC EDM was used to perform experiments and AISI 1045steel was taken as the work material.A cylindrical copper electrode having 15.8 mm external diameter was used as the electrode (tool) along with kerosene oil as dielectric. The experimental setup used in this study is shown (Fig-1).

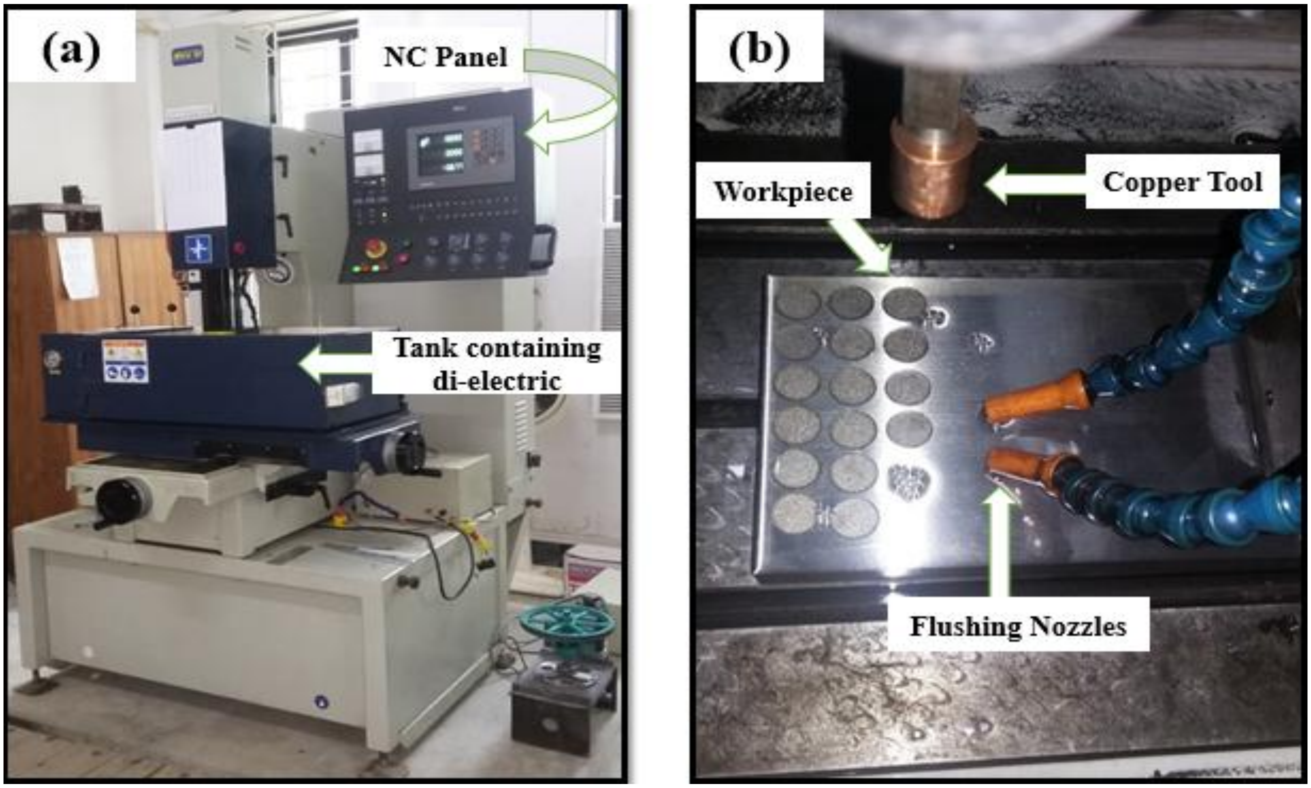


Fig- 1. Experimental Setup; a) M30 Die sinking NC EDM b) work piece along with copper electrode and flushing nozzles

Response Surface Methodology was employed to examine the effect of independent variables on surface roughness. Box–Behnken design(Ferreira, Bruns *et al*. 2007)was employed for the preparation of experimental runs and for execution of main experimentation on machine. Four parameters having three levels *i.e.*low, Medium and highwere observe forconsequence of these parameters on machined surface finish (Table 1).The levels of these parameters were selected on the basis of trial runs, in such a way that EDM machined parts were in expectable quality range. Designed experimental matrix with measured response is shown in table 2.

For measuring surface roughness, calibrated surface roughness testing machine was used. Surface roughness measurements of the holes were carried out by using a surface tester meter (Brand- Mitutoyo Surf test, Model- SJ-410). Surface roughness could be defined in different aspects including Ra, Rq and Rz. Ra is the arithmetic mean of all deviations from the center line over the sampling path. Rq is the geometric mean of all deviations from the center line over the sampling path. Rz is the average distance between all highest peaks and all deepest valleys within the sampling length. Generally surface roughness is measured in terms of arithmetic mean of all deviations from the center line over the sampling path according to ISO 4287: 1999 (Khan, Rahman *et al*. 2011). Hence Ra was considered in this study for assessment of surface roughness.

Table1.Ranges of Parameters.

Parameters	Levels		
	Low	Medium	High
Discharge Current, I (A)	3	6	9
Pulse On Time, PON (µs)	60	90	120
Pulse Off Time, POFF (µs)	3	4	5
Gap	50	60	70

Table 2.Design matrix with response.

