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PREDICTION OF SURFACE ROUGHNESS DURING ELECTRIC DISCHARGE MACHINING BY RESPONSE SURFACE METHODOLOGY

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Abstract: *EDM is a non-traditional machining process that removes metals by electric spark discharge or erosion. During the machining process, the work-piece material is rapidly fused and vapourized, leading to the generation of micro craters on the work-piece's surface. Surface roughness is, therefore, an inherent by-product of EDM. It generally is detrimental to the efficient performance of machined parts. Hence, a manifold of researches involving state-of-the-art methods (numerical, computational, or experimental etc.) have been carried out to optimize surface roughness. The authors of this research paper have developed a unique Mathematical Surface Roughness Model with the aid of Central Composite Design (CCD) using Response Surface Methodology (RSM), in order to predict and optimize surface roughness produced in EDM. Three machining parameters: Pulse on, Pulse off, and Gap Voltage were used as inputs in the model. In the CCD model the different axial points, center points, and factorial points were used and the appropriate model was determined using a Fit and Summary test. Surface roughness values (R_a) were measured, for the purpose of model formation and validation, using a novel Digital Image Processing (DIP) technique, previously developed by the authors. The model showed good precision and reliability and could be used to aid further research in similar fields.*
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Key words: *EDM, Surface Roughness Optimization, Response Surface Methodology, Central Composite Design, Machining Parameters, Digital Image Processing.*

1. INTRODUCTION

EDM or Electrical-Discharge Machining is one of the oldest and most widely used unconventional machining processes. The usefulness of this method stems from the fact that no contact between the work-piece and tool is necessary for the machining to occur [1]. Thus, no mechanical cutting forces are necessary to remove unwanted material. This has lead to the use of EDM is a manifold of industrial applications such as: machining of dies and tools, aerospace and automotive components, mirror finishing, and machining involving transient and tough alloys [2].

Since, material is removed by fusion and vapourization, by plasma discharges through the dielectric, miniature crater formation at the machining site is unavoidable. Such rough surface, if unchecked, can lead to sliding friction between moving surfaces and ultimately to heat generation, wear, and failure. These phenomena are also a source of energy loss and additional head costs at industries [3].

The prediction and subsequent optimization of surface roughness, is therefore, a crucial and important research area. Patwari et al. [4, 5] used two different and well known approaches for the prediction and optimization of surface roughness in End milling of medium carbon steel with Titanium Carbide Inserts. Their method of utilizing the statistical approach of Response Surface Methodology (RSM) and specifically a small Central Composite Design (CCD) for surface roughness model generation was used as a guideline by the authors of this study.

Arif et al. [6] and Patwari et al. [7] also utilized a novel approach to measuring surface roughness and the subsequent generation of contour surfaces, respectively, using Digital Image Processing in MATLAB 2008 [8]. This same roughness measurement technique, which is novel, simple, and very reliable was applied by the authors of this study to measure surface roughness for model building and validation purposes.

Many other researchers [9, 10] have also investigates surface roughness and tried to develop working prediction models. However, surface roughness prediction and optimization in EDM using statistical RSM approach has largely been ignored. The main reason for this is the complexity of the EDM phenomenon. As yet there is no single acceptable theory that explains the actions of EDM machines. The authors of this research have thus, developed a novel predictive model for surface roughness using the CCD approach in RSM. They then determined the optimum surface roughness attainable, within the limits of the machine tools ability, by using Desirability Function. Both their prediction and optimization results were validated using actual measurements of surface roughness made using the novel DIP technique.

2. THE EQUIPMENT AND MATERIALS

EDM Machine

All experiments were performed on the CNC JS EDM machine (Model: CNC EB600L S. F.) as shown in Figure 1. For performing the experiments the work-piece, electrode and the dielectric fluid of the EDM machine were chosen very carefully, after extensive literature review and commercial availability.

Fig. 1 The JS EDM machine

Work-piece and Electrode

EDM is mostly used to machine steel dies and tools. Thus, for the investigation and research purposes, mild steel was used as the work-piece material. A coarse mild steel plate was taken and it was surface ground to obtain a smooth surface finish, as shown in figure 2. A right circular copper cylinder was chosen as the electrode as shown in figure 3.

