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Development and Comparison of Mathematical Model for EN19 Material Using Statistical Analysis Software on WEDM

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Abstract: *Wire cut EDM (WEDM) is a thermo electric nontraditional manufacturing process in which material is removed by localized heating and melting. It is discrete spark generation method applicable for hard and difficult to machine materials. In this paper mathematical model developed for EN19 material with Stastical analysis software. Experiments are carried out using L27 Orthogonal array by varying Material Thickness, pulse on time, Pulse Off time, Flushing Pressure, Wire Tension and Servo voltage. Analysis found that varying parameters are affected for consumable wire with constant wire feed in different way for different response. Attempt to compare different order mathematical model for accurate modeling done in this research. Higher order mathematical model developed with* R^2 *value 0.9863 for MRR and 0.9918 for Surface roughness obtained which gives more accurate output for given input parameters.*

Keywords*-WEDM, PULSE ON TIME, PULSE OFF TIME, MRR, REGRESSION*

I. INTRODUCTION

WEDM is a non conventional thermo electric material removal method for conductive materials to cut intricate shapes and profiles with a thin wire electrode. The electrode is a thin wire of a diameter 0.05 to 0.25 mm copper or brass coated with molybdenum. As wire feeds from reel to reel, material is eroded from work material by a series of discrete sparks occurring between the work piece and the wire under the presence of dielectric fluid which is continuously fed to the machining zone [1]. The WEDM process makes use of electrical energy generating a channel of plasma between the cathode and anode [2] and turns it into thermal energy at a temperature in the range of 8000–12,000 °C [3]. When the pulsating direct current power supply occurring between 20,000 and 30,000 Hz is turned off, the plasma channel breaks down. This causes a sudden reduction in temperature allowing circulating dielectric fluid to implore plasma channel and flush molten particles from the pole surfaces in form of microscopic debris [4].Erosion of metals by spark was first reported by Joseph Priesily in 1978, however controlled machining by sparks was first introduced by Lazarenko in Russia in 1944. The first British patent was granted to Rudorff in 1950 [5]. In 1974 D.H. Dulebohn applied optical-line follower system to automatically control shape of component to be machined by WEDM process. By 1975, its popularity was rapidly increasing, as the process and its capabilities were better understood by the industry.

II. MATHEMATICAL MODELING

Regression analysis is used to investigate and model the relationship between a response variable and one or more predictors. The term multiple regression literally means stepping back toward the average. It was used by British mathematician Sir Francis Galton. Regression analysis is a mathematical measure of the average relationship between two or more variables in terms of the original units of the data. In regression analysis there are two types of variables. The value whose value is influenced or is to be predicted is called dependent variable and the variable which influences the values or is to be used for prediction is called independent variable. Regression analysis can be done in two ways;

A. **Bivariate regression**
B. **Multiple regression**

a) Bivariate regression

Two variables X and Y may be related to each other or inexactly. In physical sciences, variables frequently have an exact relationship to each other. The simplest relationship can be expressed by Y=a+Bx Where the values of the coefficient, a and b, determine respectively the precise height and steepness of the line. Thus coefficient a represent to as the intercept or constant, and coefficient b referred to as the slope. In contrast, relationship between variables in social sciences is almost always inexact. The equation for a linear relationship between two social science variables would be written as:
Y=a+bX+e , Where e represents the presence of error.

b) Multiple regression analysis

Multiple regression analysis is use when more than two parameters are used. In this research work, six control parameters were used. For multiple regression analysis various types of modeling tool used as shown in fig

c) Least squares principle

Least square principle tells us or identified best line which can fit the model. From the scatter plot we will calculate prediction error. It can calculate as:

Prediction error = observed error – predicted

Summing the prediction error for all observation would yield a total prediction error (TPE)

d) R^2 Value

This is called coefficient of determination indicates explanatory power of any regression model. Its value lies between +1 and 0. It can also been shown that R –sq is the correlation between actual and predicted value. It will reach maximum value when dependent variable is perfectly predicted by regression equation. 1 means the perfect 100% prediction.