Run	Parameters				Response
	DI (A)	PON (µs)	POFF (µs)	GAP	Ra (µm)
1	3.00	120.00	4.00	60.00	2.91
2	3.00	90.00	3.00	60.00	2.86
3	6.00	90.00	3.00	70.00	4.43
4	3.00	90.00	4.00	50.00	2.60
5	6.00	60.00	5.00	60.00	4.77
6	6.00	120.00	4.00	70.00	5.76
7	6.00	90.00	4.00	60.00	4.69
8	6.00	60.00	4.00	50.00	4.53
9	6.00	60.00	3.00	60.00	4.71
10	6.00	120.00	5.00	60.00	5.70
11	9.00	90.00	4.00	50.00	6.18
12	6.00	90.00	3.00	50.00	5.54
13	3.00	60.00	4.00	60.00	3.81
14	9.00	120.00	4.00	60.00	7.34
15	9.00	90.00	3.00	60.00	6.49
16	6.00	60.00	4.00	70.00	4.67
17	9.00	90.00	5.00	60.00	6.44
18	6.00	90.00	4.00	60.00	5.22
19	6.00	90.00	4.00	60.00	5.06
20	3.00	90.00	4.00	70.00	2.62
21	6.00	90.00	4.00	60.00	5.46
22	6.00	120.00	4.00	50.00	5.65
23	6.00	90.00	5.00	70.00	5.11
24	6.00	90.00	5.00	50.00	5.39
25	3.00	90.00	5.00	60.00	2.77
26	6.00	90.00	4.00	60.00	5.41
27	6.00	120.00	3.00	60.00	5.77
28	9.00	90.00	4.00	70.00	7.30
29	9.00	60.00	4.00	60.00	5.75

RESULTS AND DISCUSSION

Prediction of surface roughness was done through RSM after machining of 1045 Steel, using copper electrode tool. Among all other models, linear model was recommended and used for analysis (Table 3).

Table3.Model Summary Statistics.

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	Status
Linear	0.48	0.8834	0.8640	0.8229	8.44	Suggested
2FI	0.44	0.9261	0.8850	0.7796	10.50	
Quadratic	0.39	0.9552	0.9104	0.7759	10.67	
Cubic	0.28	0.9903	0.9545	0.7531	11.76	Aliased

It wascleared that Pulse ON time and discharge current were the most important parametersaffecting surface roughness followed by Pulse OFF time and Gap voltage (Table 4).R-square value showed that model could easily explain 88.31 % of the total variations. Contrast between Adj. R-Square (0.8636) and Pred. R-Square value (0.8223) showed that both values more close to each other and model could better predict the response (Ra)(Singh, Goyal *et al*. 2013).

Table4.ANOVA Analysis for Surface Roughness (Ra).

Source	Sum of Squares	df	MeanSquare	FValue	p-value	Status	Contribution %
Model	42.08	4	10.52	45.48	<0.001	**Significant**	
Discharge Current	40.08	1	40.08	173.25	<0.001	**Significant**	84.1%
Pulse-ON	1.99	1	1.99	8.61	0.0072	**Significant**	4.18%
Pulse-OFF	0.012	1	0.012	0.052	0.8215		0.025%
Gap	0.000	1	0.000	0.000	1.0000		0%
Residual	5.55	24	0.23				
Lack of Fit	5.17	20	0.26	2.67	0.1758	**not significant**	
Pure Error	0.39	4	0.097				
R- Square				0.8831			
Adj. R-Square				0.8636			
Pred. R-Square				0.8223			

Box-Behnken design (BBD), consisted of 29 tests which was usedtodevelop themathematicalmodel in order to relate the surface roughness and EDM parameters *i.e.* discharge current, Gap Voltage, Pulse ON, and Pulse OFF, using DESIGN-EXPERT Software. The developed linear model showing relationship between surface roughness (Ra) and process parameters is given in equation 1.

$$\text{Ra} = 5 + 1.83(\text{Discharge Current}) + 0.41(\text{PON}) + 0.032(\text{POFF}) + 0.001(\text{Gap}) \quad (1)$$

Normal probability plots of residuals(Fig-2)and predicted vs. actual values of surface roughness (Fig-3)revealed thatsuggested model was adequate and response could be predicted more accurately.

