MODELING AND PARAMETRIC OPTIMIZATION IN COATED WIRE ELECTRIC DISCHARGE MACHINING OF TOOL STEEL THROUGH RESPONSE SURFACE METHODOLOGY

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ABSTRACT

A study has been made to optimize the process parameters of wire-EDM of tool steel using zinc coated wire. Electric Discharge Machining (EDM) has been used for machining of electrically conductive difficult materials. Wire EDM is a kind of EDM where a wire is used to act as the tool and due to erosion, machining takes place. Generally, Brass and Copper wires are effectively used for machining but it was found that the productivity and characteristics for coated wires had better results hence coated wires (zinc) will be used. Some authors used coated wires and claimed to receive a 25% re-cast layer. This present research investigates optimization, design of WEDM process performed on the Tool Steel EN8. The major performance characteristic that to be evaluated is Material Removal Rate (MMR). The corresponding parameters acting as the input are Current, Pulse on Time and Pulse off Time. RSM design called central composite design (CCD) has been utilized to plan the experiment and Response Surface Methodology is implied for developing experimental model. Analysis on machining characteristics of coated WEDM was made based on developed model. ANOVA test will be carried out as well to check the adequacy of developed regression models.

Keywords: WEDM, Coated Wire, Tool Steel EN31, Central Composite Design, Response Surface Methodology

I. INTRODUCTION

WEDM is a thermoelectric process in which heat energy of a spark is used to remove material from the work-piece using a wire, where both wire and work-piece are electrically conductive. The material is removed in the form of debris by means of a series of recurring electrical discharges (created by electric pulse generators in micro seconds) between the wire and the work material in the presence of a dielectric fluid (kerosene, distilled water). The dielectric serves some important functions viz, cools down the tool and work-piece, cleans or flushes away the inter-electrode gap and localizes the spark energy into a small cross-sectional area. Effective flushing of dielectric removes products from the gap. An Ineffective flushing, results in low MRR and poor surface finish. The effective flushing may increase MRR as much as by a factor of 10 or so [*Koshy et al*, *1993*]. A spark is produced between the two electrodes and its location is determined by narrowest gap between the two. The material erosion mechanism primarily makes use of electrical energy and turns it into thermal energy through a series of discrete electrical discharges occurring between the electrode and work piece immersed in a dielectric liquid medium [Tsai, H.C. 2003]**.** A constant gap between tool and work-piece is maintained with the help of a computer controlled positioning system. This system is used to cut through complicated contours especially in difficult to machine materials. This process gives a high degree of accuracy and a good surface finish. Wire EDM has been employed for making dies of various types. It is possible of control tolerances very effectively. This process is also used for fabrication of press tools and electrodes for use in other areas of EDM. The wires generally used are of brass or copper of diameter about 0.5-0.30mm, but in recent times coated wires are widely used, usually zinc coated over brass wire. The impact of coated wires was found to have a significant effect. The productivity and surface roughness were obtained to be better than uncoated wires [Antar et al. (2011)].Coated wires are stated to protect the core from thermal shock and also from wire rupture as well. Its other effects were found on vibration, dumping effect, heat transfer and resistance which ultimately increased the machining speed [Jatinder Kapoor (2010)]**.** Wire is discarded after it has been used once because the sparking takes place at its leading surface hence, it no longer remains round.

