# ANALYSIS OF SURFACE ROUGHNESS IN ELECTRIC DISCHARGE MACHINING OF INCOLOY 800HT

Sourabh SINHA[1], Raj BALLAV[2], Amaresh KUMAR[3]

*This paper analyzes the effect of machining parameters on surface roughness of INCOLOY 800HT using Electric Discharge Machining [EDM]. Response surface methodology [RSM] has been considered for improvement and optimization of the experiments. Box-Behnken design of RSM was used to design and analyze the experiments performed. Current, voltage and pulse on-time were chosen as process parameters to study the influence on surface finish of the material which has been machined. From the analysis of the result, it is revealed that the current is the most significant factor. Surface Roughness [SR] increases with the increase in current, whereas better surface finish is achieved at lower current value.*

**Keywords**: Electric Discharge Machining [EDM], INCOLOY 800HT, Surface Roughness, Box-Behnken, Response Surface Methodology (RSM).

## 1. Introduction

Electric Discharge Machining (EDM) is the most accepted non-conventional machining process due to its high precision and ability to machine materials which are considered as hard to machine [1, 2, 3]. It is an electro-thermal process, where the work piece is submerged in dielectric fluid and material is removed through succession of electrical discharges. Successive spark erodes amount of material from the surface, hence resulting in cavity as the complementary shape of tool electrode [4]. Over the years, EDM process has been successfully applied in manufacturing of moulds and dies in manufacturing industries and components in aerospace and automotive industries [5]. Though, EDM is a widely used non-conventional machining process, it is very demanding in nature and the mechanism of the process is complex which is difficult to understand in complete sense. Hence, it is not easy to establish an analytical model and its optimal setting for exact prediction of performance and optimal response by correlation of the process parameters [6].

Petrochemical industries, electric power generators, gas turbines, chemical processing plants requires high temperature and high pressure resistive materials

[1] Research Scholar, Dept. of Manufacturing Engineering, National Institute of Technology , Jamshedpur, India, e-mail: sourabhmilan@gmail.com
[2] Associate Professor, Dept. of Manufacturing Engineering, National Institute of Technology, Jamshedpur, India, e-mail: rballav.prod@nitjsr.ac.in
[3] Associate Professor, Dept. of Manufacturing Engineering, National Institute of Technology, Jamshedpur, India, e-mail: akumar.prod@nitjsr.ac.in

for which Nickel base super alloys are generally used [7]. INCOLOY 800HT (registered trademark of Special Metals, USA) is one such Nickel based super alloy which beside exhibiting above characteristics also has the property of high creep rupture strength and great corrosion resistance in acidic and sulfur containing solutions. Owing such good characteristics, INCOLOY 800HT are used in various industries such as, heat-treating equipments, chemical and petrochemical processing industries for heat exchangers, super-heater and re-heater in power and plants, and ethylene furnace quench boilers. According to Nickel Development Institute and Special Metals Corporation, USA, INCOLOY 800HT is a difficult to machine alloy using traditional machining processes. Hence, non-conventional machining has been considered for the present study.

The second order mathematical models in terms of machining parameters were developed for surface roughness prediction using response surface methodology (RSM). Numbers of researchers have applied RSM for modeling and analysis of the process parameters in manufacturing. N. Annamalai et al. [8] used response surface modeling to investigate the effect of machining parameters on EN24 Low alloy steel. S Gopalakannan et al. [9] formulated a mathematical model by applying response surface methodology to estimate the machining characteristics such as material removal rate, electrode wear rate and surface roughness. From the previous researches it is found that different materials are investigated using electric discharge machining such as iron, aluminum, AISI D2 steel, Inconel 718. Till date no research work is carried out in the case of INCOLOY 800HT using EDM. Therefore, this paper aims at investigating the effect of different input parameters on surface roughness of the material.

## 2. Response Surface Methodology

When correlation between the response and variables need to be investigated, as the output/response is influenced by different parametric input variables, Response surface methodology (RSM) is used for modeling and analysis of the problems [10]. RSM is used to improve the robustness of the process and the product. The response surface is expressed using the following form of equation:

$$y = \beta_0 + \sum_{i=0}^{q} \beta_i x_i + \sum_{i=1}^{q} \beta_{ii} x_i^2 + \sum_{i=1}^{q-1} \sum_{j=i+1}^{q} \beta_{ij} x_i x_j \ldots\ldots, \tag{1}$$

where $y$ is the corresponding response, for example the SR produced by the various process variables of EDM and $x_i$ (1, 2,……$q$) are coded levels of $q$ quantitative process variables, the terms $\beta_0$, $\beta_i$, $\beta_{ii}$, and $\beta_{ij}$ are the second order regression coefficients.

