Electrode Wear Rate Prediction Model for EDM Machined Inconel X750 by Response Surface Methodology Using Brass Electrode

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Abstract: ***Electrical discharge machining is basically a non-conventional material removal process which is widely used to produce dies, punches and moulds, finishing parts for aerospace and automotive industry. Inconel X-750, a high strength, age-hardenable, Ni-base super alloy, finds wide range of applications in aerospace engineering on the basis of its excellent high-temperature and cryogenic properties. This paper discusses the development of a mathematical model for electrical discharge machined inconel X750 metal by using response surface methodology. The electrode wear rate (EWR), model is developed in terms of Pulse peak current (Ip),Pulse on time (Ton),Gap voltage (V). The effect of these parameters over electrode wear rate is presented. The contour plots have been generated from the mathematical model. The model generated shows that the electrode wear rate increases with an increase of gapvoltage and dcreases with increase in pulse on time. Electrode wear rate increases when pulse peak current increases.The second order is more accurate based on the variance analysis and the predicted value is closer to the experimental result.***

Key words: Brass electrode, Electrode wear rate, Response Surface methodology, EDM.

1. Introduction

Response surface methodology (RSM) has been used to plan and analyse the experiments. It is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize the response. It is a sequential experimentation strategy for empirical model building and optimization. By conducting experiments and applying regression analysis, a model of the response to some independent input variables can be obtained. Based on the model of the response, a near optimal point can be deduced. RSM is often applied in the characterization and optimization of processes. The objective of using RSM is not only to investigate the response over the entire space, but also to locate the region of interest where the response reaches its optimum or near optimum value. By studying carefully the response surface model, the combination of factors, which gives the best response, can then be established.

2. Response Model

Response surface method is adopted to model the process parameters with the response variables [1]. RSM is the procedure for determining the relationship between various process parameters with various performance criteria and exploring the effect of these process parameters on the desired responses. Response Surface methodology is an assortment of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is biased by several variables and the objective is to optimize this response. It is a sequential experimentation strategy for empirical model building and optimization. A model of the response to some independent input variables can be acquired by carrying out experimentation and applying regression analysis. In RSM, the independent process parameters can be represented in quantitative form as:

$$Y = f(X_1, X_2, X_3, \ldots X_n) \tag{1}$$

Where, Y is the response, f is the response function, and X1, X2, X3, . . .,Xn are independent variables.

On the other hand, the second-order model is normally used when the response function is nonlinear. The experimental values are analyzed and the mathematical model is then developed. The mathematical model based on a second-order polynomial is expressed as

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \sum_{i=1}^{n} \beta_{ii} X_i^2 + \sum_{i,j=1, i\neq j}^{n} \beta_{ij} X_i X_j \tag{2}$$

Where Y is the corresponding response, Xi is the input variables, Xi2 and XiXj are the squares and interaction terms, respectively, of these input variables. βo, βi, βij and βii are the unknown regression coefficients.

3. Experimental Design

To develop the first-order, a design consisting 15 experiments was conducted. Box-Behnken Design is normally used when performing nonsequential experiments. That is, performing the experiment only once. These designs allow efficient estimation of the first and second –order coefficients. Because Box-Behnken Design has fewer design points, they are less expensive to run than central composite designs with the same number of factors. Box-Behnken Design does not have axial points, thus can be sure thatall design points fall within the safe operating [2]. Box-Behnken Design also ensures that all factors are never set at their highest levels simultaneously.Fig. 1 shows the 3 factors Box-Behnken. Preliminary tests were carried out to find the suitable parameters as shown in Table 1.

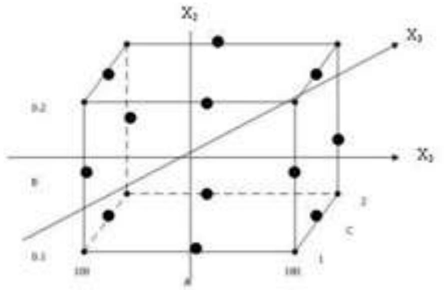

Figure 1: Factors Box-Behnken

4. Experimental Details

The experiments were conducted in a Smart ZNC Electric discharge machine manufactured by Electronica Machine tools of India. In all experiments, kerosene oil was used as dielectric fluid medium. The dielectric side flushing pressure is maintained as 0.6MPa[4]. The work piece top and bottom surfaces were ground to a surface finish using a surface grinding machine before conducting the experiments. The initial weights of the work piece and electrode were weighed using a electronic balance. A special fixture was used to hold the work plate during machining. In EDM, the work piece is connected to positive terminal whereas the electrode connected with negative terminal of the power supply. Every experiment is conducted for the depth of 2 mm. At the end of each experiment run, the tool and work piece were removed from the machine and dried using the compressor air and weighed using electronic balance. The machine time was noted using a digital stop watch. New brass electrode was used in each experiment. Table II shows the details of the parameters and its three level values.

