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Regression and Statistical Analysis of Metal Removal Rate in EDM of Tool Steel

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Abstract:

The present work is aimed to find out the mathematical models which describe the relationships between independent and dependent parameters, also to estimate the impact of independent parameters on the Metal Removal Rate (MRR). Concerning the process of electrical discharge machining (EDM). In this study, the used workpiece material is the A2-Tool Steel material, while the electrode material is copper. The influence of independent parameters could be identified via Response surface methodology (RSM), these independent parameters include: pulse current, pulse on time, and pulse off time. It has been noticed that model adequacy is acceptable because of the coefficient of determination $(\mathbf{R}^2)$ *is (97.37%) for MRR, whereas the highest percentage of error between experimental and predicted data is (10.375%).*

Keywords

Electrical Discharge Machining (EDM), Metal Removal Rate and Response Surface Methodology.

1. Introduction

Concerning the process of EDM which is an abbreviation for electrical discharge machining, the electrically conductive materials have been machined via accurately sparks at high pressure and temperature between an electrode and a workpiece in the existence of a dielectric medium. The electrode may be considered the cutting tool [1]. The material will be removed via the vaporization and melting throughout all electric discharges. Thus, a machined surface composed of thermally damaged layers which involve heat affected zone and recast layer. In these distinctive layers, the residual stresses and micro cracks will be observed [2].

Chinmayee Kar et al. [5] investigated the influence of different EDM parameters such as (peak current, gap voltage, and pulse-on-time), on the MRR. The experiments are conducted based on the concept of central composite design to find out most influencing factors in the EDM process. The authors reveal that the peak current is found to have a significant influence on the responses when compared with the other inputs. D. Mishra et al**.** [6] an attempt has been made to carry out the optimization of parameters and performance characteristics based on the Taguchi method. The pulse current, pulse duration, and gap voltage are considered as input process variable to study the EDM machined surface. The results show that cracks are observed on the machined surface due to internal stresses caused by heating and sudden cooling of a surface.

K. Morankar and R. Shelke [7], Introduced a model through utilizing RSM, which is an abbreviation for Response Surface Methodology, with regard to gap voltage, pulse on time and peak current for evaluating the metal removal rate. The results show that the pulse on time and the peak current have considerable effects on (MRR) values. V. Babu et al. [8], study the impact of different EDM variables such as (discharge current,pulse-on time, and gap voltage), on the following responses(SR, MRR, and HAZ). The experiments were carried out on EN-31 die steel material, whereas copper and brass were used as electrodes material. The obtained outcomes of experiments indicate that the s (HAZ) determined by the available amount of heat, its conduction and cooling action during the EDM process.

Mohammadreza et al. [9], the experiments have been carried out with different values of the independent parameters such as discharge current and pulse duration in electrical discharge machining (EDM) on the HAZ. The copper was used as the electrode material for machining AISI H13 with a cylindrical shape. The authors believe that the lowest depth of heat affected zone on the surface of EDM machined surface can be obtained at the high pulse current, and low pulse –on time H.R.Choudhary et al [10], investigated the influence of machining parameters on heat affected zone (HAZ) in EDM. Four processes parameters, namely peak current, gap voltage, pulse on time and electrode materials have been considered. It was concluded that in the case of the graphite electrode (HAZ) is much deeper as compared to copper and brass electrode. M. Boujelbene et al [11] performed a series of experiments on the following materials steel 50CrV4 and X200Cr15 and comparison between them, to find out the effect of process parameters (peak current, pulse discharge, and electrode materials) on white layer thickness and microhardness. The authors believe that the depth of HAZ can be minimize at lower pulse duration and discharge current .

From the above literature survey it concluded that the few studies have focused on the mathematical modeling of MRR, as well as little researches have focused on the distilled water as the dielectric medium in (EDM). The Aims of this study is to regression, statistical, and parametric analysis of the influence of process parameters on the MRR.

