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The Effect of Electric Spark Cutting Markers on Surface Roughness Using the Full Factorial Response

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ABSTRACT

Electric Discharge Machining (EDM) is a nontraditional manufacturing process that uses electric spark discharges to machine electrically conducting materials. Surface roughness (Ra) is considered one of the most important factors in EDM process. When it increases, it affects negatively the performance of the EDM process and the tolerance of resultant part. The aim of this research is to optimize the surface roughness using different current, pulse on time and pulse off time factors, then compare it with the predicted results using full factorial response. AISI M2 steel is frequently machined using EDM due to its high hardness and therefore it was used as a workpiece using copper as an electrode material. Different experimental parameters, which affect surface roughness, were used in EDM process. The full factorial response, adopting a face-centered central composite design (FCCD), was performed experimental layout design and analysis. The experimental results showed that surface roughness changed significantly under specific settings. Maximum surface roughness (Ra) was (9.01µm) got when current of (42 A), pulse on (200 µs) and pulse off (4 µs) parameters were used, while a minimum surface roughness (Ra) of (2.31 µm) could be got when current of (10 A), pulse on (100 µs) and pulse off (12 µs) parameters were used. The best-predicted value for using full factorial response was 98.25%.

KEYWORDS

EDM, Surface roughness, Full factorial response.

INTRODUCTION

Electrical discharge machining (EDM) is o anon-conventional material removal process which is widely used in industry [1]. The spark is started between a positive workpiece and a negative electrode, which are separated with a conductive liquid solution, by applying an electric current between them. The electric sparks remove the material from the workpiece. [2]. The cost associated with EDM process can be reduced and optimized through optimizing the operating parameters and reduce waste material [3]. EDM process mostly used to produce dies in automotive, energy , and aerospace industries, in addition, for high precision machining of parts. Hard materials, which are very difficult to machine and cut by conventional machining processes, can be easily machined by EDM process [4]. Surface roughness of the parts machined by EDM directly depends on the discharge current and pulse duration parameters [5]. Different models have been developed to predict material removal rate and surface roughness in EDM process using response surface technology and other parameters such as peak current, pulse-on time, and gap voltage. [6].

Attain the maximum value of MRR and minimum value of surface roughness during the production of a fine pitch spur gear made of copper by using a suitable optimize the process parameters like (pulse on time (T_{ON}), pulse off time (T_{OFF}), wire feed rate (WF), wire tension (WT), and servo voltage (SV)) with Taguchi's orthogonal array concept with five factors and two levels [7]. Three parameters with three sets of experiments; current (I) , pulse on time (Ton) and gap voltage (Vg) were adopted to find tool wear rate. Results showed that the third set gave the maximum tool wear rate when using copper as tool material [8]. By analysis of variance (ANOVA) and four process parameters (i.e. Pulse off time, pulse on time, gap voltage and discharge current), and using copper as an electrode material in die sinking EDM of EN19 material. The results showed that the the discharge current Heart rate off time, gap voltage and connection conditions have significant effects, whereas the pulse on time has a almost negligible effect on MRR. Also, a 1.45% error between the expected and the innovative MRR value was found to be very accurate [9]. The purpose of this study is to investigate the effect of the I, Ton, and Toff process parameters on the surface finish (Ra) and performance of EDM machining of AISI M2 HSS material using copper as an electrode material.

EXPERIMENTAL WORK

In the current work three different experimental parameters were considered, which are I, Ton, and Toff. All these parameters are investigated with respect to their effect on EDM process. Oil was used as a dielectric fluid. The work setup is presented in Fig. 1. AISI M2 high speed steel was used as workpiece material. A block of M2 steel was cut into 27 specimens, the sample size was 60 mm, 45 mm, and 3 mm in W, L, and H. The chemical composition and the mechanical properties of the steel material are shown in Table 1 and 2, respectively.

Figure 1. EDM CNC Machine type (CM323C).

Table 1. Chemical composition for AISI M2 material works.

