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## RESEARCH ARTICLE

# EXPERIMENTAL INVESTIGATION OF THE EFFECT OF CONTROL PARAMETERS OF EDM ON SURFACE ROUGHNESS AND TOOL WEAR RATE USING REGRESSION ANALYSIS

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**ABSTRACT**

In this paper illustration of the influence of input machining parameters on the surface roughness and Tool wear rate are determined along with regression analysis. This experiment was conducted on High Carbon High Chromium Steel (HCHCR) with Copper as tool electrode. The data collected during experimentation has been used to yield responses in respect of surface roughness and tool wear rate (TWR). The objective of this paper is to study the influence of operating input parameters of copper electrode on surface roughness of HCHCR and tool wear rate of copper followed by optimization. The effectiveness of EDM process with copper electrode is evaluated in terms of surface roughness and tool wear rate. In this work the parameters such as current, spark gap, flushing rate pulse on time, pulse off time were selected. Analysis is carried using the Anova analysis.



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## INTRODUCTION

***Electrical Discharge Machining:*** Electrical Discharge Machining (EDM): Removal of material from the work piece by spark discharges, which are produced by connecting both tool (electrode) and work piece to a power supply. This process is also known as spark erosion. Electrical Discharge Machining (EDM) is a non-conventional machining process, where Electrically conductive materials is machined by using precisely controlled sparks that occur Between an electrode and a work piece in the presence of a dielectric fluid. It uses thermoelectric energy sources for machining extremely low machinability materials; complicated Intrinsic-extrinsic shaped jobs regardless of hardness have been its distinguishing characteristics.

### A.Process Parameters of EDM:

- *i.* *Voltage:* It is a potential that can be measure by volt it is also effect to the material removal rate and allowed to per cycle.
- *ii.* *Current:* Discharge current is directly proportional to the Material removal rate.
- *iii.* *Flushing:* Flushing is the process of supplying clean filtered dielectric fluid into the machining zone.
- *iv.* *Spark gap:* The Arc gap is distance between the electrode and work piece during the process of EDM. It may be called as spark gap. Spark gap can be maintained by servo system.
- *v.* *T on:* The duration of time (μs) the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time
- *vi.* *T off:* The duration of time (μs) between the sparks (that is to say, on-time). This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to affect the speed and the stability of the cut.

### B.Output Parameters:

- *i.* *Tool Wear Rate:* Tool wear describes the gradual failure of cutting tools due to regular operation.
- *ii.* *Surface roughness:* It is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form.

### *C.Cutting tools used:*

*Copper:* copper has properties, such as its high electrical conductivity, tensile strength, ductility, creep (deformation)

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resistance, corrosion resistance, low thermal expansion, high thermal conductivity, solder ability and ease of installation. Pure copper is soft and malleable. A freshly exposed surface has a reddish-orange colour.

**Regression**

A statically measured that attempts to determine the strength of relationship between one dependent variable (usually denoted by y) and a series of other changing variables (known as independent variables). Regression analysis with a single explanatory variable is termed "simple regression.

***i. Simple Regression:*** Simple regression also known as linear regression uses one independent variables to explain or predict the outcome of y. At the outset of any regression study, one formulates some hypothesis about the relationship between the variables of interest, here, education and earnings. Common experience suggests that better educated people tend to make more money. It further suggests that the causal relation likely runs from education to earnings rather than the other way around. Thus, the tentative hypothesis is that higher levels of education cause higher levels of earnings, other things being equal.

This linearity assumption is common in regression studies but is by no means essential to the application of the technique, and can be relaxed where the investigator has reason to suppose a priori that the relationship in question is nonlinear. Then the hypothesized relationship between education and earnings may be written

y = a + bx + u … (3.1)

Where,

y = the variable that we are trying to predict.
x = the variable that we are using to predict y.
a = the intercept
b = the slope
u = the regression analysis

*a) Regression Analysis:*

Regression analysis is a statistical tool for the investigation of relationships between variables. In this lecture, we will provide an overview of the most basic techniques of regression analysis—how they work, what they assume, and how they may go away when key assumptions do not hold. Also, of necessity, there are many important topics that including simultaneous equation models and generalized least squares. The lecture is limited to the assumptions, mechanics, and common difficulties with single- equation, ordinary least squares regression.