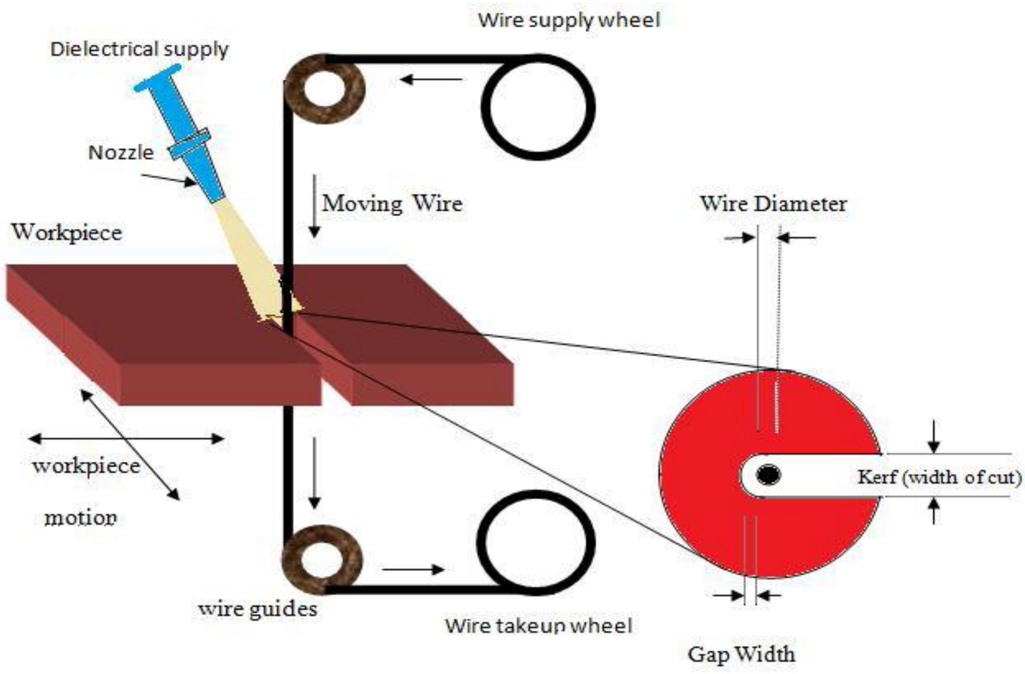

Figure1. Detailed View of WEDM (Rao Sreenivasa Et Al.)

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II. EXPERIMENTAL WORK

Experiments were conducted on SPRINTCUT WEDM in Noida Sec. 10.The material used for present investigation is EN31 block of 25mm x 28.4mm x 11.6mm. The electrode used is a zinc coated brass wire of 0.25mm diameter and dielectric of distilled water. The machining was done for 5 minutes for each run and the initial weight and final weight were noted in order to calculate the MRR (gm/min) using the following formula-

$$MRR = \frac{\text{Initial weight- Final weight}}{\text{Time Taken}} \quad (1)$$

2.1 Design Of Experiments

The machining parameters for Tool steel EN31 as current (190-230amps), pulse on time (115-127), pulse off time (42-44) and wire tension (1-5 kgf). The model to be created shall use CCRD experimental design where standard error is kept the same for all points that are at the same distance from center of the region. It requires five levels of all control factors for calculation of regression coefficients. The coded values for different levels in CCRD are -2,-1, 0, 1, 2 as shown in table 1. The total number of runs required in CCRD is:

$$N = 2^k + 2k + n_{c,} \quad (2)$$

Where N stands for total number of runs, k is the number of variables which in this case in 4 and n_c is the total number of center points which in a standard CCRD matrix is 7. The total number of runs now selected is calculated as: $2^4 + 2*4 + 7 = 31$ and shown in table 2.

Table 1: Parameters with Levels

Factors	Level 1	Level 2	Level 3	Level 4	Level 5
	-1.682	-1	0	1	1.682
Ton (A)	115	118	121	124	127
Toff (B)	42	44	46	48	50
Ip (C)	190	200	210	220	230

2.2 Response Surface Methodology

It is a collection of statistical and mathematical techniques useful for developing, improving and optimizing processes. The field of RSM consists of experimental strategy for exploring the space of the process or independent variables, empirical statistical modeling to develop an appropriate approximating relationship between yield and the process variables and optimization methods for finding values of the process variables that produce desirable values of the response[()].In order to study the effects of the EDM parameters on the above mentioned machining criteria, second order polynomial response surface mathematical models can be developed. In the general case, the response surface is described by an equation of the form:

$$Y = \beta_o + \sum\beta_j x_j + \sum\beta_{jj}x^2_j + \sum\sum\beta_{ij}x_i x_j \quad (3)$$