e) Multi co linearity

Multi co linearity means that none of that independent variable or linear variable is perfectly correlated with another independent variable or linear combination of other independent variable .In multiple regression if there is co linearity among variables , then regression surface not even define Residual analysis. The prediction errors from a regression model are also called residuals. Analysis of these residuals can help us to detect the violations of certain regression assumption. It helps us to identify OUTLIERS and to improve the model. [6]

III EXPERIMENTAL PROCEDURE

A. Material specification

Wire-cut EDM is commonly used when low residual stresses are desired, because it does not require high cutting forces for removal of material. EN19 is a Chromium-Molybdenum low alloy steel. This can be used in the toughened condition. EN-19 offers high corrosion resistance, wear strength and high hardness. The chemical composition tested at MET-HEAT ENGINEERS PVT. LTD of the selected work material is shown in Table 1.

Table 1. Chemical composition of EN19

Chemical	% C	% Si	% Mg	% P	% S	% CR	% Mo
Obtained Value	0.430	0.289	0.696	0.038	0.057	1.148	0.234

B. Design of experiment based on Taguchi method

In this study analysis carried out by varying six control factors on Ultracut f1 machine of Electronica Pvt. Limited. Molybdenum coated brass wire of 0.25 mm diameter was used. Control factors along with their levels are listed in Table 2. Full factorial design of experiments would require a large no. of runs; Hence Taguchi based design of experiment method was implemented. In Taguchi method Orthogonal Array provides a set of well-balanced experiments, and Taguchi's signal-to-noise. (S/N) ratios, which are logarithmic functions of the desired output, serve as objective functions for optimization. It helps to learn the whole parameter space with a minimum experimental runs. Here Mathematical model developed with help of statistical analysis software design expert 8.0.6.

Table 2. Control parameters and their levels

Machining Process Parameter	Notation for modeling	Level 1	Level 2	Level 3
Material thickness (mm)	A	20	30	40
Pulse On Time(μs)	B	110	120	130
Pulse Off Time(μs)	C	40	50	60
Flushing Pressure (Kgf/cm^2)	D	10	12	14
Wire Tension (gms)	E	660	900	1140
Servo Voltage (volts)	F	20	30	40

C. Specimen detail

L27 Orthogonal array obtain based on the control factors. Total 27 nos. of experiments has been carried out by travelling electrode 8 mm in linear direction and then cut a piece of 5 mm x 5 mm from Dia. 60 mm EN19 material. Wire feed and Peak current selected as constant. Specimen after machining for each thickness level shown in fig 1. Mass of material removal is calculated based on mass difference and theoretically based on kerf width. MRR is calculated based on it in mm^3/min. Surface roughness measured precisely with help of roughness tester Mitutoyo SJ-201P[8].