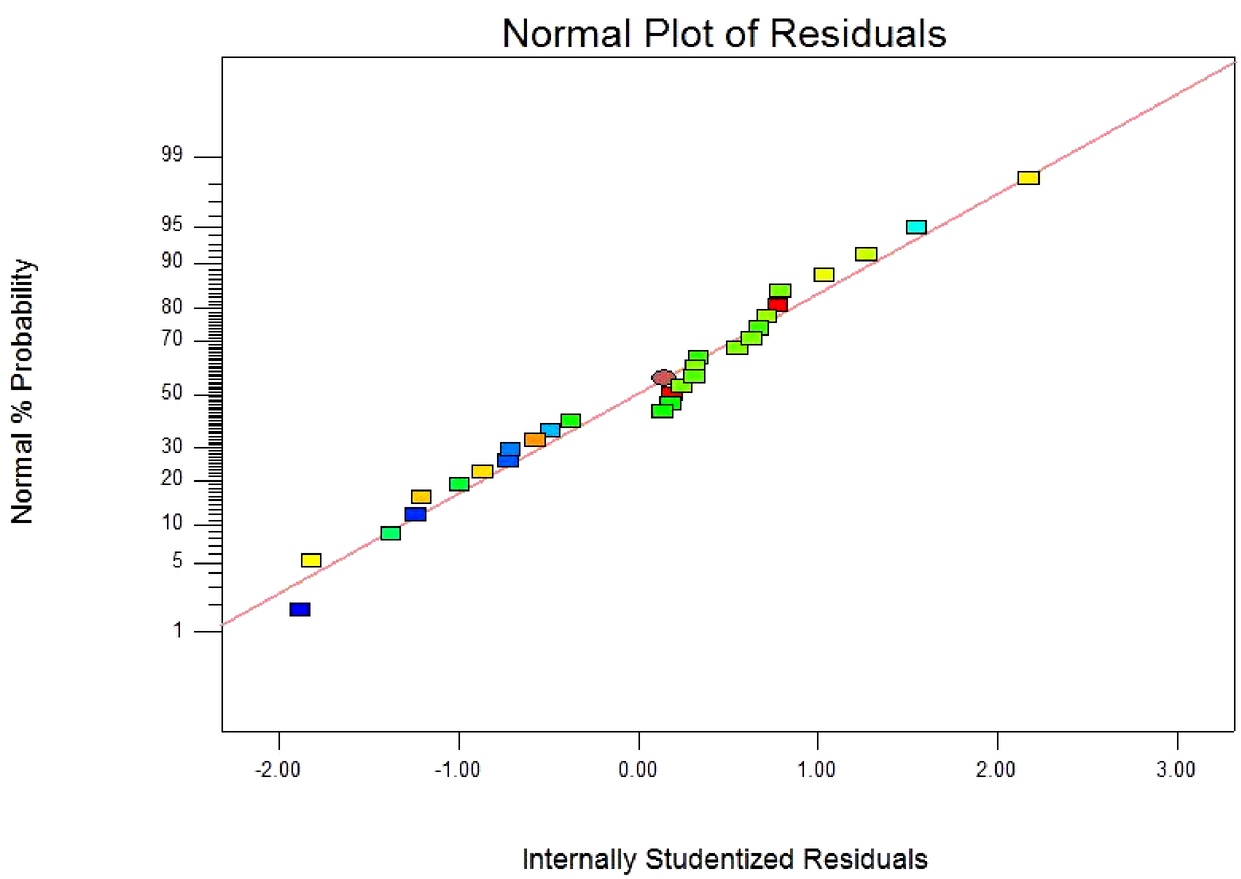


Fig-2.Normal Probability Plot of residuals for Ra.

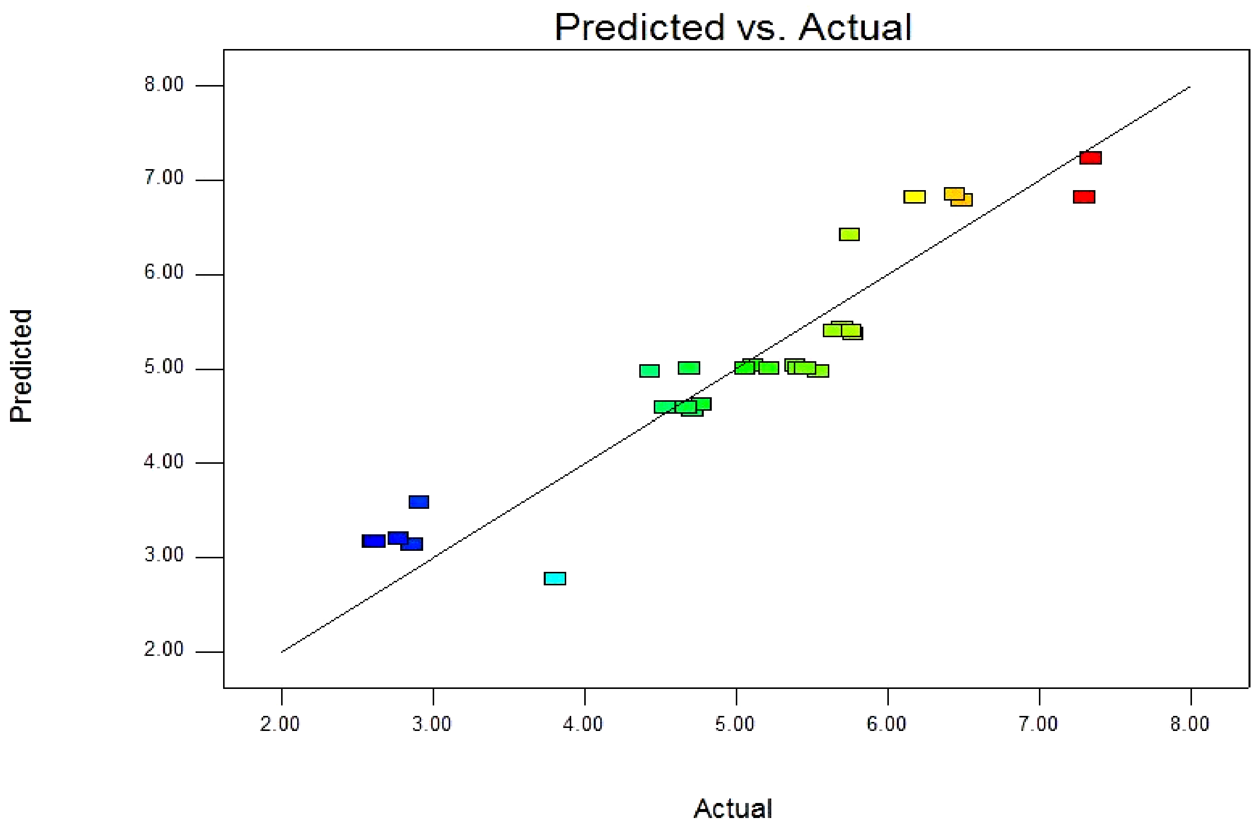
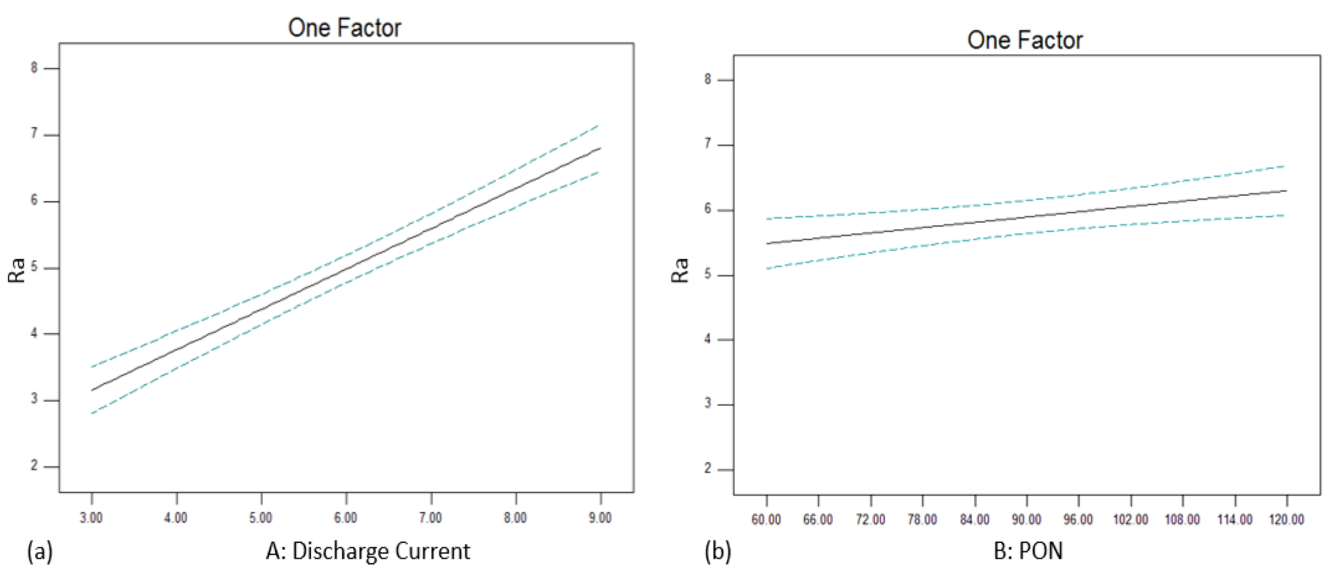