*Step 1: Normalization of the responses (Quality Characteristics):*

When the range of the series is too large or the optimal value of a quality characteristic is too huge, it will caused the influence of some factors to be overlooked. The original experimental data must be normalized to eliminate such an effect. There are three types of data normalization. The normalization is assumed by the following equations.

i. LB (lower-the-better)

$$x_i\ k = \frac{\min x_i(k)}{x_i(k)} \quad \text{(i)}$$

ii. HB (higher-the-better)

$$x_i\ k = \frac{x_i(k)}{\max x_i(k)} \quad \text{(ii)}$$

iii. NB (nominal-the-best)

$$x_i\ k = \frac{\min \{x_i\ k, x_{0b}\ k\}}{\max \{x_i\ k, x_{0b}\ k\}} \quad \text{(iii)}$$

Here, i = 1, 2 ...m; k = 1, 2 ...n

$X_i$ (k) is the normalized data of the $k^{th}$ element in the $i^{th}$sequence.

$X_{ob}$(k) is the desired value of the $k^{th}$ quality characteristic. After data normalization, the value of $X_i$ (k) will be between 0 and 1. The series, *i*=1, 2, 3,........,*m* can be viewed as the comparative sequence used in the grey relational analysis.

*Step 2: Checking for correlation between two quality characteristics:*

$$Q_i = x_0\ i\ , x_1\ i\ , x_2\ i\ \ldots\ldots\ldots\ldots x_m\ i \quad \text{(iv)}$$

Let, Where, i = 1, 2, ...n Shown above is the normalized series of the $i^{th}$ quality characteristic. The correlation coefficient between the two quality characteristics is calculated using the following equation:

$$\rho_{jk} = \frac{cov(Q_j Q_k)}{\sigma_{Qj}\sigma_{Qk}} \quad \text{(v)}$$

j = 1,2,3....,n k = 1,2,3....,n j ≠ k Here, $\rho_{jk}$ is the correlation coefficient between quality characteristic *j* and quality characteristic *k* ; cove(QjQk) is the covariance of quality characteristic *j* and quality characteristic *k* ;$\sigma_{Qj}$ and$\sigma_{Qk}$ are the standard deviation of quality characteristic *j* and quality characteristic *k* , respectively.

The correlation is checked by testing the following hypothesis
$H_0$: $\rho_{j\,k}$ = 0 (There is no correlation)
$H_0$: $\rho_{j\,k}$ ≠ 0(There is correlation)

**Step 3: Calculation of the Principal Component Score:**

i. Calculation of the Eigen value and the corresponding eigenvector $\beta_k$ (k = 1, 2,......n) from the correlation matrix formed by all quality characteristics.
ii. Calculation of the principal component scores of the normalized reference sequence and comparative sequences using the equation shown below:

$$Y_i\ k = \sum_{j=1}^{n} x_i\ j\ \beta_{kj} \quad \text{(vi)}$$

Where, $Y_i$ (k) is the principal component score of the $k^{th}$ element in the $i^{th}$ series. $X_i$ (j) is the normalized value of the $j^{th}$ element in the $i^{th}$ sequence, $\beta_{kj}$ and is the $j^{th}$ element of eigenvector $\beta_k$

iii. The principal component having highest accountability proportion (AP) can be treated as the overall quality index which is to be optimized finally. The quality loss $\Delta_{0,i}$(k) of that index (compared to ideal situation) is calculated as

$$\Delta_{0,i}\ k = \left\{\begin{matrix} |x_0\ k - x_i\ k| \\ |y_0\ k - y_i\ k| \end{matrix}\right. \quad \text{(vii)}$$

**b)Surface Roughness Measurement Terminology:**

$R_a$- Arithmetic means value of the deviation of the profile within sampling length

$R_z$- The maximum height of irregularities is the distance b/w maximum depth of the profile peaks and profile valley within of sampling length

$R_q$- Square root of the arithmetic mean of the square of profile deviation (Yi) from mean within sampling length.

$R_t$- Total peak-to-valley height .It is the sum of the height of highest peak and the depth of deepest valley over the evaluation length.