Element	Weight (%)	Material Weight (%)	
P	0.001	V	1.88
Mn	0.28	Cu	0.175
Si	0.305	Ni	0.14
Cr	4.71	Co	0.045
S	0.001	W	5.73
C	0.855	Mo	5.83
Sn	0.001	Fe	Balance

Table 2. Characteristics of high speed steel - Physical and Mechanical.

Properties	AISI M2 (%)
Thermal conductivity (W/m-K)	19
Hardness (HRC)	65
Modulus of Elasticity (GPa)	207
Density (g/cm3)	8.14
Poisson's ratio	0.30
Electrical Resistivity (ohm-cm)	$54x10^{-6}$
Chirpy Impact (J)	31.2-38
Specific Heat Capacity (J/g-°C)	0.46

Negative polarity is used with tool electrodes materials in the experimental work with copper electrode (ϕ4×100 mm). Table 3 Illustrates design and levels constraints of the education tests, which factors are selected based on our available EDM CM323C CNC machine.

Table 3. The design of experiments.

Factors of code consideration	**Grade**		
	1	**2**	**3**
Pulse on time (µs) Ton	100	150	200
Pulse off time (µs) Toff	4	12	25
Current (A) I	10	24	42

This work study the optimization of EDM method limits on machining per for using copper as an electrode with high-speed steel AISI M2 as a workpiece. By the RSM method generated Face-centered central composite design (FCCD) matrices which used in the direction of action of studies. Table 4 give the response result and experimental layout.

RESULTS AND DISCUSSION

Established on the experimental results accomplished from table 4 of 27 samples, the effect of the process bounds pulse off, pulse on and current on the surface roughness (Ra) by used copper electrode, with the help of MINITAB 17 software and by analyses of variance from full factorial approach was analyzed.

Table 4. Response result and Experimental layout.

Run-Order	**Current (A)**	**Pulse ON (µs)**	**Pulse OFF (µs)**	**Ra (µm)**	**Blocks**	**Pt-Type**	**RESIDUAL**	**FITTES**
1	10	100	4	2.73	1	1	0.223333	2.50667
2	10	100	12	2.31	1	1	-0.196667	2.50667
3	10	100	25	2.48	1	1	-0.026667	2.50667
4	10	150	4	5.64	1	1	0.526667	5.11333
5	10	150	12	4.92	1	1	-0.193333	5.11333
6	10	150	25	4.78	1	1	-0.333333	5.11333
7	10	200	4	5.77	1	1	0.166667	5.60333
8	10	200	12	5.70	1	1	0.096667	5.60333
9	10	200	25	5.34	1	1	-0.263333	5.60333
10	24	100	4	4.73	1	1	-0.570000	5.30000
11	24	100	12	5.45	1	1	0.150000	5.30000
12	24	100	25	5.72	1	1	0.420000	5.30000
13	24	150	4	5.61	1	1	0.013333	5.59667
14	24	150	12	5.66	1	1	0.063333	5.59667
15	24	150	25	5.52	1	1	-0.076667	5.59667
16	24	200	4	5.33	1	1	0.206667	5.12333
17	24	200	12	5.19	1	1	0.066667	5.12333
18	24	200	25	4.85	1	1	-0.273333	5.12333
19	42	100	4	7.63	1	1	0.160000	7.47000
20	42	100	12	7.46	1	1	-0.010000	7.47000
21	42	100	25	7.32	1	1	-0.150000	7.47000
22	42	150	4	7.87	1	1	0.063333	7.80667
23	42	150	12	7.84	1	1	0.033333	7.80667
24	42	150	25	7.71	1	1	-0.096667	7.80667
25	42	200	4	9.01	1	1	0.273333	8.73667
26	42	200	12	8.67	1	1	-0.066667	8.73667
27	42	200	25	8.53	1	1	-0.206667	8.73667