Where Y is corresponding response, which in current research is on MRR, Ra, whereas the terms $\beta_{o,}$ $\beta_{j,}$ β_{ij} are second order regression coefficients. The second term under the summation sign of this polynomial equation is attributable to linear effect, whereas the third term corresponds to the higher-order effects; the fourth term of the equation includes the interactive effects of the process parameters. Eq. (2) can be rewritten as:

$$Y = \beta_o + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_{11}X_{12} + \beta_{22}X_{22} + \beta_{33}X_{32} + \beta_{44}X_{42} + \ldots.. \quad (4)$$

The value of β, the regression coefficient, will be determined by least square method.

III. RESULTS AND DISCUSSION

Analysis were made using RSM to find the mathematical regression model for MRR and cutting speed using the data that was accumulated while machining. Interactions of the process parameters were also noted and studied. Using MINITAB 17 a mathematical model relating MRR to its process parameters as mentioned in Table 2 with its symbols was obtained as follows;

For MRR,

$$MRR = 0.001195 + 0.000278\ A - 0.000125\ B + 0.000143\ C - 0.000157\ A*A - 0.000047\ B*B - 0.000071\ C*C - 0.000074\ A*B - 0.000039\ A*C - 0.000003\ B*C \quad (1)$$

Where, A is Pulse On time (Ton), B is Pulse Off time (Toff) and C is Peak Current.

Investigations were made using RSM to find the mathematical regression model for MRR and SR using the data that was accumulated while machining. Interactions of the input parameters were also noted and studied. Using MINITAB 17 a mathematical model relating MRR to its input parameters as mentioned in table.2 with its symbols was obtained as follows.

Table2. Response Values

Run No	Coded Input Factors				Material removal rate (gm/sec.)
	T_{on} (A) (µs)	T_{off} (B) (µs)	I_p (C) (A)	Cutting Speed (mm/min.)	
1	-1	-1	-1	1.2	0.000417
2	1	-1	-1	2.3	0.000935
3	-1	1	-1	0.5	0.00014
4	1	1	-1	1.3	0.00106
5	-1	-1	1	1.3	0.000514
6	1	-1	1	2.3	0.001575
7	-1	1	1	1.1	0.000922
8	1	1	1	1.6	0.00099
9	-1.682	0	0	0.65	0.000526
10	1.682	0	0	1.7	0.001258
11	0	-1.682	0	2.2	0.001615
12	0	1.682	0	1.1	0.000793
13	0	0	-1.682	1.2	0.000989
14	0	0	1.682	2.9	0.001286
15	0	0	0	1.6	0.001355
16	0	0	0	1.6	0.001253
17	0	0	0	1.7	0.001222
18	0	0	0	1.7	0.001131
19	0	0	0	1.5	0.001096
20	0	0	0	1.6	0.001064

For speed,

$$\text{Speed} = 1.6173 + 0.3343\,A - 0.3698\,B + 0.0785\,C - 0.1605\,A*A + 0.0074\,B*B - 0.0810\,C*C - 0.1750\,A*B - 0.1250\,A*C + 0.0250\,B*C \qquad (2)$$

When R^2 approaches unity, the response model fits the actual data better. R^2 for MRR was found to be 0.8150 and for SR it is 0.7121. Consequently the lack of fit also displays to be insignificant.

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3.1 Analysis of Material Removal Rate

MNITAB 17 was able to generate graphs that could help realize relationship between the responses and the input parameters. Two parameters were taken at a time leaving the other two parameters to be constant. We shall discuss the effects various parameters on MRR and cutting speed.