**Specimen Material:**

Specimen material selected for proposed research work was High Carbon High Chromium Steel (HCHCR).

i. *Chemical Composition:*

**Table 1. Chemical Composition of HCHCR Steel**

| Element | Content (%) |
|---|---|
| C | 1.40 – 1.60 |
| Mn | 0.60 |
| Si | 0.60 |
| Co | 1.00 |
| Cr | 11.00 – 13.00 |
| Mo | 0.70 – 1.20 |
| V | 1.10 |
| P | 0.03 |
| Ni | 0.30 |
| Cu | 0.25 |
| S | 0.03 |

ii. *Physical Properties*

**Table: The physical properties of HCHCR Steel:**

| Properties | Metric | Imperial |
|---|---|---|
| Density | 7.7 x 1000 kg/m3 | 0.278 lb/in3 |
| Melting point | 1421°C | 2590°F |

iii. *Mechanical Properties*

Table: The mechanical properties of HCHCR Steel:

| Mechanical Properties | Metric | Imperial |
|---|---|---|
| Hardness, Rockwell C | 62 | 62 |
| Hardness, Vickers | 748 | 748 |
| Izod impact unnotched | 77.0 J | 56.8 ft-lb |
| Poisson's ratio | 0.27-0.30 | 0.27-0.30 |
| Elastic modulus | 190-210 GPa | 27557-30457 ksi |

**Strategy of conducting experiments**

***Hardness Test:***

The hardness of the specimens was measured by Brinell-cum-Rockwell Hardness testing machine. This method consists of indenting the test material with a hardened steel ball indenter. The indenter is forced into the test material under a load usually 150 kgf for HCHCR and Stainless Steel. When equilibrium has reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position. The permanent increase in depth of penetration, resulting from the application of the load is used to calculate the Brinell hardness number, which can be calculated through the following formula:

$$\text{BHN} = \frac{2P}{\pi D\ D - \sqrt{D^2 - d^2}}$$

Where,
P = Load Applied
D = Diameter of steel ball in mm
d = Diameter of indentation in mm

*Calculation of Hardness Number:*

Specimen 1st (HCHCR)
Applied load = 150 kgf
Diameter of the ball (D) = 3.5 mm
Diameter Of the indentation (first) = 1.9 mm
Diameter of the indentation (second) = 1.9 mm
Avg. diameter of the indentation (d) = 1.9 mm

$$\text{BHN} = \frac{2P}{\pi D\ D - \sqrt{D^2 - d^2}}$$

$$\text{BHN} = \frac{2x150}{\pi 3.5\ 3.5 - \sqrt{3.5^2 - 1.9^2}}$$

$$\text{BHN} = \frac{300}{18.22142}$$

BHN = 16.464

**Table: Hardness Number value of both the Specimen**

| S. No. | Specimen | BHN |
|---|---|---|
| 1 | High Carbon High Chromium Steel | 16.464 |

**Machining operation on electrical discharge machine**

The total length of both material was 100X100X10 mm. Materials were cut into four pieces 25X25X10 mm each for the need of experiment set up. The work pieces (HCHCR) were fixed in Electrical Discharge Machine accordance's with experimental design and measured for surface roughness, material removal rate and tool wear rate. The factors (Current, T On, T Off, Flushing rate, Spark gape) were varied at three levels for EDM.

**Designing of Experiment using Regression analysis based Design of Experiment (DOE) Method:**

*Degrees of Freedom:* Degree of Freedom in statistics is a very important value because it determines the minimum number of treatment conditions.

Degree of freedom for each factor is

$$DFA = k_A - 1 \text{.....1}$$

Where $k_A$ is the number of levels of Factor A.

In the proposed work, all the five parameters are at three levels each. Values of variables at different levels for machining on EDM of both the specimen materials are as shown in the Table No. 3.8 and Table No. 3.9.

**Table: Factors at different levels for machining HCHCR on EDM**

| Factors | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| **Current (A)** | 5.00 | 10.0 | 15.0 |
| **Spark gap (B)** | 0.10 | 0.15 | 0.25 |
| **Flushing rate (C)** | 0.50 | 1.00 | 1.50 |
| **T on (D)** | 4.00 | 5.00 | 6.00 |
| **T off (E)** | 6.00 | 7.00 | 8.00 |

**Table: Factors at different levels for machining Stainless Steel on EDM**

| Factors | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| **Current (A)** | 10.0 | 15.0 | 20.0 |
| **Spark gap(B)** | 0.10 | 0.15 | 0.20 |
| **Flushing rate(C)** | 0.50 | 1.00 | 1.50 |
| **T on (D)** | 6.00 | 7.00 | 8.00 |
| **T off (E)** | 8.00 | 9.00 | 10.0 |

The degree of freedom (DF) of a three level parameter is two (number of levels-3), hence total DF for the experiment is 10.
Table: Degrees of Freedom of the experiment

| Factors | A | B | C | D | E | Total |
|---|---|---|---|---|---|---|
| Degree of Freedom | 2 | 2 | 2 | 2 | 2 | 10 |

The selection of which Orthogonal Array to use depends upon:

i. The number of factors of interest.
ii. The number of levels for the factors of interest.