In order to verify the determined dominant conditions and the efficacy of the second order model for the machining process reaction the variance analysis (ANOVA) was utilized. To validate the null speculation of the predicted data ANOVA was used at a point of 95% confidence. Also, to verify the function accuracy Fishers statistical test (F-test) was used. A p-value ≤ 0.05 is considered to have a statistically significant impact. Table 5 lists the ANOVA variance analysis with each factor which are Ra, P-value, Mean Square (MS), F-test, Level of Liberty (DF), and the number of squares (SS). The determination coefficient (R-sq) is used to evaluate the developed convergent validity for a second-order multivariate regression. The (R-sq), (R-sq (adj)) and (R-sq(pred)) for all established mathematical models are listed in Table 6.

The coded coefficients of pulse off, pulse on and current are listed in Table 7.

Table 5. Results of Response Surface Regression: ANOVA for Ra.

Source	DF	Adj SS	AdjMS	F-Value	P-Value
Model	8	82.263	10.2829	126.61	0.000
Linear	4	72.354	18.0884	222.72	0.000
Current	2	62.713	31.3565	386.09	0.000
Ton	2	9.641	4.8203	59.35	0.000
2-Way Interactions	4	9.909	2.4774	30.50	0.000
Current*Ton	4	9.909	2.4774	30.50	0.000
Error	18	1.462	0.0812		
Total	26	83.725			

Table 6. Model Summary (Coefficient Value).

S	R-sq	R-sq(adj)	R-sq(pred)
0.284982	98.25%	97.48%	96.07%

Table 7. Coded Coefficients.

Source	DF	Adj SS	AdjMS	F-Value	P-Value
Constant	5.9174	0.0548	107.89	0.000	
Current					
10	-1.5096	0.0776	-19.46	0.000	1.33
24	-0.5774	0.0776	-7.44	0.000	1.33
Ton					
100	-0.8252	0.0776	-10.64	0.000	1.33
150	0.2548	0.0776	3.29	0.004	1.33
Current*Ton					
10 100	-1.076	0.110	-9.81	0.000	1.78
10 150	0.451	0.110	4.11	0.001	1.78
24 100	0.785	0.110	7.16	0.000	1.78
24 150	0.002	0.110	0.02	0.987	1.78
Error					
Total					

Ra = 5.9174 - 1.5096 Current_10 - 0.5774 Current_24 + 2.0870 Current_42 - 0.8252 Ton_100
+ 0.2548 Ton_150 + 0.5704 Ton_200 - 1.076 Current*Ton_10 100 + 0.451 Current*Ton_10 150
+ 0.625 Current*Ton_10 200 + 0.785 Current*Ton_24 100 + 0.002 Current*Ton_24 150
- 0.787 Current*Ton_24 200 + 0.291 Current*Ton_42 100 - 0.453 Current*Ton_42 150
+ 0.162 Current*Ton_42 200….(1)

Tables (8-9) shows the fits, residuals and means of current and pulse on time on the responses Ra respectively.

Table 8. Fits and Diagnostics for Unusual Observations.

Obs	Ra	Fit	Resid	Std	Resid
4	5.640	5.113	0.527	2.26	R

10	4.730	5.300	-0.570	-2.45	R

Table 9. Means Fitted.

Terms	Mean	SE Mean
Current		
10	4.4078	0.0950
24	5.3400	0.0950
42	8.0044	0.0950
Ton		
100	5.0922	0.0950
150	6.1722	0.0950
200	6.4878	0.0950

The Figure 2 presents the normal probability of residuals for Ra. The 27 samples cut with EDM appears as a percent at axis line.