2.Experimental Procedure

In this study, AISI A2-Tool steel has been utilized as the workpiece. The workpiece's chemical composition is listed in the table (1). The workpiece was made to the square shape with dimension (3.5x38x38) mm, whereas copper was used as the electrode material, it is a cylindrical shaft with (10) mm diameter and (60) mm length. The distilled water has been utilized as the dielectric medium.

Table (1): chemical composition of the A2-Tool Steel.

Element	C	Mn	P	S	Cr	V	Mo	Si	Fe
Weight %	1	0.6	0.03	0.03	5	0.35	1.1	0.3	balance

An Electrical Discharge machine (CHMER EDM) model(CM 323+50N) with servo-control has been used to perform the experiments as illustrated in Figure (1), which is located at the workshop and training center in the University of technology-Iraq. In order to design experiments, Response surface methodology (RSM) has been utilized, matrices have been developed based on Face-Centered Central Composite Design (FCCCD). The machining parameters as shown in the table (2).

The second-order model is flexible because it can take a variety of functional forms and approximates the response surface locally. Therefore, this model is usually a good estimation of the true response surface.

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Figure (1): EDM machine (CHMER EDM).

Table(2): EDM controlable parametrs.

	Level (1)	**Level (2)**	**Level (3)**
Current (A)	30	36	**42**
Pulse-on Time (µs)	100	150	**200**
Pulse-off Time (µs)	50	75	**100**

3.Results and Discussion

A number of trials have been made to examine the effects of input variable parameters on the process's response to determine the metal remova of Electrical Discharge Machining (EDM), these trails were carried out at depth of cut equal to (1) mm. The machining characteristics value for MRR and made the comparison between observed and predicted data are tabulated in the table (3).

The regression analysis has been performed to determine the relationship between input variable parameters and the response of the machining process. The mathematical model was developed based on the experimental data, the general second-order model has been utilized in this study were developed by RSM. The mathematical model for required performance measures was developed as illustrated in the equation (3), In order to evaluate the accuracy of this equation percentage of error has been measured. The percentage of error represents the difference between predicted and observed value divided by the observed value for all responses. As a result, the prediction accuracy of the developed model has appeared acceptable as illustrated in Table (3) .

When there is a curvature in the response surface the first-order model is insufficient. A second-order model is useful in approximating a portion of the true response surface with the parabolic curvature. The second-order model includes all the terms in the first-order model, plus all quadratic terms all cross- products terms. It is usually expressed as:-

$$Y= \beta_\circ + \sum_{j=1}^{q} \beta_j x_j + \sum_{i=1}^{q} \beta_{jj} x_j^2 + \sum\sum \beta_{ij} x_i x_j + \varepsilon \ldots\ldots\ldots(1)$$

$$= \beta_\circ + x_i^{'} \beta + x_i^{'} \beta x_i + \varepsilon_{ij} \ldots\ldots\ldots(2)$$

Where $x_i = (x_{1i} , x_{2i} ,\ldots.., x_{iq})$, $\beta = (\beta_1, \beta_2, \ldots\ldots.., \beta_q)$

MRR = -24.6+ 1.668 Current- 0.2371 Pulse-On+ 0.572 Pulse-Off- 0.0087$current^2$ + 0.000677$pulse\ on^2$ - 0.003423$pulse\ off^2$ - 0.000812 Current x Pulse-On - 0.00628 Current x Pulse-Off + 0.000436 Pulse-On x Pulse-Off………(3).

The goodness of fit for a second-order regression model was developed can be examined by a coefficient of determination(R^2). Table (4) present the value of (R^2), and (R^2_{adj}) for mathematical model that has been developed.

Table (3) EDM Machining Characteristics Value.

