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ANALYSIS OF ELECTRODE WEAR RATE ON EDM OF O1 TOOL STEEL USING ELECTROLYTIC COPPER ELECTRODES

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Abstract

EDM is efficiently employed to manufacture complex and delicate shapes, machining of hard materials, machining deep holes while maintaining close tolerances. However, inappropriate machining parameter selection results in slow rate of MRR (material removal rate), excessive electrode wear and poor surface finish. This paper aims to generate a mathematical model for analysing the effects of current, pulse-on time and pulse-off time on electrode wear rate.The study was carried out on Electronica-S50 CNC machine using Taguchi's experimental configuration. Regression models for non-linear environment were generated to determine the impact of machining variables on the EWR of copper while machining O1 Tool Steel material. The application of ANOVA on the formulated regression models revealed critical information about levels of variability and forms the basis of tests of significance.

Keywords: Electrode wear rate(EWR), Pulse-on rate(Ton), Pulse-off rate(Toff), current (I), Taguchi, ANOVA

1 Introduction

EDM is an electro-thermal process in which the machining is done by the use of controlled electric sparks effectuated between electrically conductive work piece and electrode in a dielectric environment. EDM is an apt process for making prototypes and parts for the aerospace, automobile and electronic industry.As compared to traditional machining process, EDM usually take shorter time to produce piece of desired shape and closer dimensional tolerances. Since, no physical contact takes place between the electrode and work piece, the process is well-suited for making precision dies and moulds.

1.1 Literature review

J. Marafona et.al.(2007) proposed a new method in die-sinking electrical discharge machining for reducing electrode wear. While machining D2 tool steel, a black layer was produced on the tool (copper electrode). The black color on tool was due to the migrated carbon from the dielectric during the electrical discharge. The research highlighted that black layer attached to the tool was due to bi-dimensional laminate of carbon crystals. Upon further investigation it was found that black layer was not only due to the presence of carbon but influence of other elements such as iron, chromium, vanadium and molybdenum had a considerable effect in forming black layer. The main cause of wear decrease in the tool according to the set of EDM input parameters was mostly of these elements forms the equivalent carbon.

Masanori Kunieda et.al. (2004)analyzed the mechanism of determining tool electrode wear ratio in electrical discharge machining (EDM) by spectroscopic measurement of the vapor density of the tool electrode material. The relative density of copper vapor in EDM arc plasma was measured. Increase in pulse duration result in lower tool electrode wear ratio. The deposition of a thicker carbon layer on the tool electrode surface also increase with higher pulse duration. The thicker carbon layer prevents copper vapor evaporation from the tool electrode, indicating that tool electrode wear is prevented by the protective effects of the carbon layer.

Y.S. Wong et.al (1995)reported the influence of flushing on the efficiency and stability of machining conditions in EDM. The research also included the effects of the flushing configuration on the wear of the tool and the profile of the work piece. The research highlights the effects of flushing rates on the types and distribution of recast layers in commercially pure iron, 0.5% C steel and AISI 01 tool steel after EDM. The cracks and average thickness of the recast layer are at a minimum for all three materials at optimal dielectric flushing rate. The crack density and recast thickness trends are similar, being higher at flushing rates below and above a basically similar optimum rate. The paper presents distributions of the crack density at the sides, bottoms and corners of the machined cavities under different flushing conditions. The effects of the quenching property and debris removal ability of the dielectric flow conditions on the recast layers of the three types of EDM specimens are discussed based on the observation.

Review of literature, interactions with professional and academia, highlighted the need to study the effect of **crucial parameters such as** current, pulse-on, and pulse-off on EWR in EDM ofO1 Tool steel using copper electrode

The experiments have been undertaken with O1 OHNS steel utilizing the electrolytic copper electrode to generate the experimental data. The data so obtained has been use to predict the model of in EDM process. Parametric investigation, after due validation has been further carried out to understand the behavior of these process parameters on the EWR in EDM process.

2 Experimental Set Up

The experiments for the study have been conducted on Spark erosion machine (Electronica S50 CNC). Figure.1 represents the same.EWRis expressed in percentage. The chemical composition of the work-piece is C: 0.95%, Mn: 1.15%, Cr: 0.50%, V: 0.20%,rest Fe. Electrolytic Copper was used asElectrode material.

Figure1: *Electronic EDM (S50 CNC)*

2.1 Experimental design and conditions

Taguchi design method has been applied for designing the experimental procedure using five level design matrix. A three factorand five level setup was chosen with a total of twenty-five experiments were conducted and hence the OA L25 waschosen.

The experiments were carried at room temperature. All the experiments were performed with EDM oilas a dielectric. The levels of independent variables and coding identifications are presented in Table 1.

