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Optimization of Surface Roughness using Response Surface Methodology for EN31 Tool Steel EDM Machining

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***Abstract*— The present work demonstrates the optimization process of surface roughness of electrical discharge machining (EDM) by using Response Surface Methodology (RSM). The work piece material was EN31 tool steel. The pulse on time, pulse off time, pulse current and voltage were the control parameters of EDM. RSM method was used to design the experiment using rotatable central composite design as this is the most widely used experimental design for modeling a second–order response surface. The surface roughness parameters like, root mean square (R_q), skewness (R_{sk}), kurtosis (R_{ku}) and mean line peak spacing (RS_m) are considered for modeling. The process has been successfully modeled using response surface methodology (RSM) and model adequacy checking is also carried out. The second-order response models have been validated with analysis of variance.**

***Keywords* —Electrical Discharge Machining, Response Surface Methodology, Surface Roughness, Response equations.**

I. BACKGROUND

Electrical discharge machining (EDM) is a non-traditional machining technique, which is widely used to produce finish parts through the action of an electrical discharge of short duration and high current density between the tool work pieces. The tool and the work piece are free from the physical contact with each other. Generally, the EDM is used for machining of electrical conductive materials in the presence of a dielectric fluid. It can also be used for machining of difficult-to-machine shapes and materials. The electrical discharge machining process is widely used in the aerospace, automobile, die manufacturing and plastic mould industries to machine hard metals and its alloy [1]. The basic principle in EDM is the conversion of electrical energy into thermal energy through a series of discrete electrical discharges occurring between the electrode and work piece immersed in the dielectric fluid. The insulating effect of the dielectric is important in avoiding electrolysis of the electrodes during the EDM process.

The prediction of optimal machining conditions for good surface finish plays a very important role in process planning. Spedding and Wang [2] have attempted to optimize the process parametric combinations by modeling the process using ANN and characterize the surface in wire electrical discharge machining (WEDM) on AISI 420 through time series techniques. Zhang et al. [3] have investigated the effects on material removal rate, surface roughness and diameter of discharge points in electro-discharge machining (EDM) on ceramics. From the experimental results, they have shown that the material removal rate, surface roughness and the diameter of discharge point all increase with increasing pulse-on time and discharge current. Tsai and Wang [4] have established a semi-empirical model of surface finish on work for various materials (three different grades of steel) in electrical discharge machining and the parameters of the model viz. peak current, pulse duration, electric polarity and properties of materials have been fitted based on the experimental data using Taguchi method. It is seen that the developed model is dependent on work and tool materials. Tsai and Wang (4) have developed and compared models for prediction of surface finish in EDM process on aluminium and iron work-pieces based upon neural networks and a neuro-fuzzy network. Lee and others (5) have studied the influence of operating parameters of EDM of tungsten carbide on material removal rate, relative wear ratio and the surface quality of the work-piece produced. Routara et. al. (6) developed the roughness models of EDM process for three different roughness parameters using response surface method. Study shows that the machining parameters, pulse current and pulse on time have the maximum influence on the roughness parameters while pulse of time has no significant effect on roughness parameters.

The objective of this paper is to study the influence of machining parameters of EDM on EN 31 tool steel using electrolyte copper for optimising surface roughness characteristics.

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The second order mathematical models in terms of machining parameters are developed for MRR prediction using response surface methodology (RSM) on the basis of experimental results.

II. EXPERIMENTAL DETAILS

The selection of appropriate machining conditions for EDM characteristics, such as material removal rate and surface roughness are based on the analysis relating the various process parameters to material removal and roughness. Undertaking frequent tests or many experimental runs are also not economically justified. Experience revealed that the type of material yields more influence on the EDM performance.

The influence of pulse current, pulse time, duty cycle, open circuit voltage and dielectric flushing pressure over the MRR and surface roughness on EN 31 tool steel have also been studied. Experiments are done as under using central composite second order rotatable design. As the number of variables is 4, a total of 31 experiments were planned for this investigation.