Run Order	I_p	T_{on} (μs)	T_{off} (μs)	MRR Exp.	MRR Pred.	MRR Error %
1	30	150	75	7.456	8.068	-8.208
2	36	200	75	10.23	11.26	-10.068
3	42	150	75	14.263	13.487	5.440
4	36	150	75	11.456	11.089	3.203
5	36	150	100	6.345	6.402	-0.898
6	36	100	75	15.5	14.306	7.703
7	36	150	50	11.719	11.497	1.894
8	36	150	75	10.987	11.089	-0.928
9	42	200	50	13.761	14.219	-3.328
10	36	150	75	11.052	11.089	-0.334
11	42	100	100	9.83	10.774	-9.603
12	30	100	50	10.385	11.052	-6.422
13	36	150	75	11.052	11.089	-0.334
14	30	200	100	5.241	5.282	-0.782
15	42	200	100	8.909	8.329	6.510
16	42	100	50	18.796	18.842	-0.244
17	36	150	75	10.989	11.089	-0.910
18	30	200	50	8.26	7.403	10.375
19	36	150	75	11.052	11.089	-0.334
20	30	100	100	7.122	6.751	5.209

Analysis of variance (ANOVA) technique has been utilized for the determined dominating parameters and to checking the effectiveness of the second-order model for the response of the machining process. ANOVA was used for testing the null hypothesis of the observed values at a confidence level of (95) %. The significance of the parameter has been tested by Fisher's statistical test (F-test), the higher value of the (F-test) presents the more significant factor. If p-value ≤ 0.05, it is concluded that the factor has a statistically significant effect. Table (6) presents the analysis of variance ANOVA for MRR.

As illustrated in Figure (2) the main effects of controllable input parameters on MRR, the I_p,T_{on} and T_{off} have the significant influence on MRR, the pulse current is the most significant factor between all the process variables parameters as shown in Figure (3).

From the Figure (2), can be noted that the MRR directly proportional to the current, The I_p is the most influencing factor and exhibits the sharp increase of (3.345) mm^3/min and (2.072) mm^3/min in the mean of MRR when the I_p rises from (30 Amp to 36 Amp) and (36 Amp to 42 Amp), respectively. A possible explanation for this might be that the increase in working current at constant T_{on} and T_{off}. The spark energy is increased and this will lead to a stronger spark with a high thermal energy produced, the thermal energy transferred to the workpiece and electrode tool, and introducing the high impact force in spark gap causes more molten material, thereby increased the amount of MRR.

As demonstrated in Fig. (2), the MRR decreased by (1.689) mm^3/min,when the T_{on} is increased from 100 μs to 150 μs,whereas it decreased by (1.357) mm^3/min, when the T_{on} is increased from 150 μs to 200 μs. It seems possible that these results are due to that although the spark energy increased with increased T_{on}, the MRR decreased because of the plasma channel expanded at higher values of T_{on}, the expanded plasma channel produced lower energy density.This occurrence leads to a formation of a smaller molten material which results in a lower MRR.

The combined effects of (current, pulse current and pulse-off time) on HAZ as shown in Figure (4).

Table (4): Coefficient Value

	R^2	R^2_{adj}
MRR	97.37 %	93.76 %

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Table (5) ANOVA For MRR.

Source	DF	SS	MS	F-Value	P-Value
Model	11	189.995	17.2723	26.97	0.000
I_p	1	73.414	73.4139	114.61	0.000
T_{on}	1	23.201	23.2014	36.22	0.000
T_{off}	1	64.892	64.8925	101.31	0.000
$I_p * I_p$	1	0.261	0.2611	0.41	0.541
$T_{on} * T_{on}$	1	7.699	7.6992	12.02	0.008
$T_{off} * T_{off}$	1	12.286	12.2855	19.18	0.002
$I_p * T_{on}$	1	0.475	0.4753	0.74	0.414
$I_p * T_{off}$	1	7.099	7.0989	11.08	0.010
$T_{on} * T_{off}$	1	2.374	2.3740	3.71	0.090
Residual Error	8	5.124	0.6405		
Total	19	195.120			

