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Optimization of machining parameters for electrical discharge machining using RSM

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Abstract

The prediction of optimal machining conditions for required surface finish and dimensional accuracy related to electrode wear rate plays a very important role in process planning of electrical discharge machining (EDM). The present work deals with the features of electrical discharge machining of AISI 303 stainless steel. A second-order mathematical model, in terms of machining parameters, was developed for surface roughness and electrode wear rate (EWR) using response surface methodology (RSM). The experimental plan was based on the face centered, central composite design (CCD). The experimental results indicate that the proposed models could adequately describe the performance indicators within the limits of the factors that are being investigated. Finally the responses have been optimized for a given machining condition by analysis of variance (ANOVA) analysis.

Key words: EDM, Electorde wear ratio, Surface roughness, Response surface methodology, ANOVA.

1. Introduction

Electrical Discharge Machining, commonly known as EDM is a non-conventional machining method used to remove material by a number of repetitive electrical discharges of small duration and high current density between the workpiece and the tool. EDM is an important and cost-effective method of machining extremely tough and brittle electrically conductive materials. In EDM, since there is no direct contact between the workpiece and the electrode, hence there are no mechanical forces existing between them. Any type of conductive

material can be machined using EDM irrespective of the hardness or toughness of the material.

EDM has become an important and cost-effective method of machining extremely toughand brittle electrically conductive materials. It is widely used in the process of making moulds and dies and sections of complex geometry and intricate shapes. The workpiece material selected in this experiment is AISI 303 Stainless steel taking into account its wide usage in industrial applications. In today's world 303 stainless steel contributes to almost half of the world's production and consumption for industrial purposes.

B.S. Reddy et al. [1] carried out a study on the effect EDM parameters over MRR, TWR, SR and hardness. Mixed factorial design of experiments and multiple regression analysis techniques had been employed to achieve the desired results. The parameters in the decreasing order of importance for; MRR: servo, duty cycle, current and voltage; TWR: current, servo and duty cycle; SR: current; HRB: servo only. M.M. Rahman et al. [2] investigated the effect of the peak current and pulse duration on the performance characteristics of the EDM. I. Puertas et al. [3] carried out results which showed that the intensity and pulse time factor were the most important in case of SR while the duty cycle factor was not significant at all. The intensity factor was again influential in case of TWR. The important factors in case of MRR were the intensity followed by duty cycle and the pulse time. S.H. Tomadi et al. [4] investigated the machining of tungsten carbide with copper tungsten as electrode. The full factorial design of experiments was used for analyzing the parameters [10-11]. In case of SR, the important factors were voltage and pulse off time while current and pulse on time were not significant.

The main aim of this present work to estimate the electrode wear rate and surface roughness of AISI 303 SS with copper tool.

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2. Experimentation

Conduct of experiment

The experiments were conducted using the Electric Discharge Machine, model ELECTRONICA - ELECTRAPLUS PS 50ZNC (die sinking type) the polarity of the electrode was set as positive while that of workpiece was negative. The dielectric fluid used was EDM oil (specific gravity-0.763).

Selection of the workpiece and tool material

AISI 303 Stainless Steel is one of the most widely used materials in all industrial applications and accounts for approximately half of the world's stainless steel production and consumption. Because of its aesthetic view in architecture, superior physical and mechanical properties, resistance against corrosion and chemicals, weldability, it has become the most preferred material over others. Many conventional and non-conventional methods for machining AISI 303 stainless steel are available.

The tool material used in Electro Discharge Machining can be of a variety of metals like copper, brass, aluminum alloys, silver alloys etc. The material used in this experiment is copper. The tool electrode is in the shape of a cylinder having a diameter of 10mm. Machining parameters and their levels are presented in Table 1.

