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Application of Response Surface Methodology For Determining MRR and TWR Model In Die Sinking EDM of AISI 1045 Steel

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ABSTRACT:

Whereas the efficiency of traditional cutting processes is limited by the mechanical properties of the processed material and the complexity of the workpiece geometry, electrical discharge machining (EDM) being a thermal erosion process, is subject to no such constraints. The base material used for this study was an AISI 1045 steel with copper electrode. This study highlights the development of a comprehensive mathematical model of Tool wear ratio (TWR) and Material removal rate (MRR) for correlating the interactive and higher order influences of various electrical discharge machining parameters like Peak current (IP), Spark on time (Ton) and Spark off time (Toff) through response surface methodology (RSM), utilizing relevant experimental data as obtained through experimentation. The machining experiments were conducted based on sequential approach using Full Factorial. The adequacy of the above the proposed models have been tested through the analysis of variance (ANOVA).

I. INTRODUCTION

Electrical discharge machining (EDM) is a non-traditional manufacturing process based on removing material from a part by means of a series of repeated electrical discharges (created by electric pulse generators at short intervals) between a tool, called the electrode, and the part being machined in the presence of a dielectric fluid. At present, EDM is a widespread technique used in industry for high-precision machining of all types of conductive materials [1]. The working principle is based on the thermo electric energy. The thermo electric energy (in form of spark) is created between a workpiece and an electrode submerged in a dielectric fluid with conduction of electric current. The workpiece and the electrode are separated by a specific small gap, the so called 'spark gap', and pulsed discharges occur in this gap filled with an insulating medium [2]. Mohan Kumar Pradhan et al. [3] described by analysis of variance results reveal that Ip is the most influencing factor for MRR and G, having the highest degree of contributions of 87.61% and 81.90%, respectively. In case of TWR, Ton has the highest degree of contribution of 46.05% and is the most significant factor. Sameh S. Habib [4] highlights the development of comprehensive mathematical model for correlating the interactive and higher order influences of various electrical discharge parameters like MRR, TWR and SR through response surface methodology (RSM). C.H. Che Heron , B. Md. Deros , A. Ginting and M. Fauziah [5] were used copper electrodes with diameter of 9.5,12 and 20 mm in EDM of AISI 1045 steel at two current setting of 3.5 and 6.5 A with objective of determining possible correlation between the EDM parameter and the machinability factors (MRR &TWR).

II. EXPERIMENTAL SET-UP

A number of experiments were conducted to study the effects of various machining parameters on EDM process. These studies were undertaken to investigate the effects of various machining parameters on Tool wear ratio and Material removal rate. The selected workpiece material for the research work is AISI 1045 steel was selected due to its emergent range of applications in the field of mould industries. Experiments were conducted on JOEMARS Z 50 JM-322 die sinking machine using positive polarity. The flushing pressure was 0.5 Kg/cm2. The copper with a diameter of 15 mm was used as a tool electrode and Die-electric fluid-92 (DEF-92) was used as die electric fluid. The test conditions are depicted in Table-1.

The material MRR is expressed as the ratio of the difference of weight of the workpiece before and after machining to the machining time and density of the material as shown in eq. (1).

$$MRR = \frac{(W_{tb} - W_{ta})}{D \times t} \qquad (1)$$

Where,

W_{tb} weight before machining of w/p (gm), W_{ta} weight after machining of w/p (gm), D density of work-piece material (gm/mm^3) & t time consumed for machining (min)

TWR is expressed as the volumetric loss of tool per unit time, expressed as

$$TWR = \frac{(W_{tb} - W_{ta})}{D \times t} \qquad (2)$$

Where,

W_{tb} weight before machining of tool (gm), W_{ta} weight after machining of tool (gm), D density of tool material (gm/mm^3) & t time consumed for machining (min)

The 3^q factorial design is a factorial arrangement with q factors, each at three levels. The levels of factor refer to as low, intermediate, and high, represented by the digit 1 (low), 2 (intermediate),and 3 (high). For instance, in a 3^3 design, 1-3-2 indicates the treatment combination corresponding to factor A at the low level, B at the high level, and C at the intermediate level. When the measurements on the response variable contain all possible combinations of the levels of the factors, this type of experimental design is called a complete factorial experiment. According to 3^3 full factorial design we choose various parameter and their levels as shown in the below table for our experimentation.