Fig. 2 The work-piece both raw and ground

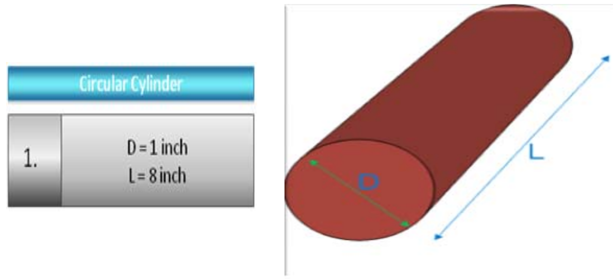


Fig. 3 The electrode and its dimensions

3. THE EXPERIMENTAL SETUP

Coding of the Independent Variables

The independent variables were coded taking into consideration the limitation and capacity of the EDM Machines. Levels of independent and coding identification are presented in Table 1, for the experiment using Copper Electrode.

Table 1 Coding Identification for EDM using Copper Electrode

Sl. No.	Levels Coding	Lowest $(-)\sqrt{2}$	Low $(-)1$	Center 0	High $(+)1$	Highest $(+)\sqrt{2}$
1	x_1, On T, T_{on}	80	120	300	700	1000
2	x_2, Off T, T_{off}	5	6	10	16	20
3	x_3, Gap Voltage, V (volts)	50	55	70	90	100

$$x_1 = \frac{\ln T_{on} - \ln 300}{\ln 700 - \ln 300};\; x_2 = \frac{\ln T_{off} - \ln 10}{\ln 16 - \ln 10};\; \text{and}\; x_3 = \frac{\ln V - \ln 70}{\ln 90 - \ln 70}$$

Experimental Design

The design of the experiments has an effect on the number of experiments required. Therefore, it is important to have a well-designed experiment to minimize the number of experiments. Cutting conditions in coded factors and the surface roughness values obtained using Copper Electrode and mild steel are presented in Table 2. Figure 4 shows the results of DIP as proposed by Anayet U Patwari et. al[7].

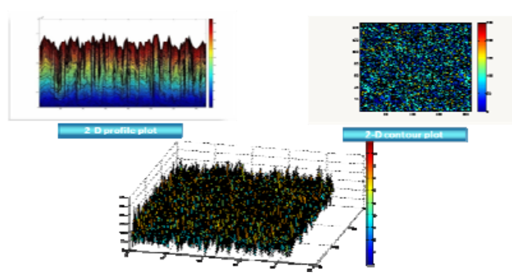


Fig. 4 Results of the DIP

Table 2 Surface roughness and cutting conditions in coded factors

Std	Run	Block	Factor 1 A:ON T S	Factor 2 B:OFF T S	Factor 3 C:GAP Voltage V	Response 1 Surface Rough Micro-m
1	9	Block 1	1.00	1.00	-1.00	0.86936
2	8	Block 1	1.00	-1.00	1.00	1.75418
3	7	Block 1	-1.00	1.00	1.00	1.85893
4	1	Block 1	-1.00	-1.00	-1.00	0.7882
5	2	Block 1	0.00	0.00	0.00	1.03149
6	4	Block 1	0.00	0.00	0.00	1.03
7	3	Block 1	0.00	0.00	0.00	1.03149
8	6	Block 1	0.00	0.00	0.00	1.03
9	5	Block 1	0.00	0.00	0.00	1.03149
10	14	Block 2	-1.41	0.00	0.00	1.62322
11	11	Block 2	1.41	0.00	0.00	1.40124
12	15	Block 2	0.00	-1.41	0.00	0.69486
13	12	Block 2	0.00	1.41	0.00	0.77588
14	10	Block 2	0.00	0.00	-1.41	1.20866
15	13	Block 2	0.00	0.00	1.41	1.60369

In the experiment, a small CCD was used to develop the Surface roughness model. The analysis of mathematical models was carried out using Design-expert 6.0 package [11].