Table 1*: The levels of independent variables and coding identifications*

Level	**1**	**2**	**3**	**4**	**5**
Factors	↓				
A. Current (amp)	1	1.5	2	3	6
B. Pulse on time	5	10	20	50	100
C. Pulse off time	16	20	20	20	26

2.2 Experimental conditions and results

Table 2 *:shows the experimental conditions together with the measured %EWR values.*

	Taguchi Array L25(5^3) Factors: 3 Numbers of Experiments = 25			Parameters			
Experiment No.	Factor A	Factor B	Factor C	T on	Toff	Current I	%EWR
1	1	1	1	5	16	1	8.5
2	1	2	2	10	16	1	4.6
3	1	3	3	20	16	1	2.2
4	1	4	4	50	16	1	1.5
5	1	5	5	100	16	1	0.5
6	2	1	2	5	20	1.5	8.8
	2	2	3	10	20	1.5	3.9
8	2	3	4	20	20	1.5	1.2
9	2	4	5	50	20	1.5	0.8
10	2	5	1	100	20	1.5	0.2
11	3	1	3	5	20	2	11.2
12	3	2	4	10	20	2	3.3
13	3	3	5	20	20	2	1.4
14	3	4	1	50	20	2	0.9
15	3	5	2	100	20	2	0.2
16	4	1	4	5	20	3	5
17	4	2	5	10	20	3	3
18	4	3	1	20	20	3	1.3
19	4	4	2	50	20	3	1
20	4	5	3	100	20	3	0.1
21	5	1	5	5	26	6	7
22	5	2	1	10	26	6	6
23	5	3	2	20	26	6	2.2
24	5	4	3	50	26	6	2.2
25	5	5	4	100	26	6	0.2

3 Results and Discussion

This analysis of the observed data has been carried out to develop parametric equations using regressionanalysis. The mathematical modelused in this process is represented by:

$$Y = \emptyset(I, Ton, Toff) \quad (1)$$

In non- linear form, equation 1 becomes

$$Y = CI^{n1} Ton^{n2} Toff^{n3} \quad (2)$$

Where Y is the machining response,

φ is the response function,

and I, Ton,Toffare machining variables.

Where C is Machining Constant

Mathematical model for %EWR

The model for %EWR is formulated as:

$$\%EWR = CI^{n1} Ton^{n2} Toff^{n3} \quad (3)$$

By applying logarithms to the equation 3

$$\log \%EWR = \log C + n1 \log I + n2 \log Ton + n3\ LogToff \quad (4)$$

First order multivariate response model for %EWR

The rate of electrode wear is affected by Ton, Toff and current. The first order model for tool wear is shown in the Table 3.

***Table 3**: Regression analysis for %EWR vs. I,T-on,T-off for 1st Order model*

Predictor	Coeff.	SE Coeff.	T	P
Constant	1.106	2.238	0.49	0.626
Log Ton	-1.10563	0.09558	-11.57	0
Log Toff	0.499	1.825	0.27	0.787
Log I	-0.1604	0.4578	-0.35	0.73

S = 0.223400 R-Sq = 89.4% R-Sq (adj) = 86.5%

The regression equation of Electrode wear is:

Log %EWR = 1.11 - 1.11 Log Ton + 0.50 Log Toff - 0.160 Log I (5)

Analysis of Variance (ANOVA) consists of calculations that provide information about levels of variability within the regression models and form the basis for tests of significance.

The basic regression line concept, Data= Fit+ Residual.

$$\text{Data} = (y_i - \bar{y}) = (\hat{y}_i - \bar{y}) + (y_i - \hat{y}_i) \quad (6)$$

Where $\bar{y}$ = sum of dependent variable

$\hat{y}_i$ = fitted value of i th dependent variable

y_i = observed value of i th dependent variable

Total sum of squares= Regression sum of squares + Residual sum of squares

$$SS_T = SS_R + SS_{Res}$$

$$\sum_{i=0}^{n} (y_i - \bar{y})^2 = \sum_{i=0}^{n} (\hat{y}_i - \bar{y})^2 + \sum_{i=0}^{n} (y_i - \hat{y}_i)^2 \quad (7)$$

Where n = Total number of Experiments

ANOVA calculation is displayed in the Table 4

***Table 4**: Analysis of Variance for %EW using 1st order model*

Source	DF	SS	MS	F	P
Regression	3	6.6846	2.2282	44.65	0
Residual Error	21	1.0481	0.0499		
Total	24	7.7327			
Source	DF	Seq SS			
Log Ton	1	6.6774			
Log Toff	1	0.001			
Log I	1	0.0061			

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Test of statistic

$$F = \frac{MS_R}{MS_{Res}} \quad (8)$$

F= 2.2282/0.0499 = 44.65

Coefficient of determination

$$R^2 = \frac{SS_R}{SS_T} = 1 - \frac{SS_{Res}}{SS_T} \quad (9)$$

R^2= 6.6846/7.7327=0.8644= 86.44%

The F-statistic = 44.65 highlights that there is evidence against the null hypothesis. The p-value for the F-test statistic is 0.000, providing strong evidence against the null hypothesis.