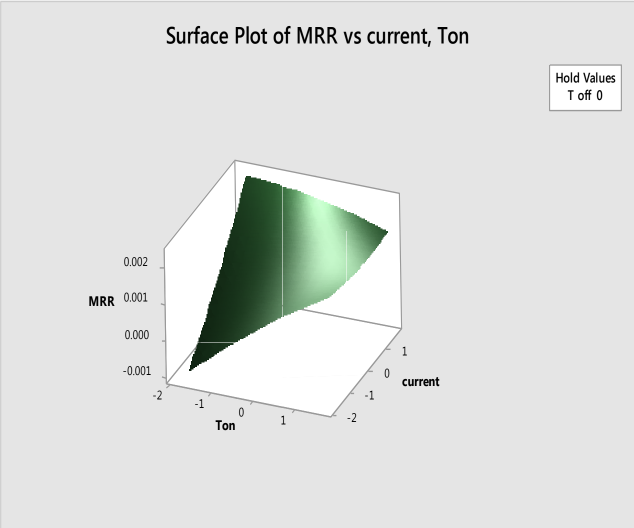
The effects of two process parameters or control factors on the response parameters are known as interaction effect. In Interaction plot, the two variable change keeping extra two input parameters on the central value and examine the response characteristics effect and the plot is known as the three-dimensional surface plot.

Table3. ANOVA Table for MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.000006	0.000001	11.66	0.000
Linear	3	0.000004	0.000001	25.52	0.000
Ton	1	0.000001	0.000001	20.94	0.001
T off	1	0.000000	0.000000	4.68	0.056
Current	1	0.000003	0.000003	50.93	0.000
Square	3	0.000000	0.000000	0.82	0.510
Ton*Ton	1	0.000000	0.000000	0.66	0.437
T off*T off	1	0.000000	0.000000	0.91	0.362
current*current	1	0.000000	0.000000	0.74	0.409
2-Way Interaction	3	0.000001	0.000000	8.64	0.004
Ton*T off	1	0.000000	0.000000	1.44	0.258
Ton*current	1	0.000001	0.000001	13.82	0.004
T off*current	1	0.000001	0.000001	10.64	0.009
ERROR	10	0.000001	0.000000		
Lack-of-Fit	5	0.000001	0.000000	8.35	0.018
Pure Error	5	0.000000	0.000000		
Total	19	0.000006			

The fit summary recommended that the quadratic model is statistically significant for analysis of MRR. The results of the quadratic model for MRR in the form of ANOVA are given in the table 3. The Analysis of Variance for MRR Table 3 expresses that the pulse on time (A), the pulse off time (B) and Peak current (C),The 2-way interaction terms (Ton Toff, Ton IP, Toff IP) and the Square terms (Ton Ton, Toff Toff, IP Ip) was significant parameters affecting MRR.

From Fig. 3.1 shows the effect of interaction of peak current (Ip) and pulse on time (Ton) on MRR. The Material removal rate increases with increase in peak current. Discharge energy increases by peak current to assist the action of melting and vaporization thereby increasing the MRR. However, after a point the MRR decreases with increase in peak current, this is due to the fact that with increase in Ip the debris formed is more and larger in size which result in gap between the electrodes, short circuiting which tends to reduce MRR. From Fig. 3.2 shows the effect of interaction of pulse on time (Ton) and pulse off time (Toff) on MRR**.** MRR increased with Ton and decreased with Toff. Since pulse off time is the pause of among discharges, there is no voltage between work piece and tool at that time so MRR decreases. While pulse on time increases the MRR since voltage is present between work piece and electrode and electric discharge take place. It recognized that MRR is relative to the energy consumed.