## 3. Experimentation

The experiments were designed using Box-Behnken design of experiments since; it avoids corner points and star points [11]. Box-Behnken designs were formulated by George E.P. Box and Donald Behnken in 1960. The designs were devised to achieve certain goals such as, (i). Each variable or factor is placed at one of three equally spaced values, (ii). The nature of design should be to fit a quadratic model, which includes square effects and interaction effects between factors, and (iii). In the quadratic model, ratio of the number of experimental points to the number of coefficients should be reasonable. Box-Behnken design of experiment as per response surface methodology helps in optimization process using a small number of experimental runs. The design was generated and analyzed using the MINITAB 16 statistical software. MINITAB is an all-in-one statistical and graphical analysis software package with tools that are accurate, reliable, and easy to use [12]. INCOLOY 800HT (Dimensions: 30mm x 30mm x 10mm, and Composition: Ni=30.0-35.0%, Cr=19.0-23.0%, Fe=39.5% min., C=0.06-0.10%, Al=0.25-0.60%, Ti=0.25-0.60%, Al+Ti=0.85-1.20%) is selected as work material because of its high creep rupture strength, high temperature strength, and high corrosive resistant strength. The electrode material selected for the present work is copper electrode of 15mm diameter which is 99.99% Cu. Experiments have been performed on AGIE 250C die-sinking EDM machine manufactured in Switzerland. Machining conditions considered during experimentation are listed in table 1.

*Table 1*

Machining conditions

| | |
|---|---|
| Work piece | Incoloy 800ht |
| Tool electrode | Copper |
| Polarity | Positive |
| Dielectric | Edm oil se 180 |
| Inter-electrode gap | 0.08mm |
| Method of flushing | Side flushing |

In this study a total of 15 experiments are conducted at the set conditions. Table 2 shows the various input parameters at three different levels.

*Table 2*

Coded and real levels of independent parameters

| Parameters | Symbol | Levels | | |
|---|---|---|---|---|
| Coded values | | -1 | 0 | +1 |
| Current(A) | A | 5 | 10 | 15 |
| Voltage(V) | B | 2 | 4 | 6 |
| Pulse on-time(μs) | C | 10 | 18 | 26 |

The number of runs and the run order is automatically created by software used.

## 4. Results and Discussion

After experimentation, the next step is to analyze and discuss the obtained results. Table 3 shows the architecture of experimental runs with obtained response. The experimental observations performed with the help of RSM are used to analyze the effect of process parameters on the responses.

For the purpose of data analysis goodness of fit for the model has to be checked. Hence, analysis of variance (ANOVA) has to be performed. The fit summary clearly recommends that the quadratic model is statistically significant for analysis of surface roughness. This analysis was accomplished for a significance level alpha (α) of 0.05 (95% confidence level). The ANOVA contains a table consisting of degrees of freedom (DOF), sum of squares (SS), mean of squares (MS), F-values (F), and probability (P) values. The P-value is the smallest level of significance at which the data are significant, whereas, the ratio of MS of the model terms to the MS of the residual is termed as F-value [13]. Statistical significance to the response ($R_a$) is evaluated by the P-values and F-values of ANOVA. The sources with P-value less than 0.05 and F-value larger than F-table are treated to have a statistically significant effect to the output response. Table 4 presents the result of quadratic model for SR.

*Table 3*

Experimental strategy with obtained responses

| Serial No. | Current(A) | Voltage(V) | Pulse-on time(μs) | Ra(μm) |
|---|---|---|---|---|
| 1 | 10 | 2 | 26 | 2.346 |
| 2 | 5 | 6 | 18 | 1.985 |
| 3 | 15 | 4 | 26 | 10.132 |
| 4 | 5 | 4 | 10 | 1.108 |
| 5 | 10 | 4 | 18 | 6.655 |
| 6 | 10 | 4 | 18 | 6.714 |
| 7 | 5 | 4 | 26 | 1.463 |
| 8 | 15 | 6 | 18 | 10.907 |
| 9 | 10 | 6 | 26 | 3.377 |
| 10 | 10 | 6 | 10 | 3.702 |
| 11 | 5 | 2 | 18 | 1.497 |
| 12 | 10 | 4 | 18 | 6.523 |
| 13 | 15 | 4 | 10 | 8.775 |
| 14 | 10 | 2 | 10 | 2.106 |
| 15 | 15 | 2 | 18 | 12.651 |