Table 1: Coding levels of process parameters

	Levels		
Parameter	1	2	3
Current (A)	13	17	21
Pulse on time (µs) (B)	40	50	60
Pulse of Time (µs) (C)	30	40	50

III. RESPONSE SURFACE METHODOLOGY

RSM is a collection of mathematical and statistical techniques that are useful for modeling and analysis of problems in which the response of interest is influenced by several variables and objective is to optimize this response [6, 7]. 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:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i<j=2}^{2} \beta_{ij} x_i x_j + \varepsilon_r \quad (3)$$

Where Y is the corresponding response, X_i is the input variables, X_i^2 and X_iX_j are the squares and interaction terms, respectively, of these input variables. The unknown regression coefficients are $\beta_0, \beta_i, \beta ij$ and β_{ii}. Using Full factorial method various 27 number of experiments to be conducted as shown in Table: 2.

Table 2: Experimental Responses

Experiment no.	Material removal rate **(MRR)** (mm^3/min.)	Tool wear rate **(TWR)** (mm^3/min.)
1	12.6426	0.0775
2	9.2649	0.4539
3	6.1698	0.2483
4	14.3777	0.0135
5	12.0887	0.0873
6	9.3270	0.3292
7	14.2725	0.0888
8	12.4651	0.4146
9	11.4056	0.0090
10	17.9037	0.4034
11	13.3942	0.3247
12	8.9341	0.6011
13	21.2662	0.2101
14	17.2902	0.1326
15	13.8162	0.0449
16	23.9430	0.0888
17	21.8327	0.0528
18	17.6476	0.0573
19	22.9797	0.6236
20	16.2560	0.7899
21	11.3853	0.6258
22	28.9189	0.5337
23	24.1191	0.2292
24	18.0304	0.2562
25	32.9670	0.1921
26	27.7655	0.0090
27	23.6641	0.1494

IV. REGRESSION MODELS

Based on the experimental data gathered, statistical regression analysis enabled to study the correlation of process parameters with the MRR and TWR.

EFFECT OF PROCESS VARIABLES ON MRR AND TWR:

The regression coefficients of the second order equation are obtained by using the experimental data (Table 3, 5). The regression equation for the MRR and TWR as a function of three input process variables were developed using experimental data and is given below eq. (4, 5). The model adequacy checking includes the test for significance of the regression model, model coefficients, and lack of fit, which is carried out subsequently using ANOVA on the curtailed model for MRR and TWR (Table-4, 6).

Table 3: Estimated Regression Coefficients for MRR

Term	Coef	SE Coef	T	P
Constant	-0.645230	7.74969	-0.083	0.935
Ip	0.892318	0.45071	1.980	0.064
Ton	0.001155	0.20243	0.006	0.996
Toff	-0.154841	0.17315	-0.894	0.384
Ip*Ip	-0.013736	0.01168	-1.176	0.256
Ton*Ton	-0.007542	0.00187	-4.036	0.001
Toff*Toff	0.000388	0.00187	0.208	0.838
Ip*Ton	0.049395	0.00330	14.954	0.000
Ip*Toff	-0.036240	0.00330	-10.971	0.000
Ton*Toff	0.007143	0.00132	5.406	0.000
R-Sq = 99.70% R-Sq(pred) = 99.35% R-Sq(adj) = 99.55%				

$$MRR = -0.645230 + 8.92318E-01 \times Ip + 1.155E-03 \times Ton - 1.54841E-01 \times Toff$$
$$-1.3736E-02 \times Ip \times Ip - 7.542E-03 \times Ton \times Ton + 3.88E-04 \times Toff \times Toff$$
$$+4.9395E-02 \times Ip \times Ton - 3.6240E-02 \times Ip \times Toff + 7.143E-03 \times Ton \times Toff \quad (4)$$

Table 4: Analysis of Variance for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	1196.92	1196.9188	132.9910	634.80	0.000
Linear	3	1115.02	1.0709	0.3570	1.70	0.204
Square	3	3.71	3.7116	1.2372	5.91	0.006
Interaction	3	78.19	78.1852	26.0617	124.40	0.000
Residual Error	17	3.56	3.5615	0.2095		
Total	26	1200.48				

Table 5: Estimated Regression Coefficients for TWR

Term	Coef	SE Coef	T	P
Constant	-0.346736	1.99948	-0.173	0.865
Ip	0.088257	0.11594	0.761	0.458
Ton	-0.029539	0.05209	-0.567	0.579
Toff	0.036047	0.04635	0.778	0.448
Ip*Ip	0.003289	0.00304	1.080	0.296
Ton*Ton	0.000658	0.00049	1.351	0.196
Toff*Toff	0.000150	0.00051	0.296	0.771
Ip*Ton	-0.002227	0.00090	-2.471	0.025
Ip*Toff	-0.001510	0.00085	-1.778	0.094
Ton*Toff	-0.000437	0.00034	-1.287	0.216
R-Sq = 82.69% R-Sq(adj) = 72.96%				