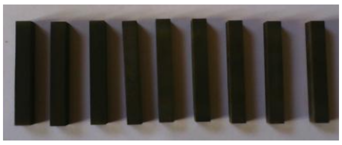



Fig. 1 Specimen after Machining: Size - Dia. 60mm and Thickness 40 mm

IV RESULTS AND ANALYSIS

Table 3. Taguchi Orthogonal L27 Array and result of MRR and surface finish

Ex pNo.	Input Parameters						Output Parameters	
	Mat. Thickness (A)	Pulse on time (B)	Pulse Off time (C)	Flushing Pressure (D)	Wire Tension (E)	Servo voltage (F)	MRR mm^3/min	Surface Roughness (Ra)
1	20	110	40	10	660	20	14.99	2.76
2	20	110	40	10	900	30	16.98	2.92
3	20	110	40	10	1140	40	13.91	2.8
4	20	120	50	12	660	20	19.24	2.2
5	20	120	50	12	900	30	15.41	3.14
6	20	120	50	12	1140	40	19.77	2.91
7	20	130	60	14	660	20	21.51	2.4
8	20	130	60	14	900	30	22.97	3.2
9	20	130	60	14	1140	40	20.55	3.01
10	30	110	50	14	660	30	9.03	2.56
11	30	110	50	14	900	40	9.95	2.78
12	30	110	50	14	1140	20	9.59	2.82
13	30	120	60	10	660	30	15.45	2.56
14	30	120	60	10	900	40	16.73	3.1
15	30	120	60	10	1140	20	13.83	2.19
16	30	130	40	12	660	30	20.13	3.21
17	30	130	40	12	900	40	24.84	3.1
18	30	130	40	12	1140	20	21.74	3.08
19	40	110	60	12	660	40	4.82	1.9
20	40	110	60	12	900	20	7.06	2.03
21	40	110	60	12	1140	30	5.89	2.64
22	40	120	40	14	660	40	21.6	2.03
23	40	120	40	14	900	20	32.3	2.32
24	40	120	40	14	1140	30	32.76	2.7
25	40	130	50	10	660	40	18.55	2.77
26	40	130	50	10	900	20	21.03	2.34
27	40	130	50	10	1140	30	23.83	2.95

D. Modeling and interpreting the experimental data:

Statistical analysis software offers a wide range of analytical and graphical techniques for model fitting and interpretation. Design descriptions, analyses and generating mathematical model for designed experiments are best done with coded factors through design expert 8.0.6. Coding reduces the range of each factor to a common scale, generally -1 to +1, regardless of its relative magnitude. Scaling establishes factor levels that can be orthogonal (or nearly so). For example, one factor may vary from 110 to 130 (pulse on time) while another varies from 600 to 1140 (wire tension). Typical coding has -1 as the lower level of a factor, +1 as the upper level, and 0 as the middle level. The values used for coding are called contrasts. The default contrasts generate coefficients that have simple interpretations [9]. During analysis process required to decide categorical factors among two nominal and ordinal. Nominal: (default) this type of factor is one that simply uses names or classes to describe the levels, for instance name of parameter types.

This research work suits 3-level ordinal categorical factor.

Table 4.0 Defined coded value

Value	[1]	[2]
Minimum	-1	1
Middle	0	-2

Maximum	1	1

Here, the coefficient [1] represents the linear component and [2] represents the quadratic component [9]. Also during process of analysis software convert actual value to coded value by linear equation using equation as shown in equation 1.1.

$$X_{Coded} = \frac{X_{Actual} - \bar{X}}{(X_{Hi} - X_{Low})/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 1.1$$

Whereas convert actual value to coded value by quadratic equation [2] using equation as shown in equation 1.2

$$X_{Coded} = aX_{Actual}^{\;2} + bX_{Actual} + c \ldots\ldots\ldots\ldots\ldots\ldots 1.2$$

Where, X_{Coded} =Factor value generated for software processing

X_{Actual} = Actual value of factor

$\bar{X}$ = Mean value of factor level

X_{Hi} = Highest value of factor level

X_{Low} = Lowest value of factor level and a, b, c are constant and found by loop mathematical method.

(A) Linear Regression Model

MRR = 16.87925926 +0.139444444 * A +5.718333333 * B - 3.913333333 * C +0.693333333 * D +0.919444444 * E -0.587222222 * F
(R-Squared = 0.7069)

SR = 2.698055556 -0.203333333 * A +0.158333333 * B -0.105 * C -0.015833333 * D + 0.150555556 * E + 0.125555556 * F
(R-Squared = 0.5388)

(B) Quadratic Model

MRR = 19.85694444 + 0.943055556 * A +0.895555556 * B - 5.872222222 * C -2.6975 * D +1.007222222 * E + 0.128888889 * F -3.917777778 * A * B -9.645555556 * A * C +1.432222222 * A * E -0.264444444 * A * F + 0.345 * B * C -0.014444444 * B * E +1.317777778 * B * F -1.758888889 * C * E +0.925555556 * C * F -0.22 * D * E +1.262222222 * E * F +2.006944444 * A^2 -1.387222222 * E^2
(R-Squared = 0.9773)