Table 1: Design of Experiments Matrix

Experiment Number	Pulse peak current (Ip) (Amps)	Pulse on time (Ton) (μs)	Gap voltage (Vg) (V)
1	5	100	70
2	7	300	50
3	5	300	60
4	5	500	70
5	7	300	70
6	5	300	60
7	5	500	50
8	7	500	60
9	5	300	60
10	3	500	60
11	3	300	50
12	3	300	70
13	7	100	60
14	3	100	60
15	5	100	50

Table 2: Parameters and its range

Parameters	Level 1	Level 2	Level 3
Pulse peak current (Ip)	3	5	7
Pulse on time (Ton)	100	300	500
Gap voltage (V)	50	60	70

The work piece material is Inconel X750 with following composition:

Components	C	Si	Mn	S	Cr	Ni	Al	Co	Cu	Nb	Ti	Fe
Percentage	0.045	0.23	0.7	0.006	15.28	72	0.58	0.36	0.29	1.03	2.53	6.72

Table IIIandTable IV shows the details of the mechanical and physical properties respectively.

Table 3: Mechanical properties of Inconel X750 alloy [1]

Mechanical Properties	*Metric*
Density	8280 kg/m3
Melting point	1430°C
Co-efficient of expansion	9.0 μm/m.°C (21-93°C)
Modulus of elasticity	213.7GPa

Table 4: Physical properties of Inconel X 750 work piece [1]

Physical Properties	*Metric*
Hardness, Rockwell C	35 HRC
Tensile Strength, Ultimate	1296 MPa
Tensile Strength, Yield	916 MPa
Elongation at Break	22%
Reduction of Area	20%
Compressive Yield Strength	689.47MPa

To develop the relation between various EDM process parameters and electrode wear rate, cylindrical brass electrode of 17mm diameter and 70mm length was used for machining the work sample. Kerosene was selected as a dielectric because of its high flash point, good dielectric strength, transparent characteristics and low viscosity and specific gravity. A new set of the brass tool was applied for each ru. The full sets of run according to the design of experiment were carried out in the state of positive polarity.EDM machined work piece with brass electrodes is shown in Fig. 2.

The material removal rate has been defined as the ratio of the wear weight of work piece to machining time [8], Material removal rate (mg/ min) = wear weight of work piece time of machining

$$MRR(mg/\ min) = \frac{WWBM - WWAM}{T} \quad (3)$$

Where WWBM is weight of work piece before machining, WWAM is weight of work piece after machining and T is the total time during which machining was performed. After completing of each machining process, the work piece was blown by compressed air using air gun to ensure no debris and dielectrics were present. A precise balance was used to measure the weight of the work piece after machining.

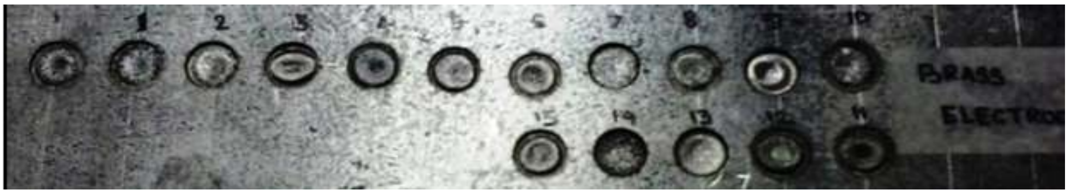

Figure 2: EDM machined work piece with brass electrodes

5. Mathematical Modelling

Response surface methodology is an assortment of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is biased by several variables and the objective is to optimize this response .It is a sequential experimentation strategy for empirical model building and optimization. A model of the response to some independent input variables can be acquired by carrying out experimentation and applying regression analysis. In RSM, the independent process parameters can be represented in quantitative form as:

$$Y = f(X_1, X_2, X_3, \ldots X_n) \pm \varepsilon \quad (4)$$

where, Y is the response, f is the response function, ε is the experimental error, and X_1, X_2, X_3, . . ., $X_n$are independent variables.