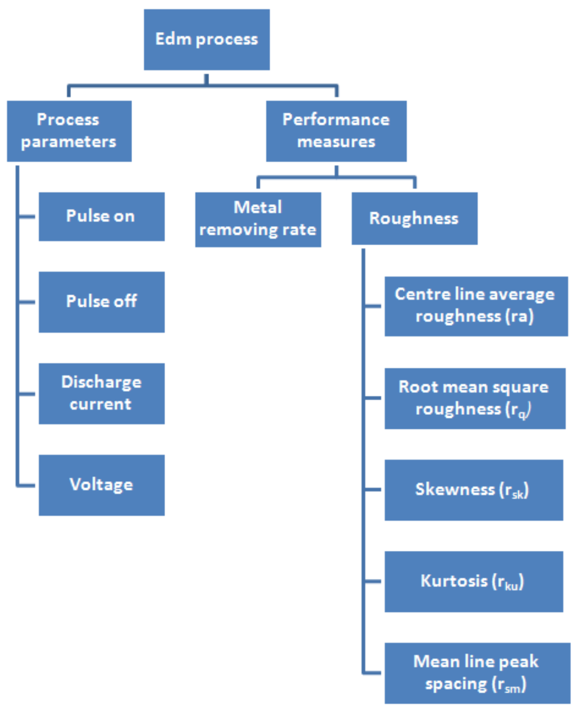

Fig.1.Process parameters & performance measure of EDM

Experiments were carried out using CNC EDM (EMT 43) Electronica die sinking machine. Table II shows the specification of die sinking EDM machine.

Machine Used: CNC EDM (EMT 43) (Electronica)
Electrode: Electrolytic Copper (99.9% Purity)
Electrode Polarity: Positive
Work piece: Oil Hardened Non Shrinking Steel
(48 – 50 R_C)
Dielectric: EDM oil

Fig.2. CNC EDM Used

EN 31 Tool Steel block of 22mmx 22mmx15mm size has been used as a work piece material for the present experiments. The chemical composition and mechanical properties of the work-piece materials are (weight %):

Carbon: 1.07, Manganese: 0.58, Silicon: 0.32, Phosphorous: 0.04, Sulphur: 0.03, Chromium: 1.12, Ferrous: 96.84. An electrolytic pure copper with 25 mm X 25 mm is used as a tool electrode (positive polarity).

The machining parameters and their levels are shown in Table I.

Surface roughness describes the morphological features on a real surface. Any real surface is not planar but covered with microscopic hills, valleys, and even scratches. Surface roughness is a bulk measure of the average size of the hills and valleys. Some surfaces

Table I. Machining parameters and levels appear smooth and planar to the naked eye when in fact the real shape is composed of a semi-infinite number of irregular forms. The contact method which is based on a stylus traversing the surface is used to measure the surface roughness of EN 31 tool steel.

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Center line average, Root mean square roughness, skewness, Kurtosis and Mean line peak spacing are the surface roughness parameters measured. The surface roughness parameters on the machined surfaces are measured with the Talysurf (Make – Taylor Hobson, UK). The Talysurf instrument (Surtronic 3+) is a portable, self-contained instrument for the measurement of surface texture. The parameter evaluations are microprocessor based.

III. Methodology

Response surface methodology (RSM) is used to investigate the interaction between several illustrative variables and one or more response variables. Box and Draper [9] were introducing RSM in 1951.The most important purpose of RSM is to use a series of designed experiments to attain an optimal response. A second-degree polynomial model is use in RSM. These models are only an approximation, but used because such a model is easy to estimate and apply, even when little is known about the process. The process of RSM includes designing of a series of experiments for sufficient and reliable measurement of the response and developing a mathematical model of the second order response surface with the best fittings. Obtaining the optimal set of experimental parameters, thus produce a maximum or minimum value of the response. The Minitab Software was used to analyze the data [10]

IV. Results And Discussions

4.1 Result and discussion for centre line average (R_a)

Based on the experimental data gathered, statistical regression analysis is carried out to study the correlation of process parameters with Ra. The various process parameters and their levels is indicated in table. ANOVA table for various input process parameters is shown in Table II.