Total Degree of freedom for this experiment is 10 as shown in Table No.3.10. As the degree of freedom required for the experiment is 10 so the orthogonal array that is to be selected should have degree of freedom higher than 10. Therefore one of the most suitable orthogonal arrays that can be used for this experiment is L27. In this experiment, the assignment of factors was carried out using MINITAB 17 Software. The Standard L27 Orthogonal Array (Reference: Appendix A) as suggested by MINITAB using Taguchi for the particular experiment are listed in Table No. 3.11.

## RESULTS

Following graphs are displaying the distribution of the set of data for judging the normality of the distribution of a group of residuals.

**Table: Control log for the Experimental trial runs to be performed on HCHCR specimens**

| S. No. | Current (A) | Spark gap (mm) | Flushing rate (kg/cm3) | T on | T off |
|---|---|---|---|---|---|
| **1** | 5 | 0.10 | 0.50 | 4 | 6 |
| **2** | 5 | 0.10 | 0.50 | 4 | 7 |
| **3** | 5 | 0.10 | 0.50 | 4 | 8 |
| **4** | 5 | 0.15 | 1.00 | 5 | 6 |
| **5** | 5 | 0.15 | 1.00 | 5 | 7 |
| **6** | 5 | 0.15 | 1.00 | 5 | 8 |
| **7** | 5 | 0.20 | 1.50 | 6 | 6 |
| **8** | 5 | 0.20 | 1.50 | 6 | 7 |
| **9** | 5 | 0.20 | 1.50 | 6 | 8 |
| **10** | 10 | 0.10 | 1.00 | 6 | 6 |
| **11** | 10 | 0.10 | 1.00 | 6 | 7 |
| **12** | 10 | 0.10 | 1.00 | 6 | 8 |
| **13** | 10 | 0.15 | 1.50 | 4 | 6 |
| **14** | 10 | 0.15 | 1.50 | 4 | 7 |
| **15** | 10 | 0.15 | 1.50 | 4 | 8 |
| **16** | 10 | 0.20 | 0.50 | 5 | 6 |
| **17** | 10 | 0.20 | 0.50 | 5 | 7 |
| **18** | 10 | 0.20 | 0.50 | 5 | 8 |
| **19** | 15 | 0.10 | 1.50 | 5 | 6 |
| **20** | 15 | 0.10 | 1.50 | 5 | 7 |
| **21** | 15 | 0.10 | 1.50 | 5 | 8 |
| **22** | 15 | 0.15 | 0.50 | 6 | 6 |
| **23** | 15 | 0.15 | 0.50 | 6 | 7 |
| **24** | 15 | 0.15 | 0.50 | 6 | 8 |
| **25** | 15 | 0.20 | 1.00 | 4 | 6 |
| **26** | 15 | 0.20 | 1.00 | 4 | 7 |
| **27** | 15 | 0.20 | 1.00 | 4 | 8 |