Fig-3.Plot of Predicted vs. Actual values for Ra.

The individual effect of machining parameters on surface roughness (Ra) (Figs-4a, b, c, and d) revealed that surface roughness increases when Discharge current is increased from 3 to 9 A and Pule ON time is increased from 60 to 120 µs. No significantly change occurredin surface roughness when Pulse OFF time was increased from 5 to 7 µs and Gap voltage was changed from 50 to 70 V, similar result was also observed by (Singh, Kumar *et al*. 2014). It clearly narrates that discharge current was the most significant parameter followed by Pulse ON time effecting the value of surface roughness.Similar behaviour was observed by (Sultan, Kumar *et al*. 2014)(Srivastava, Dixit *et al*. 2014)(Kumar, Kundu *et al*.).



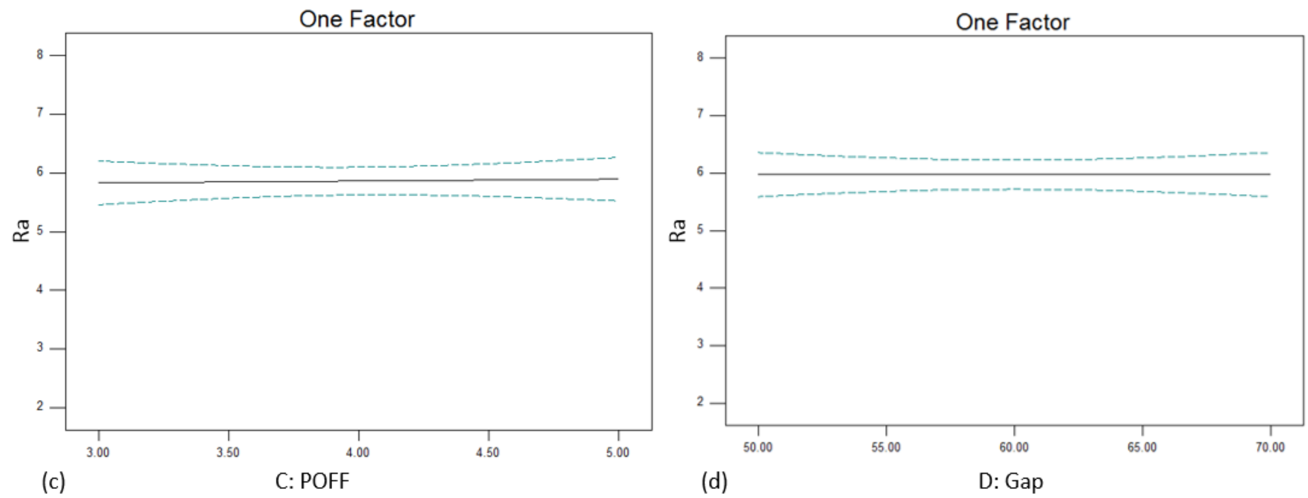


Fig- 4: a) Ra Vs. Discharge Current b) Ra Vs. PON c) Ra Vs. POFF d) Ra Vs. Gap

3D surface plots(Figs-5, 7 and 9) describedthat no twistwas detected in the plots which indicated that interaction effects werenon-significant. The contour plots (Figs-6, 8 and 10)were utilized to adjust the machining parameters in EDM against surface roughness which was vital for productivity and quality(Torres, Luis *et al*. 2015). Contour plots depicted that discharge current and Pulse ON time were significant process parameters that effected surface roughness, reported by (Singh, Goyal *et al*. 2013). Surface roughness value increasedwith the increase in discharge current and PON while keeping other parameters constant (Fig-5).Similar effect was observed by (Jabbaripour, Sadeghi *et al*. 2012) who reported that improvement in surface finish was observed when discharge current and gap voltage increased where other parameters remained constant (Fig- 7) as has been expressed by (Boujelbene, Bayraktar *et al*. 2009). Whereas non-significant effect was found against interaction in terms of POFF and Gap for surface roughness (Fig-9) as has been presented by(Tiwary, Pradhan *et al*. 2015)(Khan, Rahman *et al*. 2011).