Table I: Process parameters & levels

Table II.
ANOVA table for R_a

Term	Coeff	SE Coeff	T	P
Constant	11.0648	0.13955	79.29	0
A	0.496	0.1027	4.829	0
B	-0.1428	0.1027	-1.391	0.177
C	1.1833	0.1027	11.522	0
D	-0.0392	0.1027	-0.381	0.706
C*C	-0.2807	0.09312	-3.014	0.006
D*D	0.2433	0.09312	2.613	0.015
S = 0.503145 PRESS = 15.9615		R-Sq = 87.97% R-Sq(pred) = 68.41% Sq(adj) = 84.97%		

After eliminating the non-significant terms, the final response equation for Ra is given as follows:

$$R_a = (11.0648) + (0.496 \times T_{on}) - (0.1428 \times T_{off}) + (1.1833 \times I_p) - (0.0392 \times V) - (0.2807 \times I_p^2) + (0.2433 \times V^2)$$

Table I gives the levels of process parameters indicated in the above equation

The main effects plot is shown in Fig indicating that current is the most significant parameter in deciding the center line average roughness parameter.

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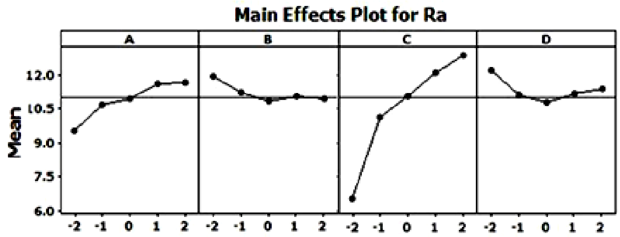

Fig.3. Main effects plot R_a

Model adequacy checking is done by normal probability and residual plots confirming the adequacy of the quadratic model proposed.

The surface response models plotted indicate that I_p and T_{on} are directly proportional, and T_{off} is inversely to the R_a for the given range of experiments conducted for our test.

Confirmation tests are carried out to check the prediction capability of the model and results are presented in table. It is observed that the calculated error is small (about 3%) This confirms the reproducibility of experimental conclusion.

Table III.
Conformation test result of Ra and comparison with predicted result as per model

T_{on} (µs)	T_{off} (µs)	I_p (A)	V (Volt)	Surface Roughness (R_a)µm		
				expt	predicted	error (%)
400	1800	16	80	12.980	12.525	3.508
300	1700	12	60	10.946	11.065	-1.08533
200	1600	8	40	9.514	9.5301	-0.169

Finally an optimum condition is obtained from RSM with an objective of minimum Ra within the experimental range and the levels of the process parameters are Pulse on 100 µs, Pulse off 1900 µs, Current 4 A and Voltage 100 V.

Similar analysis was carried out for other surface roughness parameters and the results are as under:

4.2 Result and discussion for root mean square (R_q)

The pulse current appear to be very significant as evidenced by the main effects plot as in Fig.2

The response equation:

$$R_q = (13.3498) + (0.4642 \times T_{on}) - (0.2242 \times T_{off}) + (1.2778 \times I_p) - (0.1458 \times V) - (0.3812 \times I_p^2) + (0.2243 \times V^2)$$

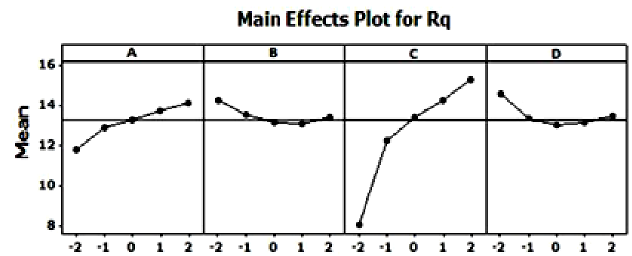

Fig.4 Main effects plot for R_q.