Table 6: Analysis of Variance for TWR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	1.05849	1.058489	0.117610	8.49	0.000
Linear	3	0.86912	0.022064	0.007355	0.53	0.667
Square	3	0.03814	0.042796	0.014265	1.03	0.406
Interaction	3	0.15124	0.151237	0.050412	3.64	0.036
Residual Error	16	0.22155	0.221552	0.013847		
Total	25	1.28004				

$$TWR = -0.346736 + 8.8257E-02 \times Ip - 2.9539E-02 \times Ton + 3.6047E-02 \times Toff + 3.289E-03 \times Ip \times Ip + 6.58E-04 \times Ton \times Ton + 1.50E-04 \times Toff \times Toff - 2.227E-03 \times Ip \times Ton - 1.51E-03 \times Ip \times Toff - 4.37E-04 \times Ton \times Toff \quad (5)$$

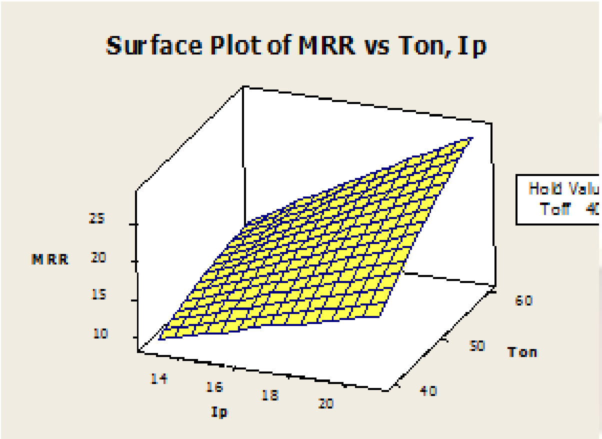

Figure 1: Effect of Ip & Ton on MRR

Figure: 1 shows the estimated response surface for Material removal rate in relation to the process parameters of Ip and Ton while Toff remain constant at their middle value. It can be seen from the figure, the MRR tends to increase significantly with the increase in Ip for any value of Ton. However, the MRR tends to increase with increase in Ton, especially at higher Ip. Hence, Maximum MRR is obtained at high peak current 21 amp and high pulse on time 60 µs in this investigation. This is due to their dominant control over the input energy.

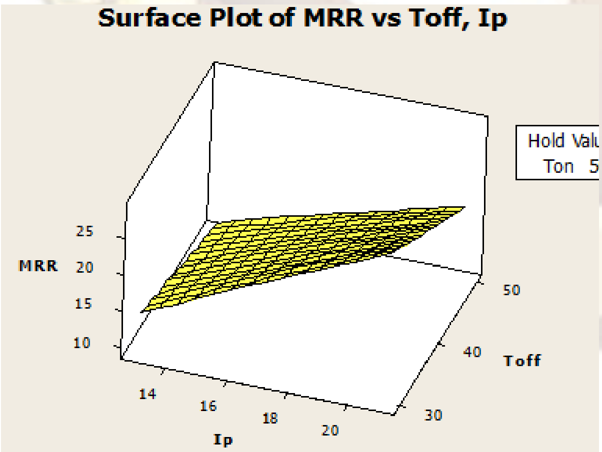

Figure 2: Effect of Ip & Toff on MRR

Figure 2 shows the estimated response surface for Surface Material removal rate in relation to the process parameters of Ip and Toff while Ton remains constant at their middle value. The MRR tends to decrease with increase in Toff. Hence, Maximum MRR is obtained at high peak current and low pulse off time.

Figure 3 represents MRR as a function of Ton and Toff, whereas the Ip remains constant at its middle level. It is observed that the MRR values are low when Ton is low with higher Toff. From the analysis it is said that the interaction of Ton and Toff is significant. Although the influence of this two parameter is very less when compared with the effect of Ip on MRR.