3. RESULTS AND DISCUSSIONS

Development of second order model using CCD design

The Fit and Summary test which is shown in Table 3, indicates that the quadratic model CCD models was more significant than the linear model and it also proved that the linear model had a significant lack of fit (LOF). Therefore, the quadratic model was chosen in order to develop the CCD model.

Table 3 Fit and Summary test of the second order CCD model

Sequential Model Sum of Squares

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	0.22	1	0.22			Suggested
Block	5.215E-003	1	5.215E-003			
Linear	0.50	3	0.17	1.91	0.1911	
2FI	0.18	3	0.059	0.60	0.6367	
Quadratic	0.69	3	0.23	3.654E+005	< 0.0001	Suggested
Cubic	0.000	0				Aliased
Residual	2.508E-006	4	6.269E-007			
Total	1.59	15	0.11			

The second order surface roughness model is given as:

Ln (Surface Roughness) = + 0.031 - 0.052*A + 0.039*B + 0.100 *C + 0.19*A² - 0.17*B² + 0.15*C² - 0.29*A*B -8.733E-006*A*C – 0.062*B*C

To verify the adequacy of the proposed second order CCD model, ANOVA was used and the results are shown in the Table 4 below. The response surfaces are shown in figures 5 and 6.

Table 4 ANOVA analysis of the CCD model

ANOVA for Response Surface Quadratic Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Block	5.215E-003	1	5.215E-003			
Model	1.36	9	0.15	2.409E+005	< 0.0001	significant
A	*0.011*	*1*	*0.011*	*17247.80*	*< 0.0001*	
B	*6.082E-003*	*1*	*6.082E-003*	*9701.32*	*< 0.0001*	
C	*0.040*	*1*	*0.040*	*63785.47*	*< 0.0001*	
A²	*0.27*	*1*	*0.27*	*4.326E+005*	*< 0.0001*	
B²	*0.22*	*1*	*0.22*	*3.447E+005*	*< 0.0001*	
C²	*0.17*	*1*	*0.17*	*2.698E+005*	*< 0.0001*	
AB	*0.17*	*1*	*0.17*	*2.683E+005*	*< 0.0001*	
AC	*1.525E-010*	*1*	*1.525E-010*	*2.433E-004*	*0.9883*	
BC	*7.686E-003*	*1*	*7.686E-003*	*12260.95*	*< 0.0001*	
Pure Error	2.508E-006	4	6.269E-007			
Cor Total	1.36	14				

The Model F-value of 240869.54 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.

Figure 5 and 6, below, show the 3D-response surface of quadratic CCD model based on the effect of ON T and OFF T and ON T and Gap Voltage on surface roughness. The contours affirm that surface roughness can be affected by the Gap voltage followed by ON T and OFF T.

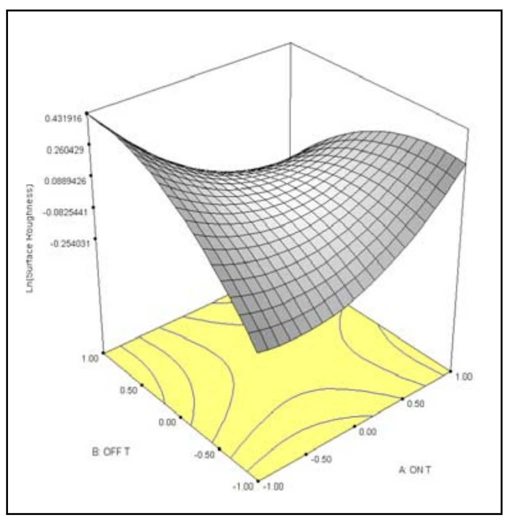
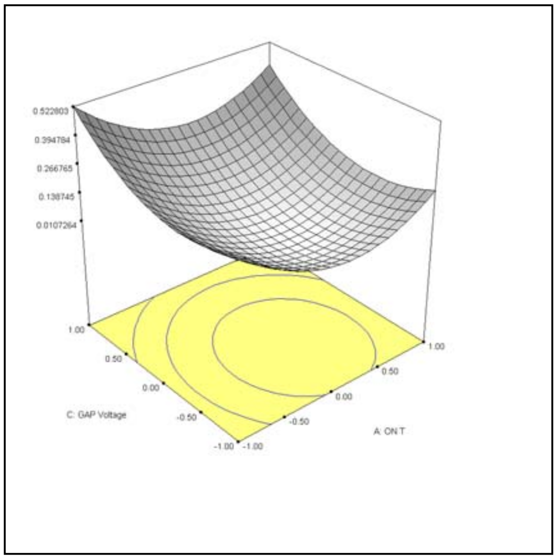