The Model F-value of 28.09 suggests that the model is significant. There is only a chance of 0.01% that a "Model F-value" so large could occur due to noise. The values of "P" in Table 4 for the term of models less than 0.05 indicate that model terms are significant. From the table 4 we can conclude that A, B, C, $A^2$, and $C^2$ are the significant model terms. Values that are greater than 0.1000 point out the model terms are not significant. The table also shows the R-squared and adjusted R-squared values for the model. If the $R^2$ is near to unity, the response model better fits the experimental data. In this study obtained value of $R^2$ is 98.06%. The “Pred. R-squared” of 69.10% is in reasonable agreement with the “Adj. R-squared” of 94.57%. Also, the value of predicted residual error sum of squares “PRESS” in this model is greater than 4 which is desirable and this value of 64.632 indicates an adequate signal. This model provides an excellent explanation of the relationship between the process parameters and surface roughness.

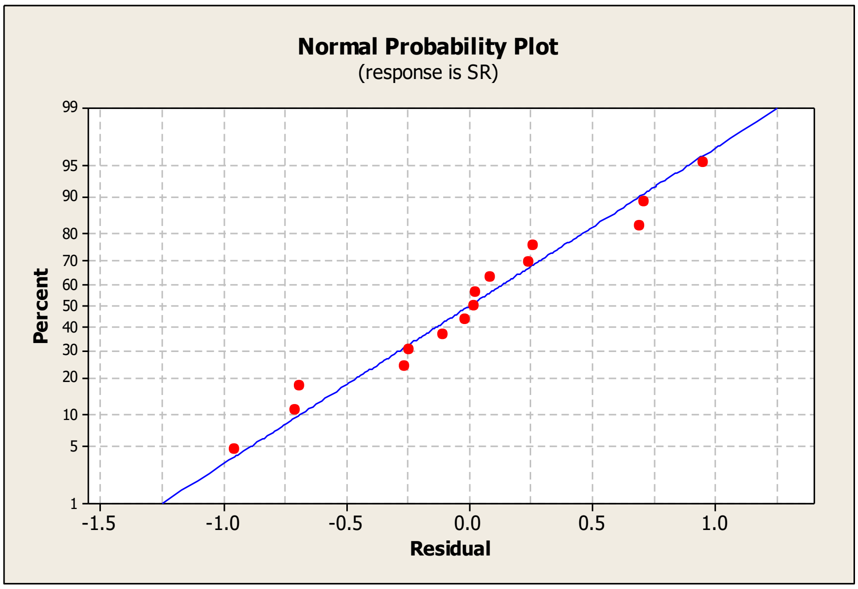


Fig. 1. Normal Probability plot for SR

Normality test is conducted for SR and it can be seen in fig. 1 that all the points on the normal plot come close to a straight line. The obtained data reported the normal behavior and having no deviations from the normality. Further, regression equation for SR is obtained which helps in prediction and optimization of output variables in relation to input variables.

$$SR = -17.50 - 0.026A + 3.16B + 1.44C + 0.0523A^2 - 0.295B^2 - 0.04014C^2 - 0.055AB + 0.0063AC - 0.0088BC \quad (2)$$

where A is current, B is voltage and C is pulse on-time.

*Table 4*

ANOVA table for SR

| SOURCE | SUM OF SQUARES(SS) | DOF | MEAN SQUARE(MS) | F VALUE | P VALUE |
|---|---|---|---|---|---|
| MODEL | 205.088 | 9 | 22.788 | 28.09 | <0.001 SIGNIFICANT |
| A-CURRENT | 0.002 | 1 | 0.0024 | 0.00 | 0.008 |
| B-VOLTAGE | 5.940 | 1 | 5.9403 | 7.32 | 0.042 |
| C-PULSE ON-TIME | 17.520 | 1 | 17.5201 | 21.60 | 0.006 |
| AB | 1.245 | 1 | 1.2455 | 1.54 | 0.270 |
| AC | 0.251 | 1 | 0.2510 | 0.31 | 0.602 |
| BC | 0.080 | 1 | 0.0798 | 0.10 | 0.766 |
| $A^2$ | 6.317 | 1 | 6.3174 | 7.79 | 0.038 |
| $B^2$ | 5.130 | 1 | 5.1299 | 6.32 | 0.054 |
| $C^2$ | 24.372 | 1 | 24.3723 | 30.05 | 0.003 |
| RESIDUAL | 4.056 | 5 | 0.8112 | | |
| LACK OF FIT | 4.037 | 3 | 1.3456 | 140.69 | 0.007 |
| PURE ERROR | 0.019 | 2 | 0.0096 | | |
| CORR. TOTAL | 209.144 | 14 | | | |
| | $R^2$=98.06% | | | PRESS=64.632 | |
| | ADJ. $R^2$=94.57% | | | PRED. $R^2$=69.10% | |