On the other hand, the second-order model is normally used when the response function is nonlinear. The experimental values are analysed and the mathematical model is then developed. The mathematical model based on a second-order polynomial is expressed as:

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \sum_{i=1}^{n} \beta_{ii} X_i^2 + \sum_{i,j=1, i \neq j}^{n} \beta_{ij} X_i X_j + \varepsilon \quad (5)$$

where Y is the corresponding response, X_i is the input variables, X_i^2 and X_iX_j are the squares and interaction terms, respectively, of these input variables. β_o, β_i, β_{ij} and $\beta_{ii}$are the unknown regression coefficients.

6. Results and Discussion

The EWR second order model is

$$Y_{EWRmin} = 0.06775 + 0.03276A + 0.00008B + 0.00049C + 0.00107A^2 + 0.0001B^2 - 0.00008C^2 + 0.000012AB + 0.0000206BC - 06BC - 0.00003AC \quad (6)$$

Table V shows the results obtained using ANOVA. The coefficient of determination is the ratio of the sum of squares of the predicted responses (corrected for the mean) to the sum of squares of the observed responses .The value of $R^2$and adjusted R^2 is over 98%. This means that mathematical model provides an excellent explanation of the relationship between the independent variables and the response (EWR). The obtained values of standard deviation and R^2- predicted evidence that the proposed model is adequate to predict the response. The associated p-value for the model is lower than 0.05 (i.e. α = 0.05, or 95% confidence) [5] indicates that the model is considered to be statistically significant.

Table 5: Analysis of Variance for EWR

Source	Degree of freedom	Sum of Square	Adjusted mean square	F-Value	P-Value
Regression	3	0.0365	0.012178	881.08	0.000
Linear	3	0.0365	0.0121	10.53	0.00
Residual Error	11	0.000905	0.000082		
Lack of Fit	9	0.000853	0.000095	3.66	0.09
Pure error	2	0.000052	0.000026		
Total	14	0.037439			

Table 6: Estimated regression coefficients for EWR of Inconel X750 using brass electrode

Symbol	*Co efficient*	*P value*
Constant	0.06775	0.001
A	0.03276	0.001
B	0.00008	0.000
C	0.00049	0.047
A^2	0.00107	0.000
B^2	0.0001	0.205
C^2	-0.00008	0.348
AB	0.000012	0.488
BC	0.0000206	0.175
AC	-0.00003	0.495

When the p-value is less than the α-level, evidence exists that the model does not accurately fit the data. The p-value for the lack-of-fit is 0.099, which is larger than 0.05 (95% confidence). Hence, the lack-of-fit term is insignificant as it is desired. The fit summary recommended that the quadratic model is statistically significant for analysis of EWR. Fig. 3 indicates the normal probability plot for EWR of Inconel X750 using Brass electrode and Fig. 4 depicts residual Vs fitted values for EWR of Inconel X750 using brass electrode.

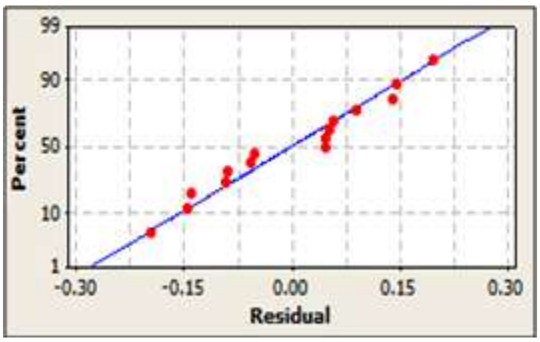

Figure 3: Normal probability plot for EWR of Inconel X750 using Brass electrode

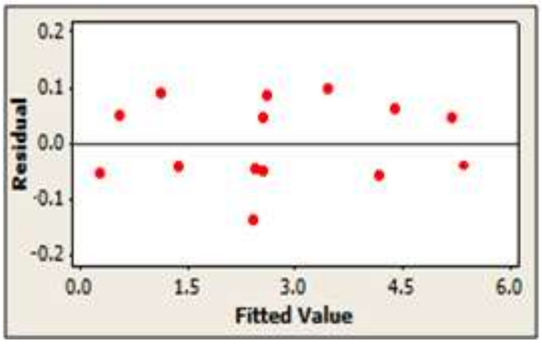

Figure 4: Residual Vs fitted values for EWR of Inconel X750 using Brass electrode

Equation 6 is helpful to develop the EWR graphs with selected parameters. Figure 5 to 8 shows the EWR with selected pulse peak current, pulse on time and gap voltage. These graphs help to predict the EWR at any point.