**Table: Control log for the Experimental trial runs to be performed on Stainless Steel specimens**

| S. No. | Current (A) | Spark Gap (mm) | Flushing rate (kg/cm3) | T on | T off |
|---|---|---|---|---|---|
| **1** | 10 | 0.10 | 0.50 | 6 | 8 |
| **2** | 10 | 0.10 | 0.50 | 6 | 9 |
| **3** | 10 | 0.10 | 0.50 | 6 | 10 |
| **4** | 10 | 0.15 | 1.00 | 7 | 8 |
| **5** | 10 | 0.15 | 1.00 | 7 | 9 |
| **6** | 10 | 0.15 | 1.00 | 7 | 10 |
| **7** | 10 | 0.20 | 1.50 | 8 | 8 |
| **8** | 10 | 0.20 | 1.50 | 8 | 9 |
| **9** | 10 | 0.20 | 1.50 | 8 | 10 |
| **10** | 15 | 0.10 | 1.00 | 8 | 8 |
| **11** | 15 | 0.10 | 1.00 | 8 | 9 |
| **12** | 15 | 0.10 | 1.00 | 8 | 10 |
| **13** | 15 | 0.15 | 1.50 | 6 | 8 |
| **14** | 15 | 0.15 | 1.50 | 6 | 9 |
| **15** | 15 | 0.15 | 1.50 | 6 | 10 |
| **16** | 15 | 0.20 | 0.50 | 7 | 8 |
| **17** | 15 | 0.20 | 0.50 | 7 | 9 |
| **18** | 15 | 0.20 | 0.50 | 7 | 10 |
| **19** | 20 | 0.10 | 1.50 | 7 | 8 |
| **20** | 20 | 0.10 | 1.50 | 7 | 9 |
| **21** | 20 | 0.10 | 1.50 | 7 | 10 |
| **22** | 20 | 0.15 | 0.50 | 8 | 8 |
| **23** | 20 | 0.15 | 0.50 | 8 | 9 |
| **24** | 20 | 0.15 | 0.50 | 8 | 10 |
| **25** | 20 | 0.20 | 1.00 | 6 | 8 |
| **26** | 20 | 0.20 | 1.00 | 6 | 9 |
| **27** | 20 | 0.20 | 1.00 | 6 | 10 |

**For this reason the following residuals plots consists of –**

i) Histogram – is a frequency plot obtained by placing the data in regularly spaced cells and plotting each cell frequency versus the centre of the cell.

ii) Normal probability plots – since the sample sizes for residuals are generally small (less than 50) because experiments have limited treatment combinations. In present research work only twenty sevetreatment combinations work chosen at a time, so a histogram may not be the best choice for judging the distribution of residuals.

Therefore normal probability plot is plotted since it is more sensitive graph.

The following steps were taken in forming following normal probability plots

By sorting the residuals into the ascending order.

By calculating the cumulative probability of each residual by using the formula

$P\,(it\square\,residual) = i\,/\,(N + 1)$

Where,

P - Cumulative probability of a point.
I – order of the value in list
N – Number of entries in the list

By plotting the calculated p values versus the residual values on normal probability paper

iii) The plots of residual versus FITS should produce a distribution of points scattered randomly about zero regardless of size of the fitted value.

After experiment the following observations were obtained where we use the array L-27 to arrange the combination of process parameters. The two output parameters are Surface Roughness (Ra) and Tool Wearing Rate (TWR).

**Regression Analysis for High Carbon High Chromium Steel:**

**Table: Analysis of Variance (ANOVA)**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Regression | 5 | 78.056 | 15.611 | 2.97 | 0.035 |
| Current (A) | 1 | 22.222 | 22.222 | 4.22 | 0.052 |
| Spark gap (mm) | 1 | 10.889 | 10.889 | 2.07 | 0.165 |
| Flushing rate (kg/cm$^3$) | 1 | 3.556 | 3.556 | 0.68 | 0.420 |
| T on | 1 | 9.389 | 9.389 | 1.78 | 0.196 |
| T off | 1 | 32.000 | 32.000 | 6.08 | 0.022 |
| Error | 21 | 110.463 | 5.26 | | |
| Total | 26 | 188.519 | | | |

**Table: Model Summary**

| **S** | **R-sq** | **R-sq(adj)** | **R-sq(pred)** |
|---|---|---|---|
| **2.29350** | 41.40% | 27.45% | 9.40% |

**Table: Coefficients**

| Term | Coef | SE Coef | T-Value | P-Value | VIF |
|---|---|---|---|---|---|
| Constant | -1.09 | 5.18 | -0.21 | 0.835 | |
| Current (A) | -0.222 | 0.108 | -2.06 | 0.052 | 1.00 |
| Spark gap (mm) | -15.6 | 10.8 | -1.44 | 0.165 | 1.00 |
| Flushing rate (kg/cm$^3$) | -0.89 | 1.08 | -0.82 | 0.420 | 1.00 |
| T on | 0.722 | 0.541 | 1.34 | 0.196 | 1.00 |
| T off | 1.333 | 0.541 | 2.47 | 0.022 | 1.00 |