### 4.1. Effect of process parameters on SR ($R_a$)

An attempt has been made to study the effect of EDM parameters such as current, voltage and pulse on-time on surface roughness. Figure 2 show that SR increases with increase in current. It is due to the fact that with the increase in current there is strong spark, creating higher temperature and crater [14].

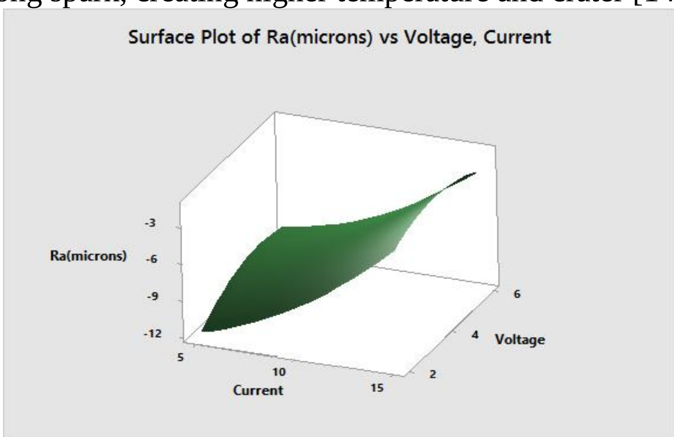


Fig. 2. 3-D Surface Plot of the Effect of Current and Voltage on SR ($R_a$)

Also from fig. 2 it is seen that as the voltage increases there is corresponding increase in surface roughness. As the voltage increases, there is intense striking of the discharges on the surface of the workpiece, resulting in larger cavities, hence deteriorating the surface roughness [15]. Even long pulse on-time increases surface roughness which can be clearly sited from fig. 3

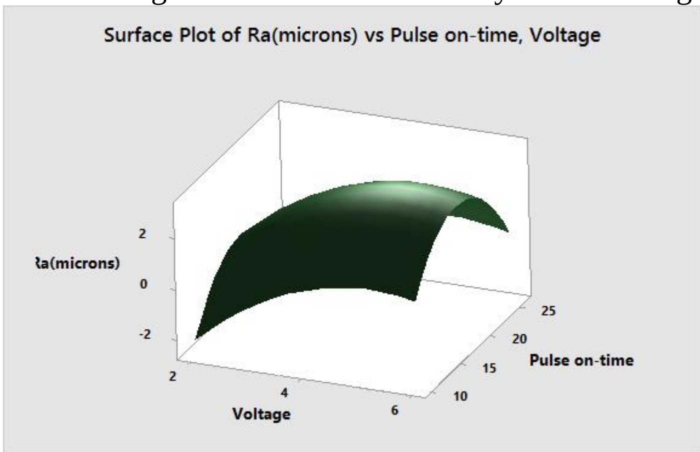


Fig. 3. 3-D Surface Plot of the Effect of Voltage and Pulse on-Time on SR ($R_a$)

## 5. Confirmation Experiments

After the selection of optimal level of the process parameters, the last step is to predict and verify the improvement of the response using the optimal level of the machining parameters. The optimal level was found as Current: 15A, Voltage: 4V, and Pulse on-Time: 26µs. Table 5 shows the percentage of error present for experimental validation of the developed model for the responses with optimal parametric setting.

*Table 5*

Experimental validation of developed model with optimal parameter setting

| Responses | Predicted | Experimental | Error(%) |
|---|---|---|---|
| SR (µm) | 7.31213 | 8.00358 | 8.64 |

The error between experimental and predicted SR is 8.64%. The result confirms proper reproducibility of the experimental conclusion.