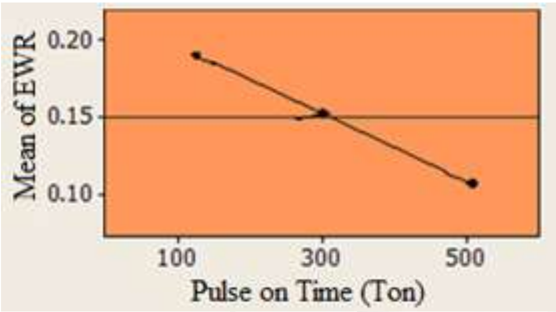

Figure 5: Graph of EWR Vs. I_p

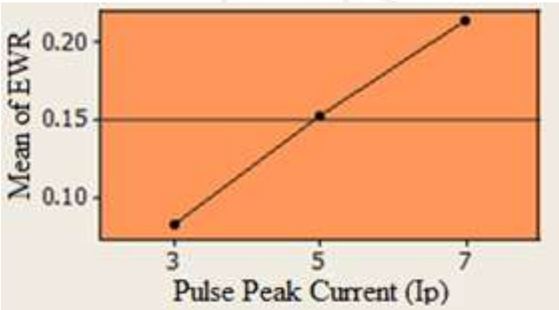

Figure 6: Graph of EWR Vs. Ton

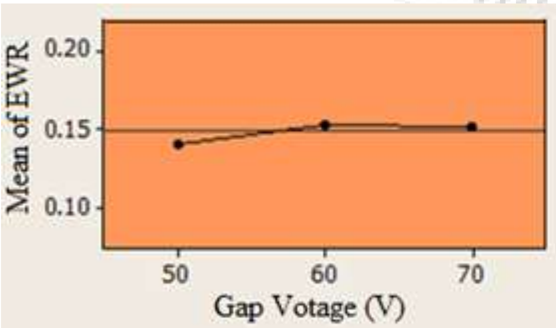

Figure 7: Graph of EWR Vs

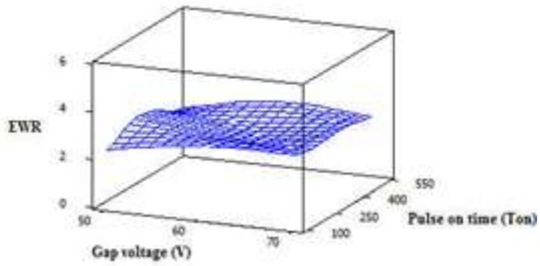

Figure 8: Dimensional surface plot

It can be observed from Fig. 5 that EWR increases with increase in pulse peak current for the machining processes. This may be due to more electrical discharge energy being conducted into the machining gap with the increase in discharge current, thereby increasing the EWR [2].When tool is cooled with electrolyte, the temperature of tool tip reduces drastically, which reduces the size of the crater formed and also increase the recast layer in the tool, therefore tool wear reduces.

It is observed that an increase in pulse-on time decreases the values of electrode wear rate. This is due to the fact that the diameter of the discharge column increases with the pulse duration [9] which eventually reduces the energy density of the electrical discharge on the discharge spot. It has also been reported that at longer pulse-on time, the carbon from the decomposition of hydrocarbon-based dielectric liquid deposits on the surface of the tool [8]. This deposited layer increases the wear resistance of the tool and reduces EWR. Further it can be seen from the figure that EWR in EDM process with brass electrode is greater as compared to EDM process with copper electrode. From Fig. 7 the effect of gap voltage on the value of EWR shows the increasing from 50V to 60V and then decreasing trend up to 70V.

7. Conclusion

Electrode wear rate prediction model has been developed and used in machining of Inconel X750 with brass electrode in electric discharge machine. It is observed from the graph that the metal removal rate increases with an increase of pulse on time, and relatively with gap voltage also, MRR decreases with increase of pulse peak current. In order to get the minimizeEWR the higher value of gap voltage should be used. Response surface methodology gives more information from the conducted experiments with less runs.

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