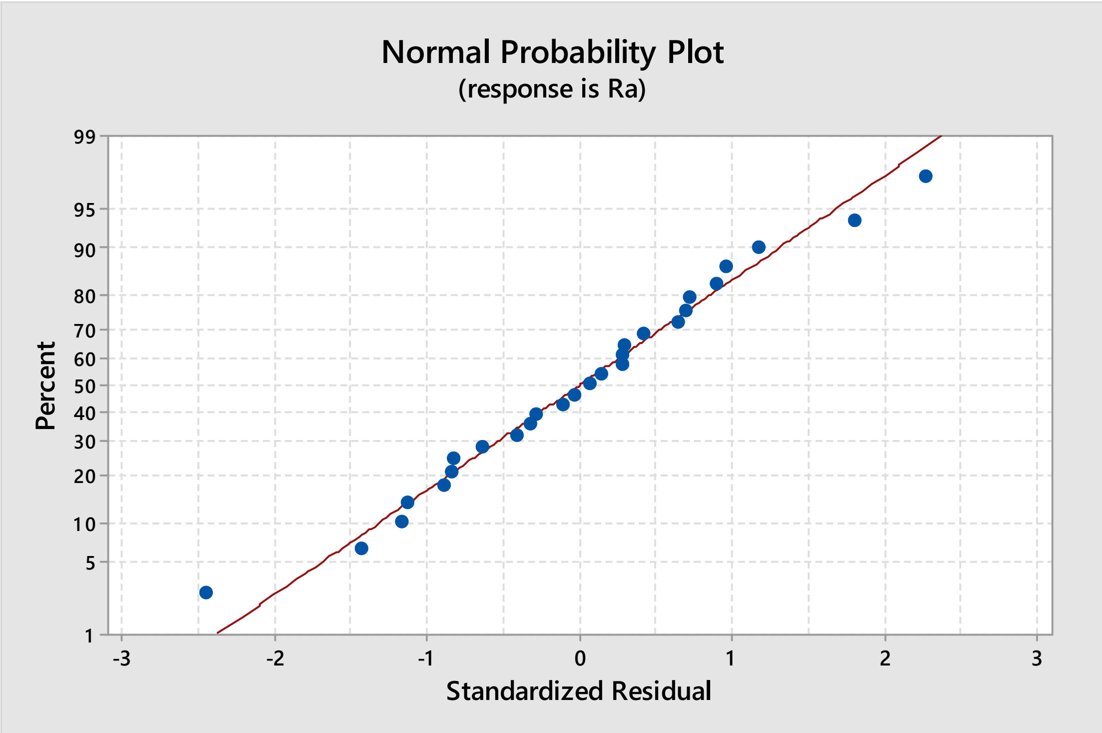

Figure 2. Effect Ra of number samples.

The surface plots, shown in Fig. (3), for Ra observing that when the copper electrode increased that help bridging this difference between the current, therefore the Ra incline to improve. When cutting the workpiece, its thickness does not change, and a 4 mm diameter hole is made in the center of the workpiece, where we notice an increase in the rate of the removed material. Upon the increase of pulse on time the Ra value increases. This change becomes more perceptible as the current value increases. This is due to the development of higher temperature during spark creation which results in the melting and evaporation of the workpiece material and development of craters on its surface, which eventually results to higher Ra value [10]. Likewise, with the rise of current, Ra increase dramatically. This shows that a high spark was generated because of higher current that removes electrode [11]. From the results obtained, it have been would like to show through the numbered table (6) that the coefficient of the response values was for Ra of copper electrode, as follows 98.25% of R-sq , 97.48% of R-sq(adjacent), and 96.07% of R-sq(predicted) respectively by use the full factorial response.

CONCLUSION

In this study experiments by EDM on high-speed steel AISI M2 workpiece and by using copper electrode tool with full factorial response design method to optimized the surface roughness. The parameters current, pulse on, and pulse off selected to make the experiment. The major conclusions of this work as follow:

1- Ra is affected more by current, less affected by pulse on and the least influence by pulse off for electrode copper.

2- The best Ra parameters are current 10 A, Ton 100 µs, and Toff 12 µs for copper electrode as appeared in table (3).

3- Copper electrode is the best Ra by the value (2.31µm) with current 10A and the highest Ra by the value (9.01µm) with current 42A.

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