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Experimental Investigation of the Effect of Control Parameters of EDM using Regression Analysis

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ABSTRACT

In this paper illustration of the influence of input machining parameter material removal rate is 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 material removal rate (MRR). The objective of this paper is to study the influence of operating input parameters of copper electrode on material removal rate of HCHCR followed by optimization. The effectiveness of EDM process with copper electrode is evaluated in terms of material removal 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.

1. INTRODUCTION

1.1 Electrical Discharge Machining:

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. EDM founds its wide applicability in manufacturing of plastic moulds, forging dies, press tools, die castings, automotive, aerospace and surgical components As EDM does not make direct contact (an inter electrode gap is maintained throughout the process) between the electrode and the work piece it's eradicate mechanical stresses, chatter and vibration problems during machining .Varioustypes of EDM process are available, but here the concern is about die-Sinking (also known as ram) type EDM machines which require the electrode to be machined in the opposite shape as the one in the work piece. EDM originally observed by English Scientist Joseph Priestly in 1770.

1.2 Principle of Electrical Discharge Machine:

In this process the metal is removing from the work piece due to erosion case by rapidly recurringspark discharge taking place between the tool and work-piece. A thin gap about 0.025mm is maintained between the tool and work piece by a servo system. Both tool and work piece are submerged in a dielectric fluid. Kerosene/EDM oil/deionized water is very common type of liquid dielectric although gaseous dielectrics are also used in certain cases. The tool is made cathode and work piece is anode.

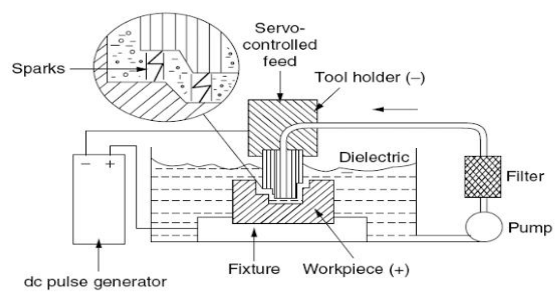

Fig. 1: Schematic diagram of Electrical Discharge Machine

When the voltage across the gap becomes sufficiently high it discharges through the gap in the form of the spark in interval of from 10 micro seconds and positive ions and electrons are accelerated, producing a discharge channel that becomes conductive. The moment spark occurs sufficiently pressure developed between work and tool as a result of which a very high temperature is reached and at such high pressure and temperature that some metal is melted and eroded. Such localized extreme rise in temperature leads to material removal. Material removal occurs due to instant vaporization of the material as well as due to melting. The molten metal is not removed completely but only partially. As the plasma channel collapse, it generates pressure or shock waves, which evacuates the molten material forming a crater of removed material around the site of the spark.

1.3 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.

v. T on: The duration of time (μs) the current is allowed to flow per cycle.

vi. T off: The duration of time (μs) between the sparks (that is to say, on-time).

1.4 Output Parameters:

i. Material removal rate: The volume of material removed divided by the machining time. Another way to define MRR is to imagine an "instantaneous" material removal rate as the rate at which the cross-section area of material being removed moves through the work piece.

2. 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).

2.1 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)

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

iii. NB (nominal-the-best)

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

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:

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

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:

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

j = 1,2,3....,n k = 1,2,3....,n j ≠ k

Here, ρ_{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* ;σ_{Qj} andσ_{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: $\rho_{jk} = 0$ (There is no correlation)

H_0: $\rho_{jk} \neq 0$(There is correlation)

Step 3: Calculation of the Principal Component Score:

i. Calculation of the Eigen value and the corresponding eigenvector β_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:

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

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, β_{kj} and is the j^{th} element of eigenvector β_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

$$\Delta_{0,i}(k) = \{\frac{|x_0(k) - x_i(k)|}{|y_0(k) - y_i(k)|} \text{(vii)}$$

3. SURFACE ROUGHNESS MEASUREMENT TECHNIQUES

Surface roughness may be measured in two ways: contact and non-contact methods. Contact methods involve dragging a measurement stylus across the surface; these instruments are called profile meters.