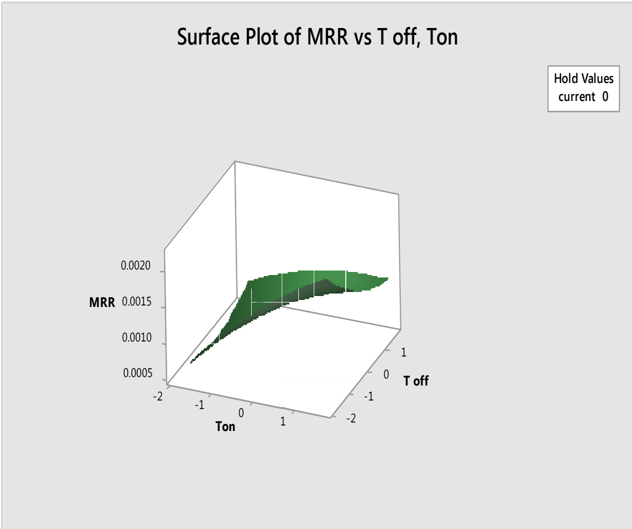


Fig3.1. Interaction Effect of Peak Current (Ip) and **Pulse on Time (Ton) on MRR Fig. 3.2 Interaction effect of Peak** Pulse off Time (Toff) **and Pulse on Time (Ton) on Material Removal Rate**

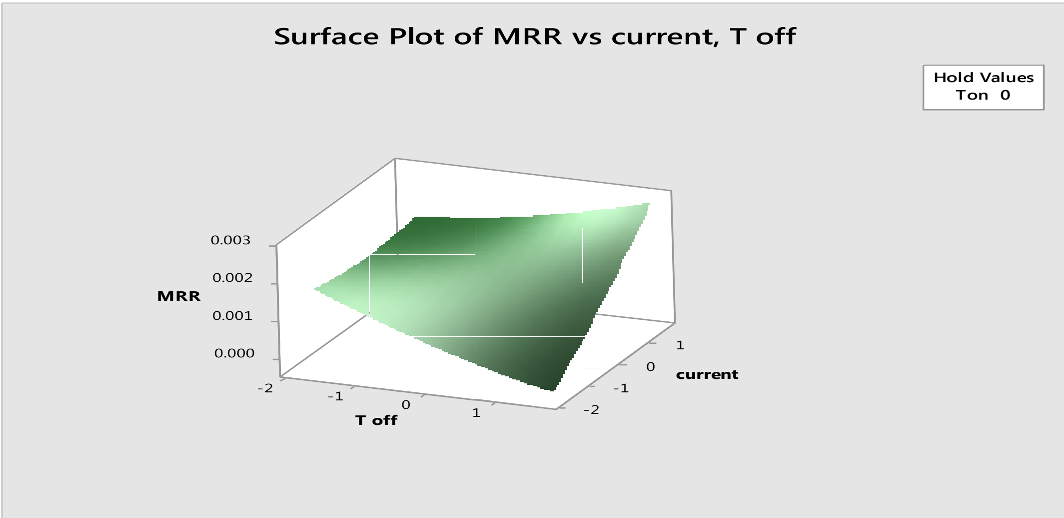


Fig. 3.3 Interactions effect of pulse off time (Toff) and peak current (ip) on MRR

From Fig. 3.3, shows the effect of interactions of pulse off time (Toff) and peak current (ip) on MRR**.** The MRR decreases with increase in the pulse off time values since pulse off time is the pause of among discharges, there is no voltage between work piece and tool at that time so MRR decreases and increases with increase in the Peak current values. If peak current setting is higher, larger is the discharge energy which ultimately leads to increase MRR.

3.2 Optimization Plot

Optimal solution is calculate by Minitab and draws the plot. The starting point is serves as the optimal solution for the plot. (Refer Table. 4). From the optimization plot it can be said that the maximum metal removal rate is 0.0012 mm^3/min.