Table 1 Machining parameters and their levels

Machining parameter	**Symbol**	**Unit**	**Levels**		
			Low	Medium	High
Discharge current	(Ip)	A	2	4	8
Pulse on time	(T_{on})	µs	50	250	450
Voltage	(V)	V	40	45	50

3. Results and Discussions

For each experimental run, machining was carried out for 60 min and, MRR and TWR were calculated by measuring the weight loss of workpiece (Equation 1) and tool (Equation 2), respectively.

$$\text{MRR} = \frac{W_{jb} - W_{ja}}{t \times \rho} \quad (1)$$

$$\text{TWR} = \frac{T_{jb} - T_{ja}}{t \times \rho} \quad (2)$$

$$\text{EWR} = \frac{\text{MRR}}{\text{TWR}} \quad (3)$$

Where W_b&W_a arethe weights of workpiece and tool before and after machining, respectively, and T_b and T_a are the weights of tool before and after machining, respectively, whereas the machining time is t. The density of AISI 303 Stainless steel material is ρ = 7.85 g/cm^3, and density of copper electrode is ρ= 8.92 g/cm3. EWR and SR with the machining parameters are tabulated in Table 2.

Surface Roughness is the measure of the texture of the surface. It is measured in µm. If the value is high then the surface is rough and if low then the surface is smooth. It is denoted by Ra. The values are measured using Portable style type profilometer, Talysurf (Model: Taylor Hobson, Surtronic 3+) The arithmetic mean of three readings is taken as the final value.

Table 2 Observation Table

Run Order	Pt Type	Blocks	Ip A	T_{on} µs	V	EWR (MRR/TWR) (mm3/min)	SR µm
1	1	1	2	50	40	22.471	2.87
2	1	1	8	450	40	131.805	7.77
3	1	1	8	50	50	116.969	5.06
4	1	1	2	450	50	93.547	3.72
5	0	1	5	250	45	62.689	4.41
6	0	1	5	250	45	63.034	4.28
7	1	2	8	50	40	104.150	5.90
8	1	2	2	450	40	35.476	3.90
9	1	2	2	50	50	26.417	2.80
10	1	2	8	450	50	162.112	7.67
11	0	2	5	250	45	77.393	5.35
12	0	2	5	250	45	51.111	4.11
13	-1	3	2	250	45	59.953	3.56
14	-1	3	8	250	45	199.844	5.86
15	-1	3	5	50	45	23.383	4.84
16	-1	3	5	450	45	11.165	5.87
17	-1	3	5	250	40	53.705	2.50
18	-1	3	5	250	50	85.405	2.78
19	0	3	5	250	45	71.504	3.15
20	0	3	5	250	45	70.417	3.40

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Fig.1 Tool and Workpiece

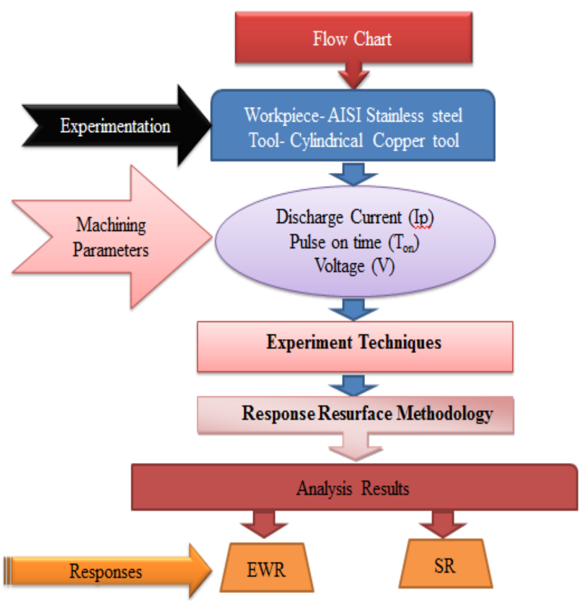

Fig.2 Flow chart of Experiment

4. Analysis and Discussion of EWR

In Fig.3 the main effect plots for EWR (electrode wear ratio). In this EWR increases as the discharge current is (Ip) increases throughout the entire range. In case of pulse on time, the EWR first slightly increases up to 250 µs and then also increasing in a similar fashion till 450 µs [5]. The EWR decrease linearly along with the increase in Voltage within the range but the magnitude of increase is not very large.