SR = 2.516388889 -0.411944444 * A +0.323333333 * B -0.05 * C +0.094166667 * D -0.067916667 * E +0.415555556 * F +0.11 * A * B +0.33 * A * C +0.58 * A * E -0.481111111 * A * F +0.098333333 * B * C -0.146944444 * B * E +0.139444444 * B * F -0.036388889 * C * E +0.230555556 * C * F -0.022083333 * D * E -0.515555556 * E * F -0.001388889 * A^2 +0.108888889 * E^2
(R-Squared = 0.9503)

(C) Cubic Polynomial Model

MRR = 19.64777778 + 0.813888889 * A +0.895555556 * B -5.970555556 * C-2.746666667 * D +0.253888889 * E +0.387222222 * F -3.917777778 * A * B -9.645555556 * A * C +1.432222222 * A * E -0.781111111 * A * F +0.345 * B * C +0.725555556 * B * E +0.949444444 * B * F -0.133888889 * C * E -0.081111111 * C * F +0.275 * D * E +1.003888889 * E * F +2.136111111 * A^2 -1.128888889 * E^2 +0.5 * A * B * E +0.736666667 * A * B * F -1.27 * A * C * E +2.013333333 * A * C * F -0.775 * B * C * E +0.295 * B * E * F
(R-Squared = 0.9863)

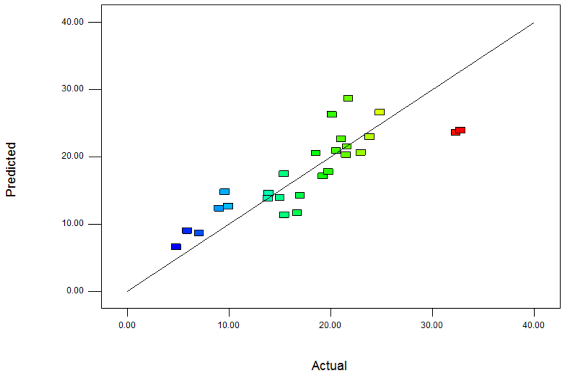
SR = 2.422638889 -0.444027778 * A +0.323333333 * B +0.009166667 * C +0.12375 * D

-0.109583333 * E +0.479722222 * F +0.11 * A * B +0.33 * A * C +0.58 * A * E
-0.609444444 * A * F +0.098333333 * B * C -0.326944444 * B * E+ 0.170277778 * B * F
-0.013888889 * C * E +0.312222222 * C * F -0.044583333 * D * E -0.579722222 * E * F
+0.030694444 * A^2 +0.173055556 * E^2 +0.27 * A * B * E -0.061666667 * A * B * F
-0.135 * A * C * E -0.163333333 * A * C * F -0.1925 * B * C * E -0.1775 * B * E * F

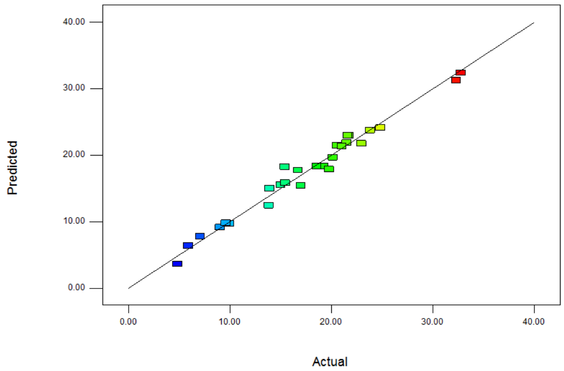
(R-Squared= 0.9918)

Comparison (Actual and Prediction Result)

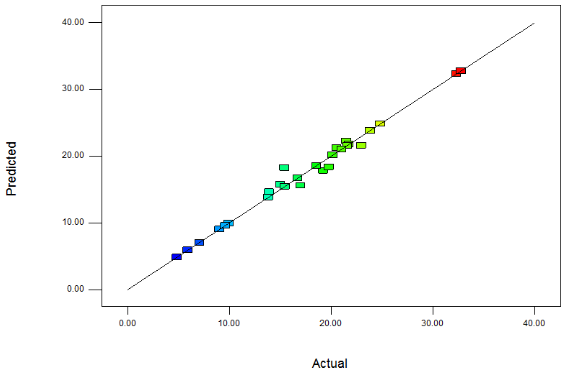
1) Comparison between actual and prediction result for MRR