Non-contact methods include: inferometry, confocal microscopy, focus variation, structure light, electrical capacitance, electron microscopy, and photogrammetric.

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3.1 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.

4. SPECIMEN MATERIAL:

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

4.1 High Carbon High Chromium Steel

Cold-work tool steels include the high-carbon, high-chromium steels or group D steels. These steels are designated as group D steels and consist of D2, D3, D4, D5, and D7 steels. These steels contain 1.5 to 2.35% of carbon and 12% of chromium. Except type D3 steel, all the other group D steels include 1% Mo and are air hardened. Type D3 steel is oil-quenched though small sections can be gas quenched after austenitization using vacuum. As a result, tools made with type D3 steel tends to be brittle during hardening. Type D2 steel is the most commonly used steel among the group D steels.

Fig. 2: High Carbon High Chromium Steel (HCHCR)

i. *Chemical Composition:*

Table : 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

Cutting tools used:

Copper: copper has properties, such as its high electrical conductivity, tensile strength, ductility, creep (deformation) resistance, corrosion resistance, low thermal expansion, high thermal conductivity, solder ability, and ease of installation.It is a ductile metal with very high thermal and electrical conductivity. Pure copper is soft and malleable.

Fig. 3: Copper (Tool)

5. STRATEGY OF CONDUCTING EXPERIMENTS:

5.1 Hardness Test: Hardness test was performed on High Carbon High Chromium Steel (HCHCR)

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. 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:

$$BHN = \frac{2P}{\pi D\left[D - \sqrt{D^2 - d^2}\right]}$$

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

$$BHN = \frac{2P}{\pi D\left[D - \sqrt{D^2 - d^2}\right]}$$

$$BHN = \frac{2x150}{\pi 3.5\left[3.5 - \sqrt{3.5^2 - 1.9^2}\right]}$$

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

BHN = 16.464

Table : Hardness Number value of the Specimen

S. no.	Specimen	BHN
1	High Carbon High Chromium Steel	16.464

5.2 Machining Operation on Electrical Discharge Machine:

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

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

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

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 as control log table.

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

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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

6. RESULTS AND DISCUSSION

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

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 seve treatment 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

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

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 output parameter is Material Removal Rate (MRR)

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 of f	MRR
1	5	0.10	0.50	4	6	6
2	5	0.10	0.50	4	7	10
3	5	0.10	0.50	4	8	10
4	5	0.15	1.00	5	6	28
5	5	0.15	1.00	5	7	72
6	5	0.15	1.00	5	8	1
7	5	0.20	1.50	6	6	89
8	5	0.20	1.50	6	7	5
9	5	0.20	1.50	6	8	52
10	10	0.10	1.00	6	6	153
11	10	0.10	1.00	6	7	108
12	10	0.10	1.00	6	8	120
13	10	0.15	1.50	4	6	8
14	10	0.15	1.50	4	7	28
15	10	0.15	1.50	4	8	30
16	10	0.20	0.50	5	6	20
17	10	0.20	0.50	5	7	48
18	10	0.20	0.50	5	8	58
19	15	0.10	1.50	5	6	70
20	15	0.10	1.50	5	7	79
21	15	0.10	1.50	5	8	183
22	15	0.15	0.50	6	6	185
23	15	0.15	0.50	6	7	161
24	15	0.15	0.50	6	8	237
25	15	0.20	1.00	4	6	29
26	15	0.20	1.00	4	7	6
27	15	0.20	1.00	4	8	75

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6.1 Regression Analysis for machining of High Carbon High Chromium Steel:

6.1.1 Regression analysis for HCHCR Steel for MRR:

Table : Analysis of Variance (ANOVA)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	88088	17618	15.51	0.000
Current (A)	1	31417	31417	27.66	0.000
Spark gap (mm)	1	7081	7081	6.23	0.021
Flushing rate (kg/cm^3)	1	2027	2027	1.78	0.196
T on	1	45804	45804	40.33	0.000
T off	1	1760	1760	1.55	0.227
Error	21	23850	1136		
Total	26	111938			