*Regression Equation*

TWR = -1.09 - 0.222 Current (A) - 15.6 Spark gap (mm) - 0.89 Flushing rate (kg/cm$^3$)+ 0.722 T on + 1.333 T off

**Table: Fits and Diagnostics for Unusual Observations**

| **Obs** | **TWR** | **Fit** | **Resid** | **StdResid** |
|---|---|---|---|---|
| **4** | 0.000 | 6.185 | -6.185 | -2.92 R |

**Table: Results of Experimental trial runs performed on HCHCR specimens**

| S. No. | Current (A) | Spark gap (mm) | Flushing rate (kg/cm$^3$) | T on | T off | Roughness (Ra) | TWR |
|---|---|---|---|---|---|---|---|
| 1 | 5 | 0.10 | 0.50 | 4 | 6 | 2.91 | 7 |
| 2 | 5 | 0.10 | 0.50 | 4 | 7 | 2.295 | 10 |
| 3 | 5 | 0.10 | 0.50 | 4 | 8 | 2.595 | 7 |
| 4 | 5 | 0.15 | 1.00 | 5 | 6 | 3.68 | 0 |
| 5 | 5 | 0.15 | 1.00 | 5 | 7 | 3.465 | 6 |
| 6 | 5 | 0.15 | 1.00 | 5 | 8 | 3.935 | 12 |
| 7 | 5 | 0.20 | 1.50 | 6 | 6 | 4.07 | 8 |
| 8 | 5 | 0.20 | 1.50 | 6 | 7 | 3.8 | 6 |
| 9 | 5 | 0.20 | 1.50 | 6 | 8 | 4.36 | 7 |
| 10 | 10 | 0.10 | 1.00 | 6 | 6 | 6.815 | 6 |
| 11 | 10 | 0.10 | 1.00 | 6 | 7 | 5.245 | 11 |
| 12 | 10 | 0.10 | 1.00 | 6 | 8 | 5.98 | 12 |
| 13 | 10 | 0.15 | 1.50 | 4 | 6 | 3.22 | 6 |
| 14 | 10 | 0.15 | 1.50 | 4 | 7 | 4.185 | 7 |
| 15 | 10 | 0.15 | 1.50 | 4 | 8 | 3.575 | 6 |
| 16 | 10 | 0.20 | 0.50 | 5 | 6 | 4.11 | 5 |
| 17 | 10 | 0.20 | 0.50 | 5 | 7 | 3.56 | 8 |
| 18 | 10 | 0.20 | 0.50 | 5 | 8 | 4.12 | 6 |
| 19 | 15 | 0.10 | 1.50 | 5 | 6 | 5.12 | 3 |
| 20 | 15 | 0.10 | 1.50 | 5 | 7 | 5.325 | 5 |
| 21 | 15 | 0.10 | 1.50 | 5 | 8 | 5.62 | 5 |
| 22 | 15 | 0.15 | 0.50 | 6 | 6 | 7.205 | 6 |
| 23 | 15 | 0.15 | 0.50 | 6 | 7 | 7.14 | 5 |
| 24 | 15 | 0.15 | 0.50 | 6 | 8 | 5.76 | 7 |
| 25 | 15 | 0.20 | 1.00 | 4 | 6 | 3.5 | 3 |
| 26 | 15 | 0.20 | 1.00 | 4 | 7 | 4.57 | 3 |
| 27 | 15 | 0.20 | 1.00 | 4 | 8 | 4.72 | 6 |