Linear regression model



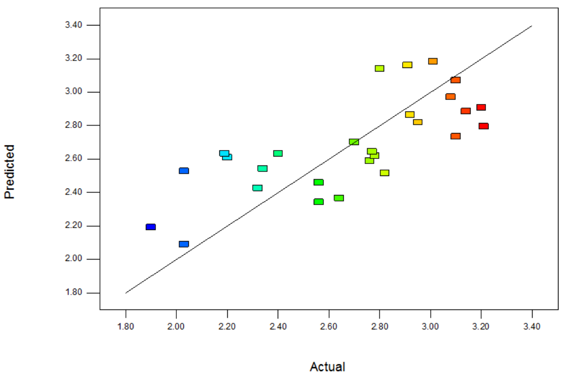
Quadratic model

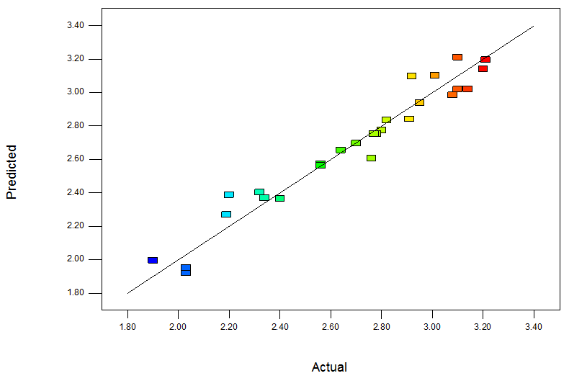


Cubic polynomial model

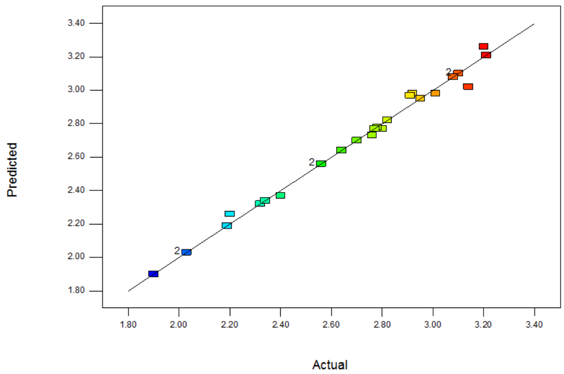
Results obtained with above three models are compared with their modeling strength for MRR. In regression model the results are away from the reference line, means more residual error leads less accuracy. The accuracy of any model can be defined with its R^2 value. If R^2 value reaches 1, that model will be most accurate. In regression analysis for MRR the R^2 value obtains is 0.7069. In quadratic model the pattern obtained become more oriented towards line. R^2 value obtain is 0.9773. In cubic polynomial model the plotted data almost fall on line, shows this higher order model predicts with much accuracy. The R^2 value of this model is 0.9863.

2) Comparison between actual and prediction result for Surface roughness





Linear regression model ***Quadratic model***



Cubic polynomial model

Results obtained with above three models are compared for surface roughness prediction with their modeling strength. In regression model the results are away from the reference line, means more residual error are their which leads less accuracy. The accuracy of any model can be defined with its R^2 value. If R^2 value is 1, that model will be most accurate. In regression analysis for Surface roughness the R^2 value obtains is 0.5388. In quadratic model the pattern obtained become more oriented towards line. R^2 value obtain is 0.9503. In cubic polynomial model the plotted data almost fall on line, shows this higher order model predicts with much accuracy. The R^2 value of this model is 0.9918.

V. CONCLUSION

WEDM is Nontraditional machining methods in which setting of process parameters affects on outcome response. A little change in one parameter, greatly affects the response. Mathematical model help to analyze the input parameter selection. Cubic polynomial model gives R^2 value 0.9863 for MRR and 0.9918 for surface roughness. Hence among three models, Cubic polynomial model will be the most accurate.

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