The higher value of R^2 states that the model fits the data Electrode wear rate with the usage of equation (5) has been transformed as

$$\%EW = \frac{0.0453\ XToff^{0.50}}{I^{0.16} XTon^{0.116}} \quad (6)$$

It is also evident from the equation (6) that the Toff is a dominant factor, followed by current and Ton because of the respective values of exponents.

Second-order multivariate response model for electrode wear rate

First-order model was found to be adequate. In order to extend the variables range in obtaining the relationship between the %EWR and the machining independent variables second order models was postulated and validated with the experimental data. The effect of Ton, Toff and current on %EWR for the second order model is listed in the Table 5.

***Table 5**: Regression analysis for %EWR vs. I, Ton, Toff for 2^{nd} Order*

Predictor	Coef	SE Coef	T	P
Constant	99.2	102.6	0.97	0.348
Ton	2.292	4.305	0.53	0.602
Toff	-155.1	159.4	-0.97	0.345
I	1.405	3.52	0.4	0.695
Ton * Ton	-0.3666	0.2307	-1.59	0.132
Toff * Toff	61.23	61.67	0.99	0.336
I* I	-3.361	4.98	-0.67	0.509
Ton * Toff	-1.93	3.479	-0.55	0.587
I * Ton	0.3283	0.8728	0.38	0.712

S = 0.199079 R-Sq = 91.8% R-Sq (adj) = 87.7%

The regression equation is

$$\%EWR = -1.738 - 0.144 * Ton + 0.0015Ton^2 + 2.031Toff - 0.0013Toff^2 - 0.148I - 1.14I^2 - 0.0045Ton * Toff + 0.00849Ton * I + 1.019Toff * I \quad (7)$$

Analysis of Variance for %EWR in 2nd order model is displayed in Table 6

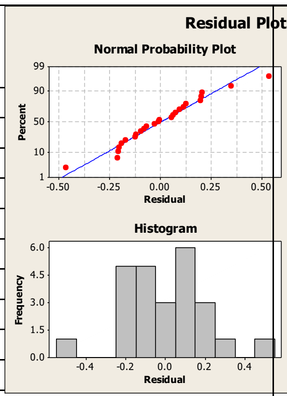
***Table 6**: Analysis of Variance for 2^{nd} order model (%EWR)*

Source	DF	SS	MS	F	P
Regression	8	7.09855	0.88732	22.39	0
Residual	16	0.63412	0.03963		
Total	24	7.73266			

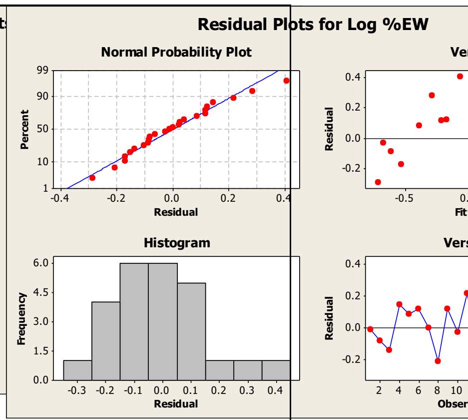
Source	DF	Seq SS
Ton	1	6.67744
Toff	1	0.00104
I	1	0.00613
Ton * Ton	1	0.10011
Toff *Toff	1	0.27779
I* I	1	0.01806
Ton * Toff	1	0.01239
I * Ton	1	0.00561

The analysis of variance as shown in Tables 6 indicates that the ratio of lack of fit to pure error i.e. F-statistics is 22.39, whilst the P-statistics is 0.000.

The analysis through ANOVA indicated that non-linear model presents sufficiently accurate results. The first & the second order models were validated using the experimental data. The square multiple correlations (R^2) of the first and second order models were compared and no significant variation was observed between the two. Figure 2 shows the residual plot of first order and second order models.



Residuals Plots for %EWR for 1^{st} order Models



Residuals Plots for %EWR for 2^{nd} order Models

***Figure 2**: Residual plot of first and second order models*

4 Conclusion

A non-linear regression models for predicting electrode wear rate was developed with respect to three key machining parameters i.e. current, Pulse-on Time, Pulse-off Time.

1. The mathematical models could predict the responses for different predictors' values in case of O1 Tool Steel and copper electrode.
2. Electrode wear rate is inversely proportional to pulse-on time
3. Increase in Pulse-off Time resulted in decrease in electrode wear rate
4. At higher levels of current, wear rate of copper electrode increased and caused some machining problems which further reduced MRR and surface finish. This might be due to sparking produced at high current intensity.
5. Percentage electrode wear rate could be minimizing to 0.1% by selecting proper process parameters.

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