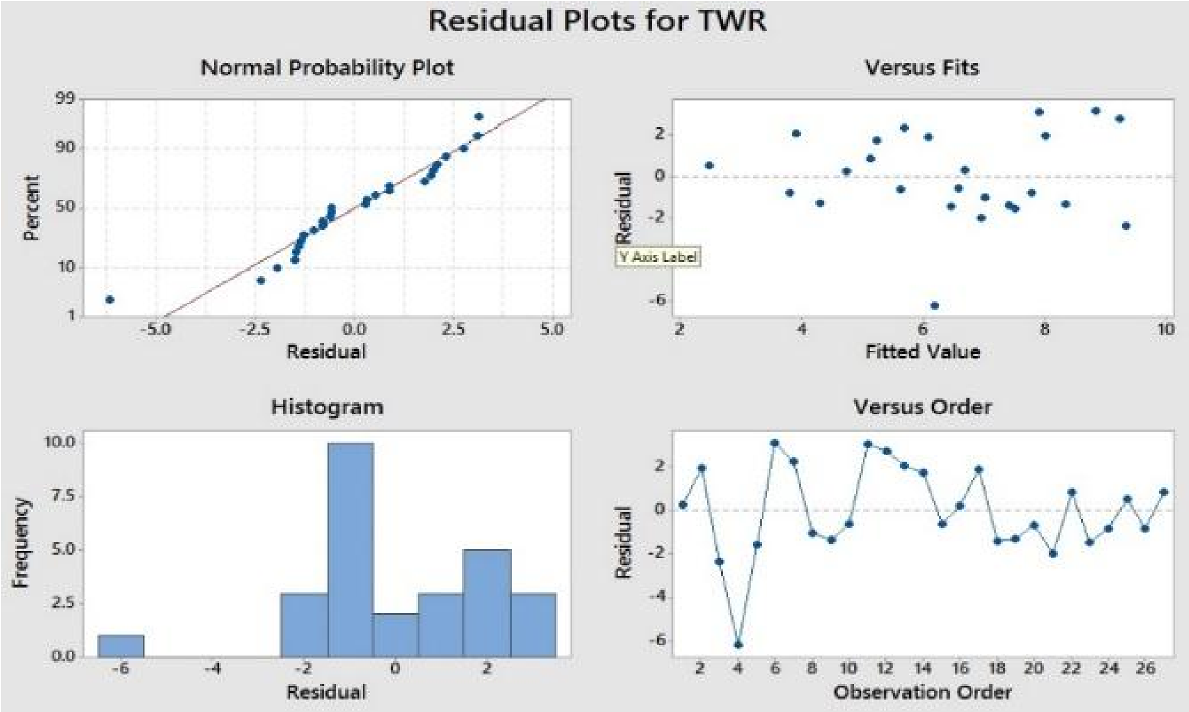


**Fig.1. Residual plots for Tool Wear Rate of HCHCR**

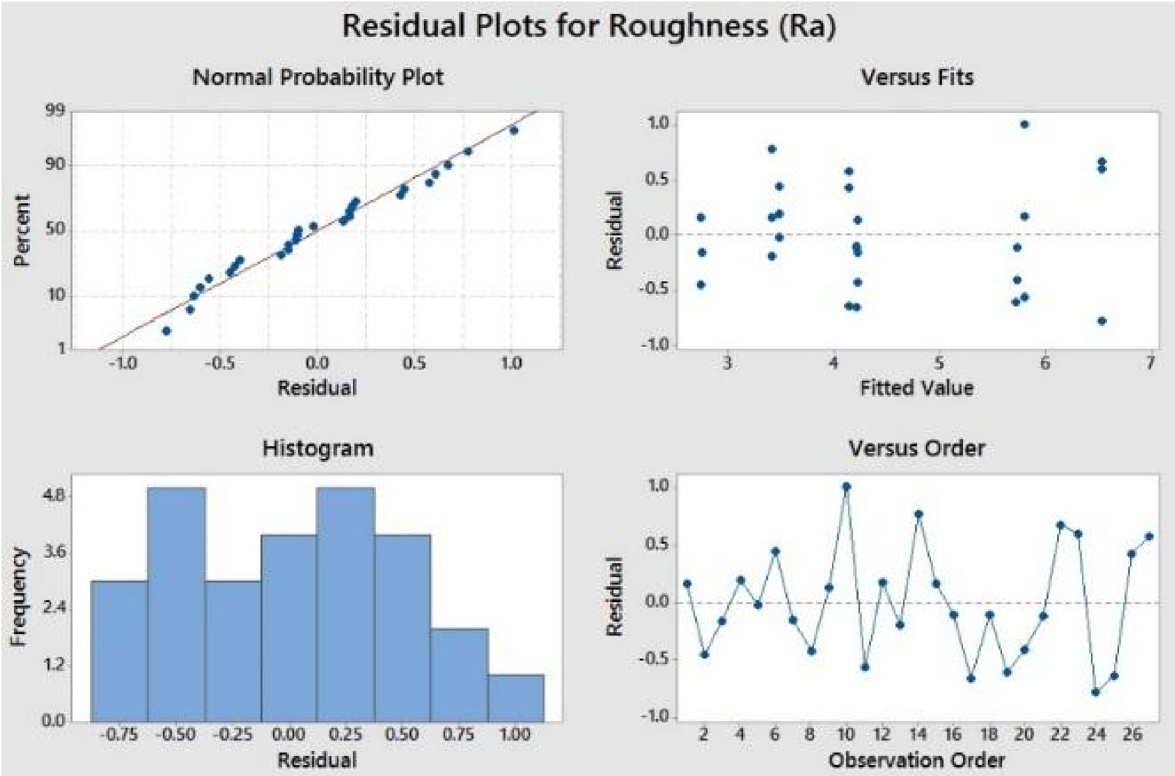


**Fig. 2. Residual plots for roughness of HCHCR**

According to ANNOVA table T off was the factor that affected Tool Wear rate significantly. While at the same time the other factors were found to be insignificant.

Roughness (R versus Current (A), Spark gap (mm), Flushing rate (k, Ton, T off) for HCHCR Steel:

*Regression Equation:*

Roughness (Ra)= -1.85 + 0.1983 Current (A) -5.66 Spark gap (mm)- 0.047 Flushing rate (kg/cm$^3$) + 1.045 T on+ 0.002 T off

**Table: Analysis of Variance (ANOVA)**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Regression | 5 | 38.7993 | 7.7599 | 26.77 | 0.000 |
| Current (A) | 1 | 17.7013 | 17.7013 | 61.06 | 0.000 |
| Spark gap (mm) | 1 | 1.4422 | 1.4422 | 4.97 | 0.037 |
| Flushing rate ($kg/cm^3$) | 1 | 0.0098 | 0.0098 | 0.03 | 0.856 |
| T on | 1 | 19.6460 | 19.6460 | 67.77 | 0.000 |
| T off | 1 | 0.0001 | 0.0001 | 0.00 | 0.988 |
| Error | 21 | 6.0879 | 0.2899 | | |
| Total | 26 | 44.8872 | | | |

**Table 4.10: Model Summary**

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| **0.538425** | 86.44% | 83.21% | 77.80% |

**Table 4.11: Coefficients**

| Term | Coef | SE Coef | T-Value | P-Value | VIF |
|---|---|---|---|---|---|
| Constant | -1.85 | 1.22 | -1.52 | 0.143 | |
| Current (A) | 0.1983 | 0.0254 | 7.81 | 0.000 | 1.00 |
| Spark gap (mm) | -5.66 | 2.54 | -2.23 | 0.037 | 1.00 |
| Flushing rate ($kg/cm^3$) | -0.047 | 0.254 | -0.18 | 0.856 | 1.00 |
| T on | 1.045 | 0.127 | 8.23 | 0.000 | 1.00 |
| T off | 0.002 | 0.127 | 0.02 | 0.988 | 1.00 |

**Table : Fits and Diagnostics for Unusual Observations**

| Obs | Roughness (Ra) | Fit | Resid | StdResid |