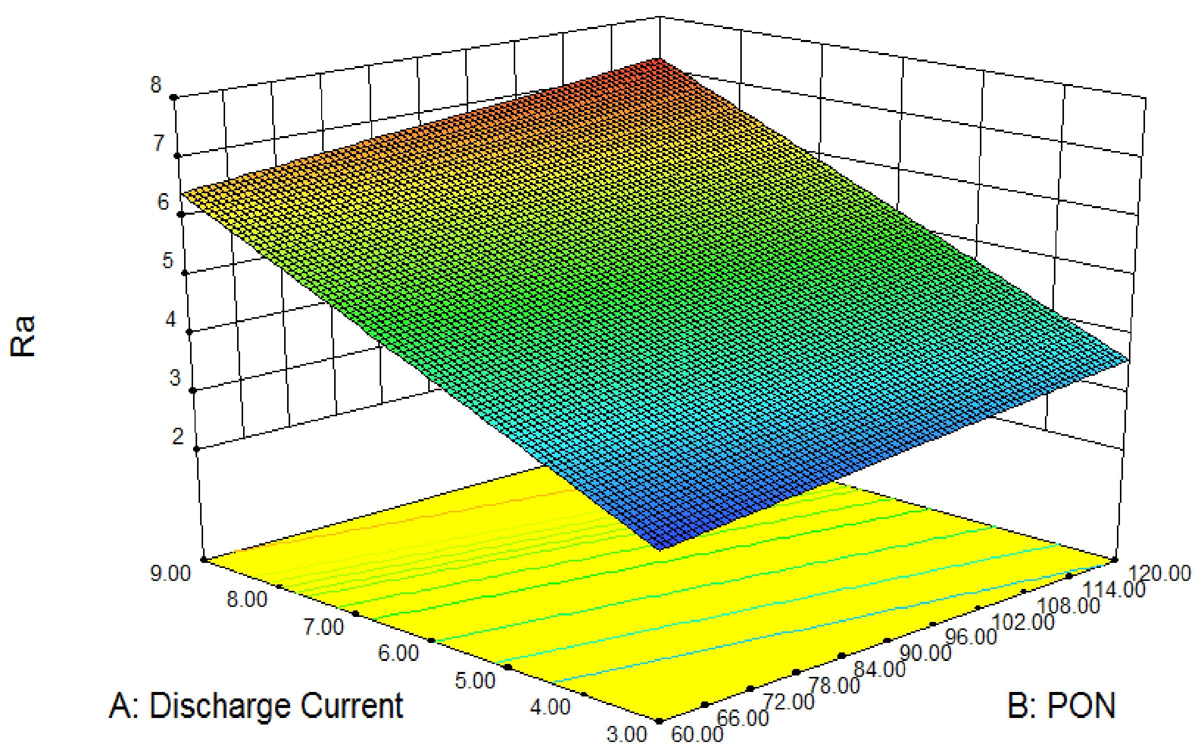


Fig- 5. 3D response surface Ra vs Discharge current and PON

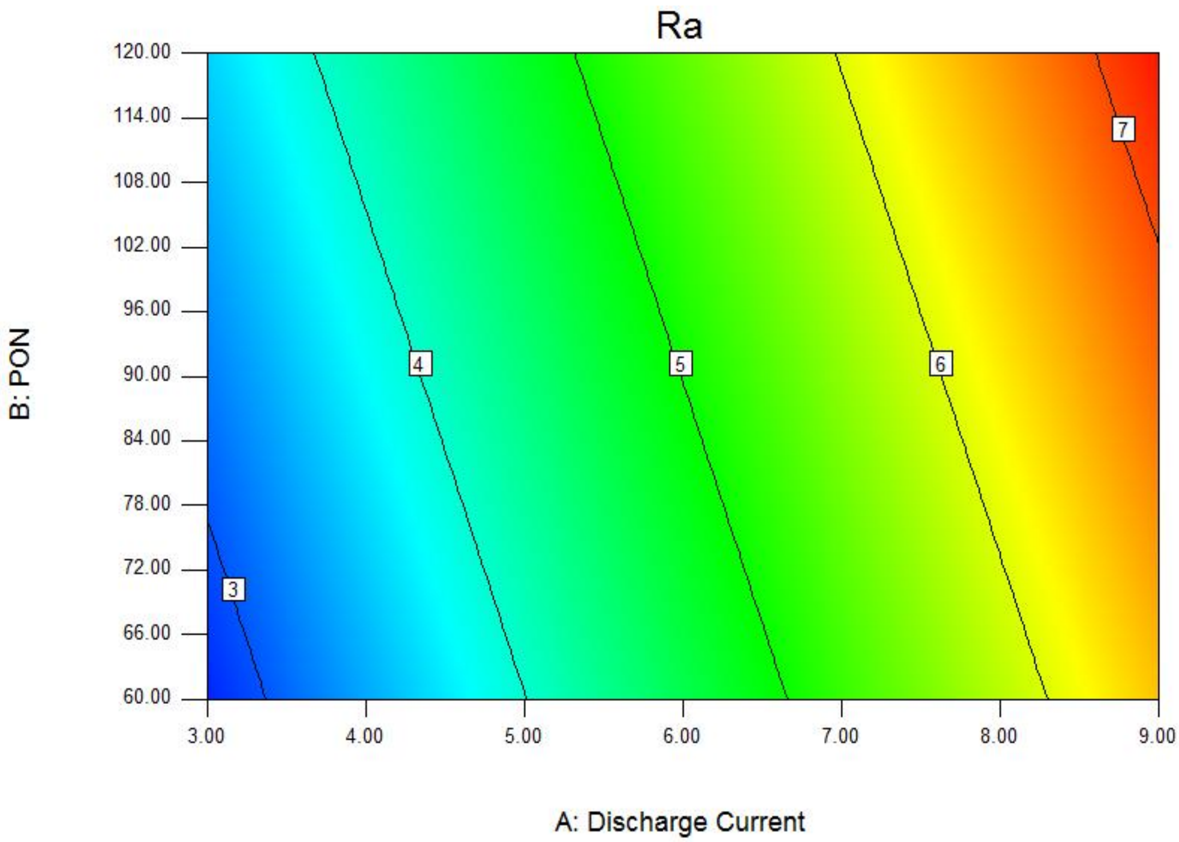


Fig- 6. Contour plot: Discharge current vs. PON.