## 6. Conclusions

In this experimental work an attempt has been made to investigate the machining parameters such as current, voltage and pulse on-time on SR of INCOLOY 800HT. The EDM process was successfully modeled in terms of SR using Response Surface Methodology. The analysis of variance suggests that the factors current and pulse on-time are the most significant parameters. SR increases with increase in current, voltage and pulse on-time. The error between experimental and predicted values at the optimal combinations of parameters setting for SR is 8.64%. This confirms proper reproducibility of experimental conclusion.

## REFERENCES

[1]. *Raoul Roth, Hartmi Balzer, and Friedrich Kuster, Konrad Wegener*, "Influence of the Anode Material on the Breakdown Behavior in Dry Electrical Discharge Machining", in Procedia CIRP, **vol. 1**, 2012, pp. 639-644

[2]. *S.N. Joshi, and S.S. Pande*, "Intelligent process modeling and optimization of die-sinking electric discharge machining", in Applied Soft Computing, **vol. 11**, 2011, pp. 2743-2755

[3]. *Saeed Daneshmand, Ehsan Farahmand Kahrizi, Esmail Abedi, and M. Mir Abdolhosseini, "*Influence of Machining Parameters on Electro Discharge Machining of NiTi Shape Memory Alloys", in International Journal of Electrochemical Science, **vol. 8**, 2013, pp. 3095-3104

[4]. *S. Assarzadeh, and M. Ghoreishi*, "Statistical modeling and optimization of process parameters in electro-discharge machining of cobalt-bonded tungsten carbide composite (WC/6%Co)", in Procedia CIRP, **vol. 6**, 2013, pp. 463-468

[5]. *Chinmaya P Mohanty, Siba Shankar Mahapatra, and Manas Ranjan Singh*, "An Experimental Investigation of Machinability of Inconel 718 in Electrical Discharge Machining", in Procedia Materials Science , **vol. 6**, 2014, pp. 605-611

[6]. *M.K. Pradhan*, "Estimating the effects of process parameters on surface integrity of EDMed AISI D2 tool steel by response surface methodology coupled with grey relational analysis", in International Journal of Advanced Manufacturing Technology, **vol. 67**, 2013, pp. 2051-2062

[7].*V.Muthukumar, N.Rajesh, R.Venkatasamy, A.Sureshbabu, and N.Senthilkumar*, "Mathematical Modelling for Radial Overcut on Electrical Discharge Machining of Incoloy 800 by Response Surface Methodology", in Procedia Materials Science, **vol. 6**, 2014, pp. 1674-1682

[8]. *N. Annamalai, V. Sivaramakrishnan, and N. Baskar*, "Response Surface Modeling of Electric Discharge Machining Process Parameters for EN 24 Low Alloy Steel", in 5$^{th}$ International & 26$^{th}$ All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12$^{th}$-14$^{th}$, 2014, IIT Guwahati, Assam, India

[9]. *S Gopalakannan, T Senthivelan, and K Kalaichelvan*, "Modeling and Optimization of EDM of Al 7075/10 wt% $Al_2O_3$ metal matrix composites by Response Surface Method", in Advanced Materials Research, **vol. 488-489**, 2012, pp. 856-860

[10]. D.C. Montgomery - Design and analysis of experiments, John Willy and Sons Inc., 2001

[11]. *K. Palanikumar and J. Paulo Davim*, "Electrical discharge machining: study on machining characteristics of WC/Co composites", in Machining and machine-tools: Research and development, **vol. 5**, 2013, pp. 135-168

[12]. *Groebner, David F., Mark L. Berenson, David M. Levine, Timothy C. Krehbiel, and Hang Lau*, "Applied management statistics", in Custom ed. Boston, MA: Pearson Custom Publishing/ Pearson/ Prentice Hall, 2008

[13]. *S.S. Baraskar, S.S. Banwait and S.C. Laroiya*, "Mathematical Modeling of Electrical Discharge Machining Process through Response Surface Methodology", in International Journal of Scientific & Engineering Research, **vol. 2(11)**, 2011, pp. 1-10

[14]. *Ahmet Hascalik and Ulas Caydas*, "Electrical discharge machining of titanium alloy (Ti-6Al-4V)", in Applied Surface Science, **vol. 253**, 2007, pp. 9007-9016

[15]. *A.K.M. Asif Iqbal and Ahsan Ali Khan*, "Modelling and Analysis of MRR, EWR and Surface Roughness in EDM Milling through Response Surface Methodology", American J. Of Engineering and Applied Sciences, **vol. 3(4)**, 2010, pp. 611-619