|---|---|---|---|---|
| **10** | 6.815 | 5.803 | 1.012 | 2.11 R |

According to coefficient table Current, Spark gap and Ton were the factors that affected Surface roughness significantly. While at the same time the other factors were found to be insignificant.

## Conclusion

This comparative study utilized an efficient method for determining the optimum machining operation parameters of Electrical Discharge Machine in the different cases for Tool Wearing Rate and Surface Roughness through the use of the Response Process. The specimens chosen for the project work were High Carbon High Chromium Steel (HCHCR). The hardness tests on the specimen materials were conducted on the Hardness testing Machine at the Strength of Material laboratory, Department of Civil Engineering, S.S.E.T., SHIATS, Allahabad, India. The machining of specimen materials was performed on the Electrical Discharge Machine (EDM) machine (C-3822) at Rajat Engineering workshop, Kanpur, India.

**Conclusions can be summed up with following:**

i. The use of standard L27 orthogonal array, with five control parameters required three levels of each to design the experiment for the work pieces.
ii. In machining of HCHCR on EDM by copper tool, the cutting combination obtain for the optimal levels of the parameters were current (5Amp,10Amp,1Amp), spark gap (0.1mm, 0.15mm, 0.2mm), flashing rate ($0.5kg/Cm^3$, $1.0kg/Cm^3$, $1.5kg/Cm^3$), T On (4,5,6), T Off (6,7,8).

The present work has successfully demonstrated the application Regression method for experimental investigation of the effect of control parameters of EDM.

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