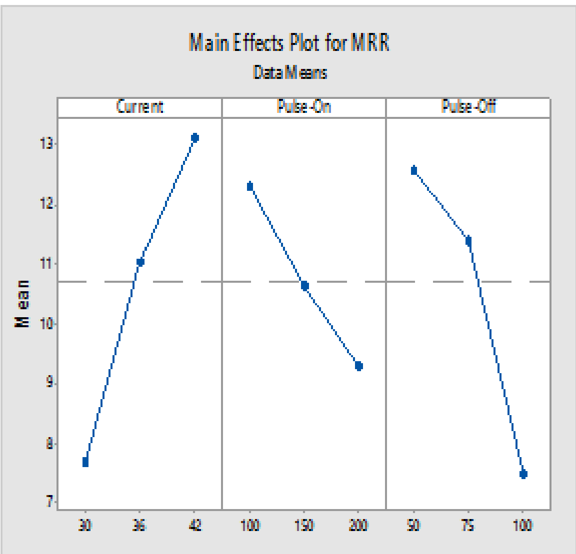

Figure (2): Main effects plot for MRR.

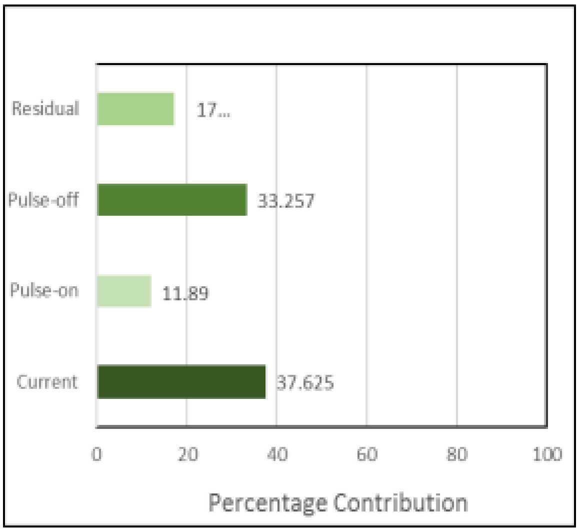

Figure (3): The Percentage Contribution of parameters to MRR.

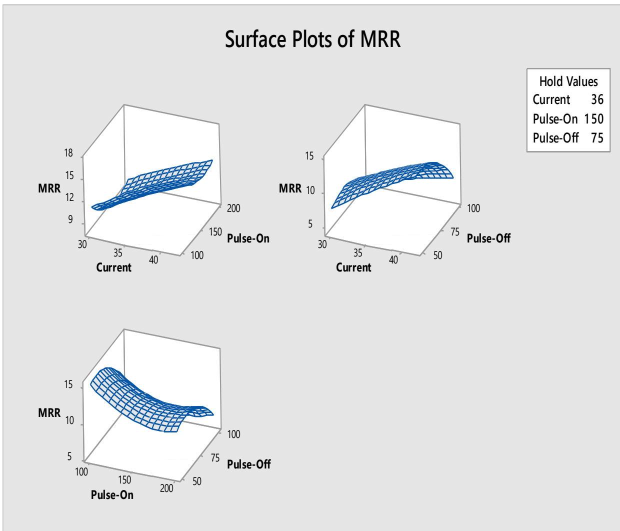

Figure (4): Combination effects of (current, pulse current and pulse-off time) on HAZ.

4.Conclusions

Based on the experimental results, the following conclusions are drawn:

- The developed model shows high accuracy of prediction model within the experimental data with (10.375 %) the highest percentage of error.
- The input parameters have significantly influenced the response of the process.
- From statistical analysis, it can be concluded that the I_p are the most dominating factors affecting MRR by percentage contribution (37.625%) followed by T_{off} with (33.257%), and T_{on} with (11.89%).

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