Fig. 5 Response surface generated from CCD model



The normal probability plots of the residuals and the plots of the residuals versus the predicted response for Surface roughness are shown in figures 7 and 8, respectively. A check on the plots in figure 7 revealed that the residuals generally fall on a straight line implying that the errors are distributed normally.

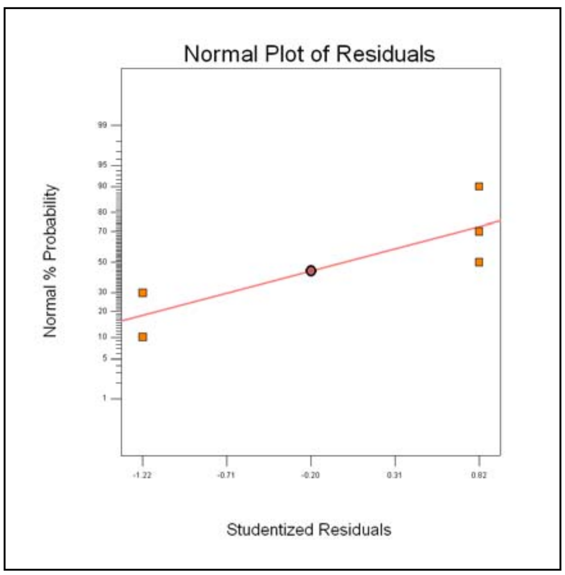


Fig. 7 Normal probability plot of residuals for F_a data.

Also figure 8 revealed that they have no obvious pattern and unusual structure. This implies that the models proposed are adequate and there is no reason to suspect any violation of the independence or constant variance assumption. By analysis the developed quadratic model, it has been observed that with the increase of OFF T and GAP Voltage the surface roughness increases but with the increase of ON T the surface roughness decreases.

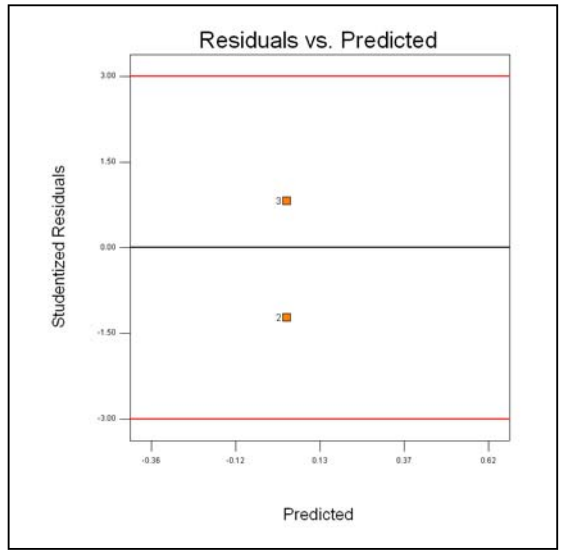


Fig. 8 Plot of residuals vs. predicted response for Fa data

CONCLUSIONS

This research paper discussed the development of a mathematical model based on experimental findings for predicting the surface roughness during EDM of steel alloy using copper electrode. The general conclusions can be summarized as follows: The developed quadratic CCD indicates that the GAP Voltage was the most significant influence on surface roughness, followed by ON T and OFF T. The CCD model developed by RSM using Design Expert package is able to provide accurately the predicted values of surface roughness close to actual values found in the experiments. The equations are checked for their adequacy with a confidence level of 95%.

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