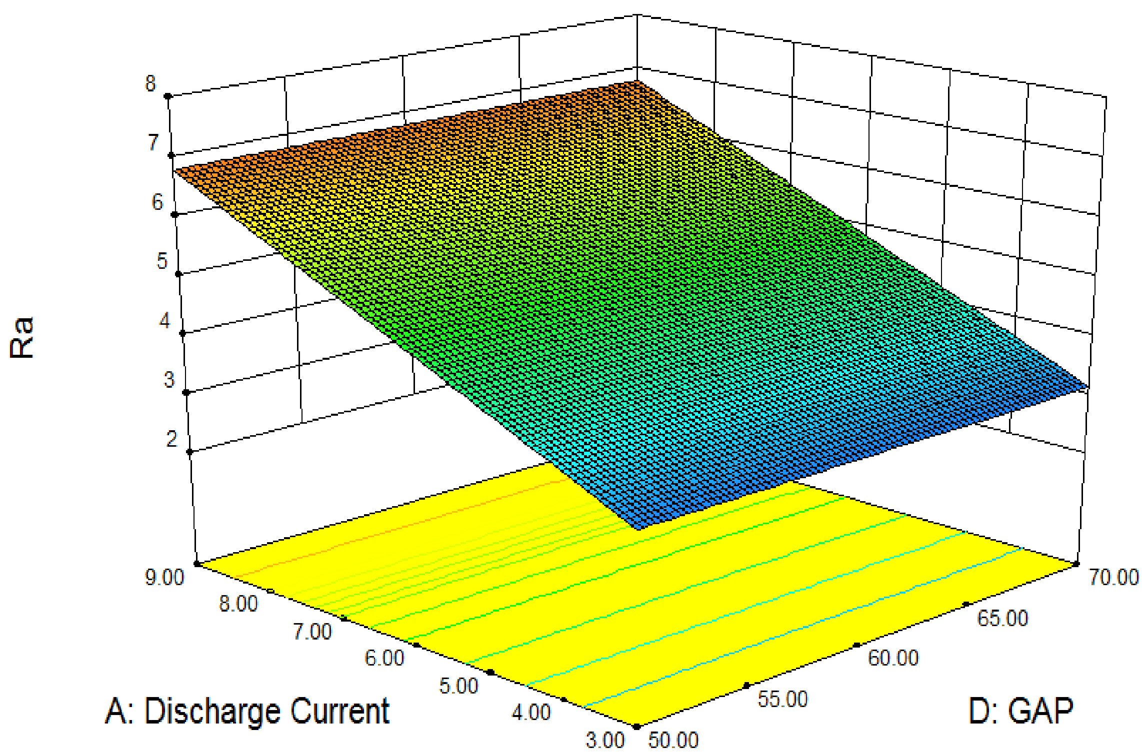


Fig- 7. 3D response surface Ra vs. Discharge current and Gap

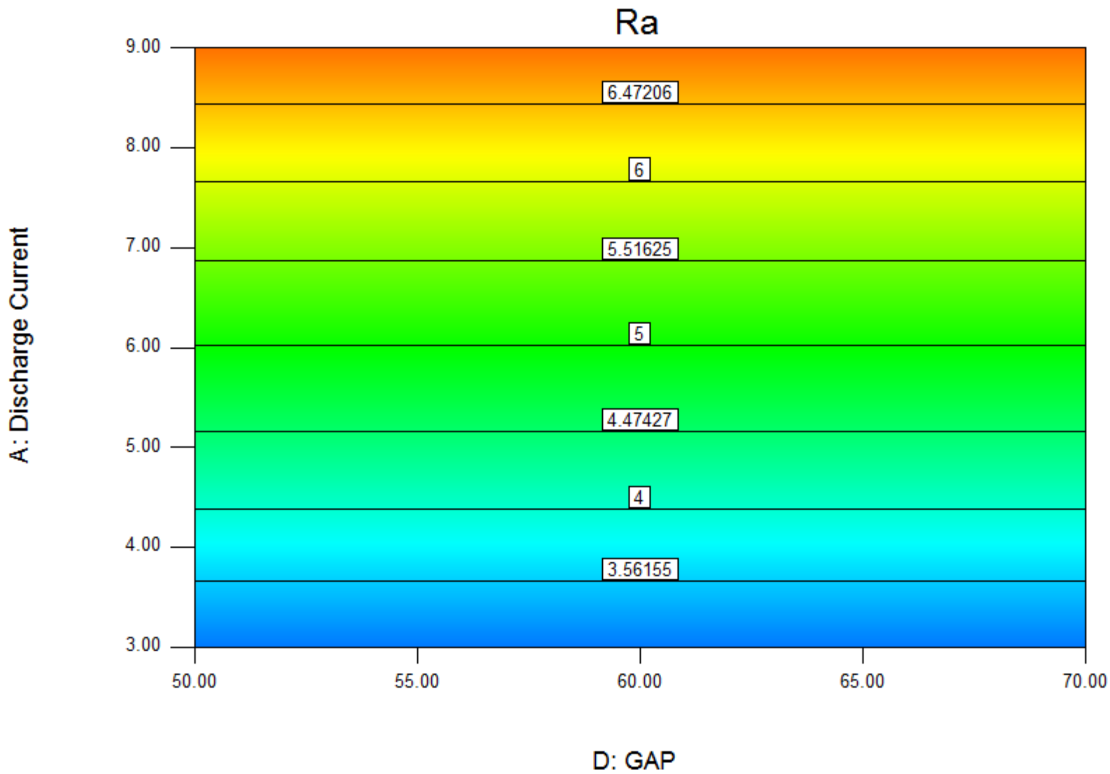


Fig- 8. Contour plot: Discharge current vs. Gap.