4.3. Result and discussion for skewness (R_{sk})

The pulse on time appear to be very significant as evidenced by the main effects plot though other factors also found to influence the response (Fig.3)

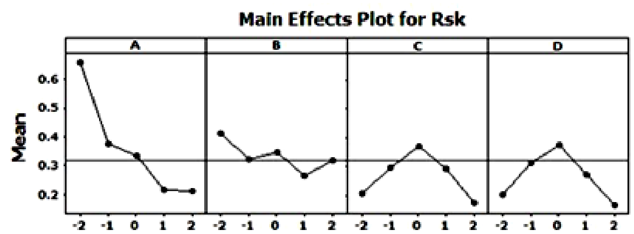

Fig.5 Main effects plot R_{sk}

The response equation:

$$R_{sk} = (0.388975) - (0.09486 \times T_{on}) - (0.02312 \times T_{off}) - (0.2429 \times I_p) + (0.000984 \times V) - (0.05524 \times I_p^2) - (0.05322 \times V^2)$$

4.4. Result and discussion for kurtosis (R_{ku})

The main effects plot indicates that the current is most significant, pulse on and voltage are quite significant and pulse off is non significant. Fig.4 shows the main effects plot for this.

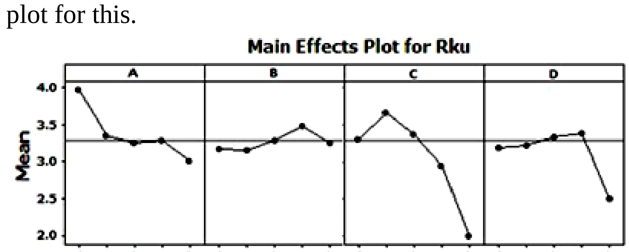

Fig.6 Main effects plot R_{ku}

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The response equation:

$$R_{ku}= (3.58940)-(0.07879 \times T_{on}) + (0.12912 \times T_{off}) - (0.31763 \times I_p)-(0.04129 \times V)-(0.20682 \times I_p^2) - (0.15832 \times V^2)$$

4.5 Result and discussion for mean peak line spacing (R_{sm})

The pulse current appear to be very significant as evidenced by the main effects plot, also other factors have influence on the response. Fig.5 shows the main effects plot for mean peak line spacing.

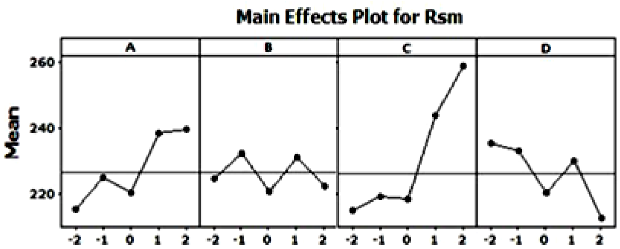

Fig.7 Main effects plot for R $_{sm}$

The response equation:

$$R_{sm}= (213) +(6.592 \times T_{on}) – (0.575 \times T_{off}) + (11.925 \times I_P) - (2.908 \times V) + (4.123 \times T_{on}^2) + (3.148 \times T_{off}^2) + (6.623 \times I_P^2) + (3.373 \times V^2) – (3.3788 \times T_{on} \times V) – (3.462 \times T_{off} \times V)$$

For the above five roughness parameters optimum parameters for each parameter was arrived at, followed by a confirmation experiment to validate the results.

V. CONCLUSION

Experimental investigation on electrical discharge machining of EN 31 tool steel is performed with a view to correlate the process parameters with the responses such as R_a, R_q, R_{sk}, R_{ku} and RS_m.The following are the conculsions

(i) process model using RSM and result validate.model adequacy checking is also done.
(ii) The various 2nd order response equation have been modeled and validated with ANOVA
(iii) The optimum level of process parameter for five surface roughness measurement has been arrived at followed by conformation experiment for validation.

This study can help researchers and industries for developing a robust, reliable knowledge base and early prediction surface roughness without experimenting with EDM process for EN 31 tool steel.

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