Table4. Optimization Plot

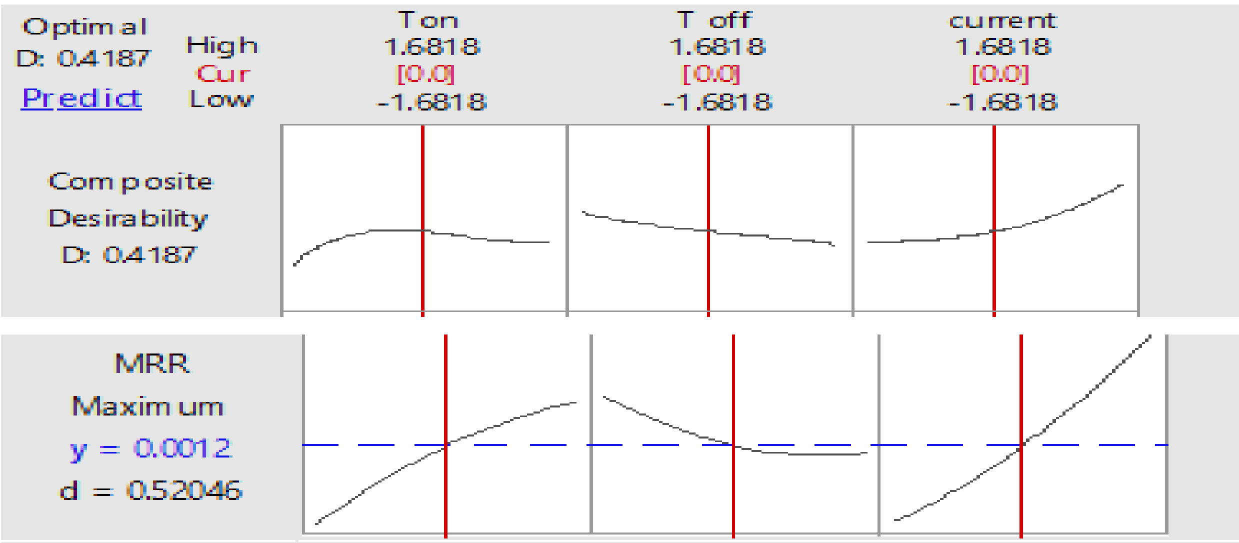


Table4. A maximum or minimum level is providing for each response characteristic, which has to be optimized.

Response	Goal	Lower	Target	Upper	Weight	Importance
MRR	Maximum	0.00014	0.00214		1	1

Table5. Solution of table 4

				ASR	Speed	MRR	Composite
	Ton	T off	current	Fit	Fit	Fit	Desirability
1	0	0	0	2.14863	1.61830	0.0011783	0.418677

3.3 Confirmation Experiment

In the present study, RSM are derived from quadratic regression fit, so to verify their validity confirmation tests are to be performed taking independent variables values within the range for which the formula were derived. Table 6 shows the result of the confirmation runs and their comparisons with predicted design for MRR. It is observed that the calculated error is small (within 10%). This confirms the reproducibility of experimental conclusion.

Table 6 Confirmation test result and comparison with predicted result as per model.

Response characteristics	Predicted optimal value of response characteristics	Confirmation values	Percentage error
Material removal rate	0.0012	0.0011	8.33%

IV. CONCLUSION

1. On the basis of the present experimental study, following conclusions can be drawn.
2. Wire-EDM of EN8 is feasible with zinc coated wire as electrode.
3. It shows that the Central composite design has a powerful tool for providing statistical-mathematical models and experimental diagrams, to accomplish the experiments appropriately and economically
4. Pulse on time and peak current are the most important parameters affecting the MRR cutting speed, surface roughness.
5. The second order regression model has obtained using RSM. It also predicts values for MRR, for different input parameter values that are not use in the CCRD matrix.
6. The main influence on MRR is found to be Pulse on time and Pulse off time which increases and then decreases after a certain point, even though significant influence of Current is witnessed over MRR but not as great as Pulse on time and Pulse off time.
7. The MRR increased with Ton and the Ton has the most influence on the MRR.
8. The peak current has very less influence on the MRR.

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