Table : Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
33.7002	78.69%	73.62%	63.91%

Table : Coefficients

Term	Coef.	SE Coef.	T-Value	P-Value	VIF
Constant	-255.0	76.1	-3.35	0.003	
Current (A)	8.36	1.59	5.26	0.000	1.00
Spark gap (mm)	-397	159	-2.50	0.021	1.00
Flushing rate (kg/cm^3)	-21.2	15.9	-1.34	0.196	1.00
T on	50.44	7.94	6.35	0.000	1.00
T off	9.89	7.94	1.24	0.227	1.00

Table : Response Table for Means of MRR of HCHCR

Level	Current(A)	Spark Gap(mm)	Flushing rate(kg/cm3)	T on	T off
1	30.33	82.11	81.67	22.44	65.33
2	63.67	83.33	65.78	62.11	75.44
3	113.89	42.44	60.44	123.33	85.11
Delta	83.56	40.89	21.22	100.89	27.67
Rank	2	3	5	1	4

By response table which shows that T on has the highest rank of 1. As a result of that T on was found to be the main effective factor which affects the MRR to the maximum extent. Therefore the obtained sequence indicates that T on has the highest effect on MRR followed by Current (2), Spark gap (3), T off (4) and Flushing rate (5).

Regression Equation

MRR = -255.0 + 8.36 Current (A) - 397 Spark gap (mm)) - 21.2 Flushing rate (kg/cm^3) + 50.44 T on + 9.89 T off

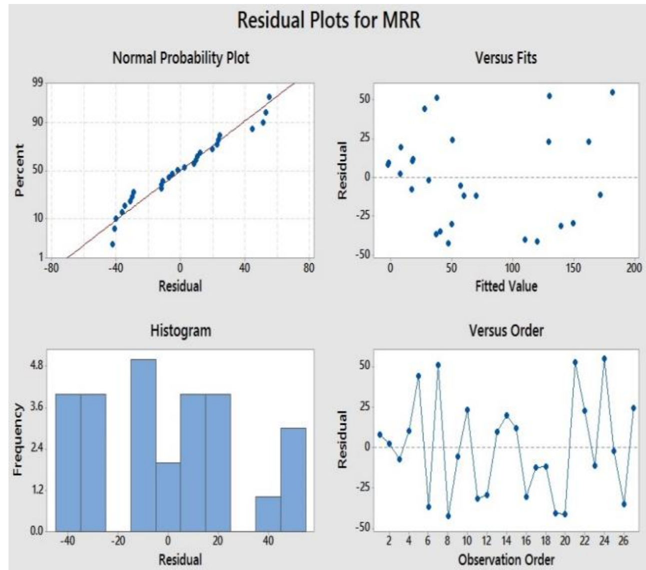

Fig. 4: Residual plots for Material Removal Rate of HCHCR

According to ANOVAtable Current, Spark gap and Ton were the factors that affected Material removal rate significantly. While at the same time the other factors were found to be insignificant.

7. COMBINATION OF THE OPTIMAL LEVELS OF THE PARAMETERS

7.1 Combination of the optimal levels of the Parameters for HCHCR

Table : Combination of the optimal levels of the Parameters of MRR for HCHCR

S. no	Current (A)	Spark Gap (mm)	Flushing rate (kg/cm^3)	T on	T off	MRR
1	15	0.15	0.5	6	8	273

The maximum MRR will obtained when the above combination of the levels of the parameter is run

8. CONCLUSION

According to ANOVA table Current, Spark gap and Toff were the factors that affected MRR significantly. While at the same time the other factors were found to be insignificant.

This comparative study utilized an efficient method for determining the optimum machining operation parameters of Electrical Discharge Machine in the different cases for Material Removal Rate. The specimens chosen for the project work was High Carbon High Chromium Steel (HCHCR). The hardness test on the specimen material was 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).

iii. The combination of the optimal levels of the parameters for maximum MRR of the HCHCR was found in experimental run no 24 in the table.

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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