The residual plot of EWR is shown in Fig. 4. This layout is necessary to check whether the model meets the expectation of the analysis. The interpretation of the residual plots is as follows:

i. Normal probability plot indicates that the data are distributed normally. It can be seen that the standardized residue lies between -2 and 2.
ii. Versus Fits graph indicate the variance is constant and a nonlinear relationship exists as well as no outliers exist in the data.
iii. Histogram of the data forms a desired skew shape.
iv. Versus order graph shows that there are systematic effects in the data.

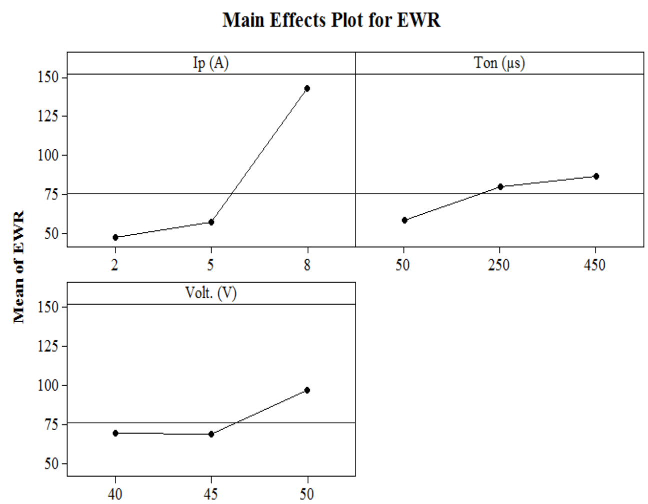

Fig.3 Main effects plots for EWR

Table 3Aanalysis of variance on EWR

Source	DF	Seq SS	Adj MS	F	P
Blocks	2	331.3	56.2	0.16	0.852
Regression	9	41368.3	4596.5	13.40	0.001
Linear	3	26607.1	8869.0	25.85	0.000
Ip (A)	1	22754.5	22754.5	66.31	0.000
Ton (µs)	1	1980.1	1980.1	5.77	0.043
Volt. (V)	1	1872.6	1872.6	5.46	0.048
Square	3	14068.8	4689.6	13.67	0.002
Ip (A)*Ip (A)	1	7557.3	11329.1	33.02	0.000
Ton (µs)*Ton (µs)	1	6454.1	6096.6	17.77	0.003
Volt. (V)*Volt. (V)	1	57.4	57.4	0.17	0.693
Interaction	3	692.4	230.8	0.67	0.593
Ip (A)*Ton (µs)	1	6.7	6.7	0.02	0.892
Ip (A)*Volt. (V)	1	44.6	44.6	0.13	0.728
Ton (µs)*Volt. (V)	1	641.0	641.0	1.87	0.209

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Residual Error	8	2745.0	343.1		
Lack-of-Fit	5	2399.0	479.8	4.16	0.135
Pure Error	3	346.0	115.3		
Total	19	44444.6			

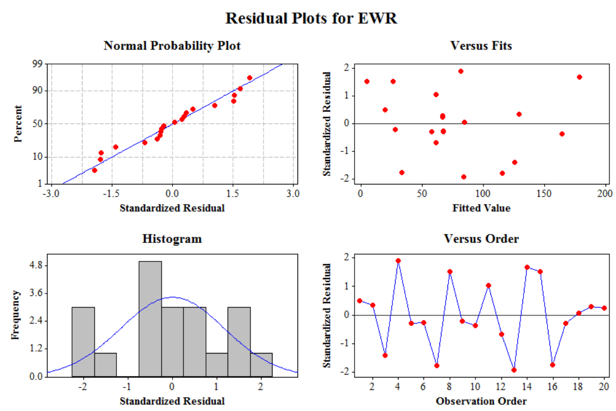

Fig.4 Residual plot for EWR

5. Analysis and Discussion of SR

The various machining parameter has given the significant effect on the SR, graphical representation of SR as shown in Fig. 5. This figure indicate that pulse current (Ip) is most effected as compare to pulse duration and other factor, because a higher pulse current may cause more frequently creaking of dielectric fluid, there is more frequent melt expansion resulting is a poor surface finish Guu et al. (2003) [6-8].

The residual plot of SR is shown in Fig. 6. This layout is necessary to check whether the model meets the expectation of the analysis. The interpretation of the residual plots is shown in Fig 5. And ANOVA table is shown in Table 4.