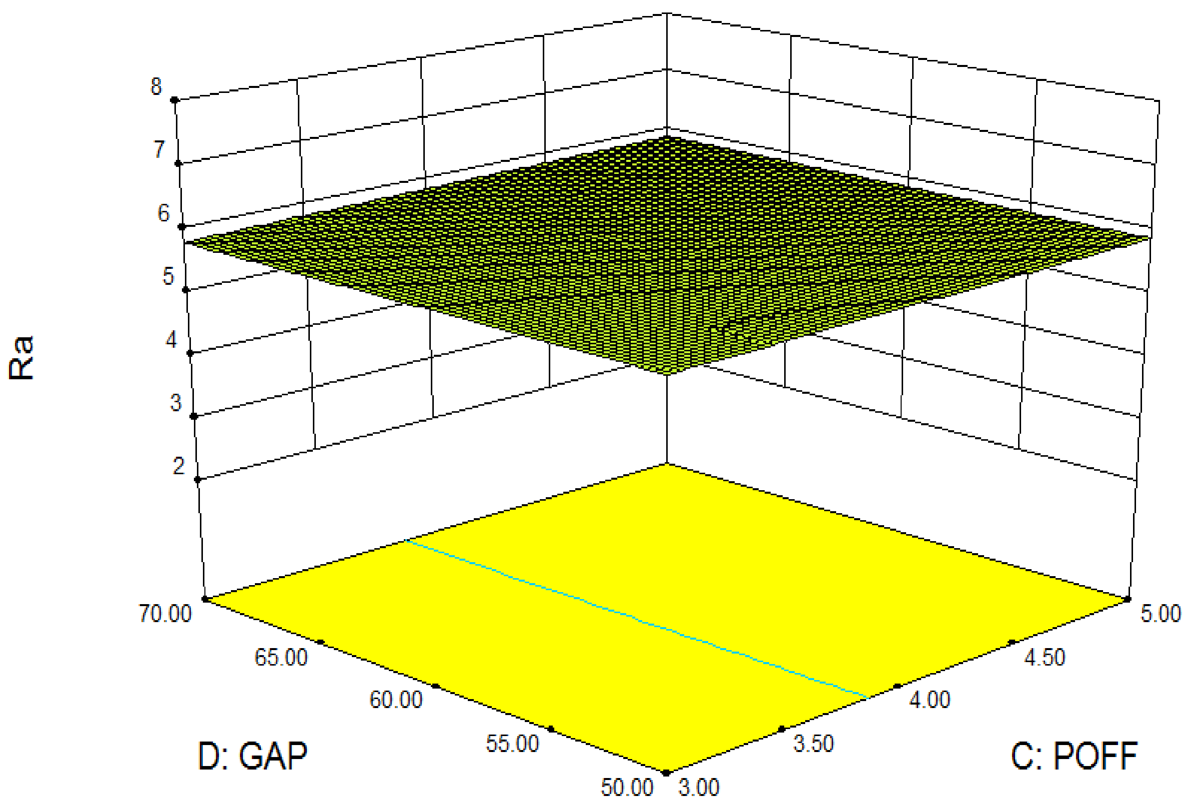


Fig- 9. 3D response surface Ra vs. POFF and Gap

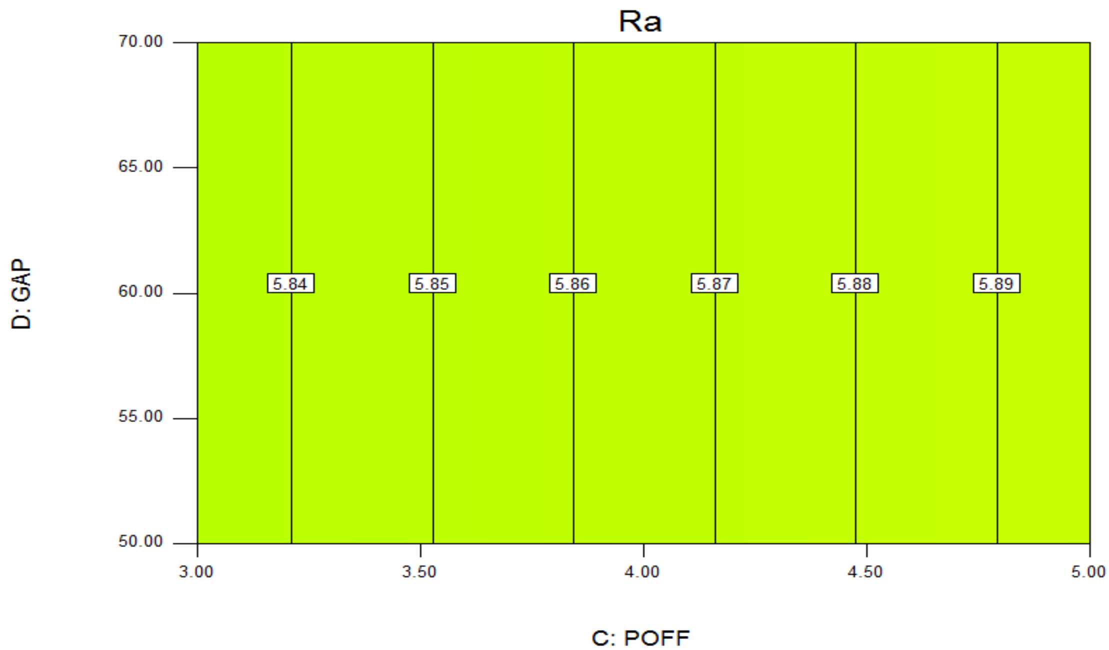


Fig- 10. Contour plot: POFF vs. Gap.