Table 4 Analysis of variances on SR

Source	DF	Seq SS	Adj MS	F	P
Blocks	2	3.4857	0.7511	2.48	0.145
Regression	9	39.2670	4.3630	14.40	0.000
Linear	3	29.3948	9.7983	32.34	0.000
Ip (A)	1	23.7468	23.7468	78.38	0.000
Ton (µs)	1	5.5652	5.5652	18.37	0.003
Volt. (V)	1	0.0828	0.0828	0.27	0.615
Square	3	8.9630	2.9877	9.86	0.005
Ip (A)*Ip (A)	1	1.5729	1.1849	3.91	0.083
Ton (µs)*Ton (µs)	1	2.0870	4.6022	15.19	0.005
Volt. (V)*Volt. (V)	1	5.3031	5.3031	17.50	0.003
Interaction	3	0.9092	0.3031	1.00	0.441
Ip (A)*Ton (µs)	1	0.8001	0.8001	2.64	0.143
Ip (A)*Volt. (V)	1	0.0595	0.0595	0.20	0.669
Ton (µs)*Volt. (V)	1	0.0496	0.0496	0.16	0.696
Residual Error	8	2.4237	0.3030		
Lack-of-Fit	5	1.6152	0.3230	1.20	0.470
Pure Error	3	0.8085	0.2695		
Total	19	45.1764			

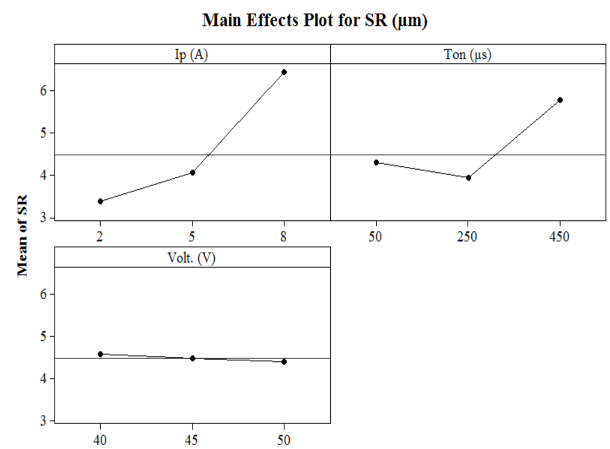

Fig.5 Main effect plots for SR

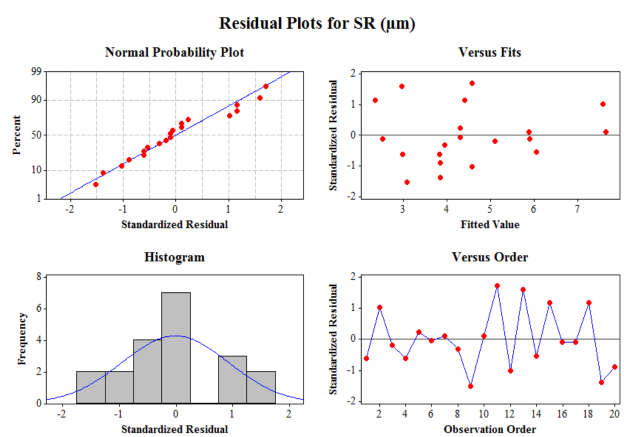

Fig.6 Residual plot for SR

6. Conclusions

In this study the experiment was conducted by considering three variable parameters namely current, pulse on time and voltage. The objective was to find theelectrode wear rate, Surface Roughness and to study the effects of the variable parameters on these characteristics. The tool material was taken as copper and the workpiece was chosen as AISI 303 stainless steel. Using the response surface methodology was created and the experiments were performed accordingly. The following conclusions were drawn:

1. For EWR the most significant factor was found to be peak current followed by pulse on time and the least significant was Voltage. The EWR increased nonlinearly with the increase in current.
2. For SR the most significant factor was again current followed by pulse on time and lastly the voltage. SR increased significantly with the increase in current in a nonlinear fashion. For increase in pulse on time SR increased up to 250 µs and then there was no significant increase.

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