Target value of surface roughness was achieved from the contour plots against process parameters. It could be seen from contour plots that a required value of surface roughness can be attained by the best combination of discharge current, Pulse ON, Gap voltage, and Pulse OFF. It was deduced from contour plotsthat;to achieve a target surface roughness value of 5 µm,value of discharge current should be 5.4~6.6 A and Pulse ON time 60-120 µs (Fig-6). Similarly a target surface roughness value of 5 µm could be attained by setting Gap of 50~70V and discharge current to 6.1 A (Fig-8).However, POFF and Gap voltage should be set to 3.2 µs and within 50~70 V respectively to achieve surface roughness value of 5.84 µm (Fig- 10). Hence, any target Ra value can be obtained on different combinations of parameters within designed parametric conditions that would conform maximum output without compromising aimed surface quality.

Additional eight experiments were performed to validate the model. These combinations of experimentalparameterswere beyond the BBD designed matrix. The accuracy of the developed model was evaluated through relation delivered by (Hashmi, Zakria *et al*. 2015) which is given below.

$$\Delta = \frac{100}{N}\sum_{i=1}^{N}\left|\frac{Y_{i,exp} - Y_{i,pred}}{Y_{i,pred}}\right| (2)$$

Where Δ= error estimator

The predicted and actual values for average surface roughness ofadditional trial runs in table5 clarified that predicted and experimental values lie closely to each other (Fig-11). The calculated average prediction error for model validation was 3.28%. These results supported the validity of developed mathematical model.

Table 5.Data for Validation.

Trial no.	Levels				Average surface roughness (Ra)		Residuals
	DI (A)	**PON (µs)**	**POFF (µs)**	**Gap**	**Exp.**	**Pred.**	**Diff**
1	3	120	5	50	2.78	2.546	0.234
2	3	120	5	70	2.711	2.786	-0.075
3	3	90	4	60	4.607	4.534	0.073
4	6	120	3	70	5.723	5.631	0.092
5	6	60	3	60	5.748	5.522	0.226
6	9	60	4	70	5.732	5.831	-0.099
7	9	90	4	70	6.602	6.354	0.248
8	9	90	3	50	6.284	6.194	0.09

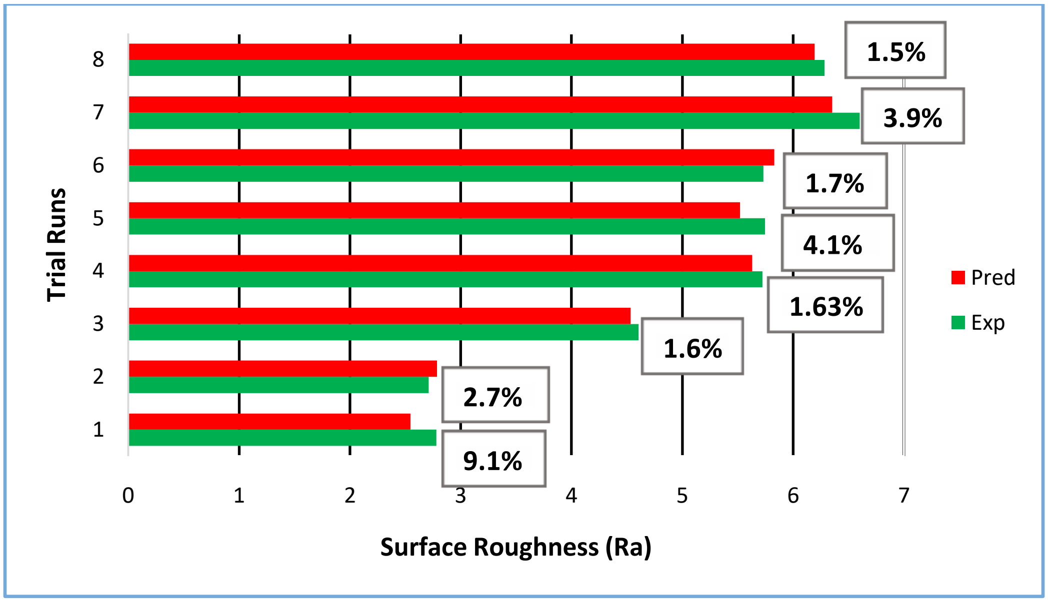


Fig-11. Experimental Vs. Predicted Ra

It was concluded that the developed mathematical model clearly represented that discharge current and Pulse on time were the most influencing parameter on surface roughness, reported by(Kansal, Singh *et al*. 2005)while, Pulse off time and Gap voltage are insignificant parameters. Lowest surface roughness (Ra)was achieved while machining of AISI 1045 was 2.60µm which was majorly influenced by the two parameters discharge current and Pulse ON time. In order to get better surface finish, discharge current as well as Pulse ON time should be set at low levels as has been reported by (Kao, Tsao *et al*. 2010)(Khan, Rahman *et al*. 2011).

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