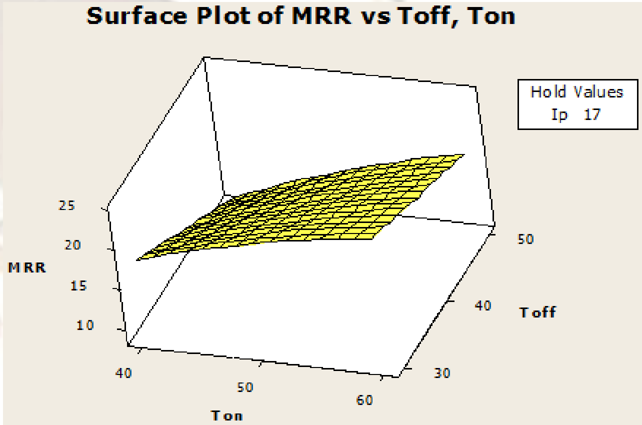

Figure 3: Effect of Ton & Toff on MRR

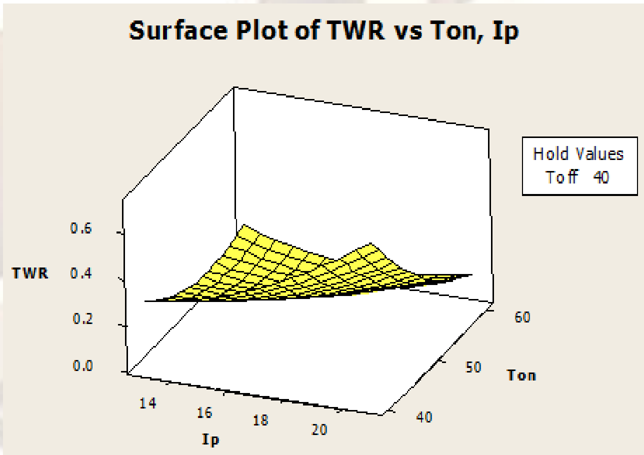

Figure 4: Effect of Ip & Ton on TWR

From Figure 4 the TWR is found to have an increasing trend with the increase of current and pulse on time. TWR is increasing nonlinearly with the current. This is obvious, as the Ip increases, the pulse energy increases, and thus more heat is produced in the tool work piece interface that leads to increase the melting and evaporation of the electrode. One can interpret that Ip has a significant direct impact on TWR.

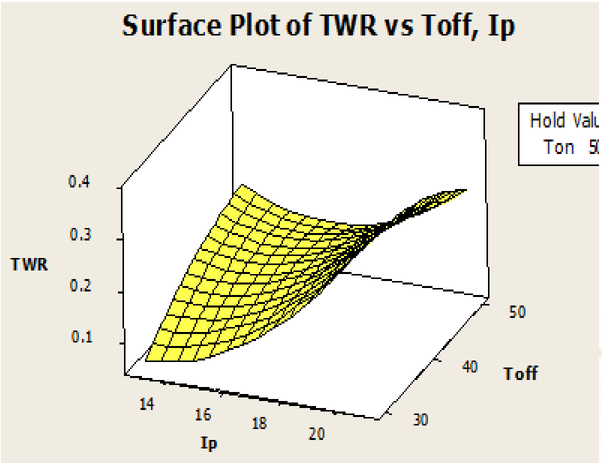

Figure 5: Effect of Ip & Toff on TWR

From Figure 5 the TWR is found to have an increasing trend with the increase of peak current and pulse off time. It is observed that the TWR values are high when Ip is high with higher Toff or Toff is low with higher Ton.

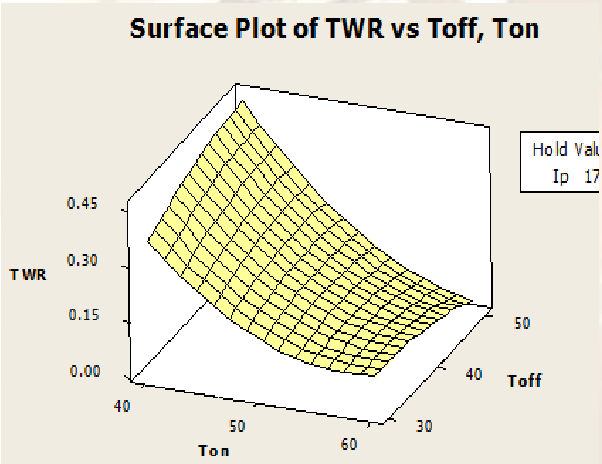

Figure 6: Effect of Ton & Toff on TWR

Figure 6 shows that with increase in Ton the TWR is reduced at any value of Toff. With increase in Toff the TWR increases at low value of Ton. This establishes that TWR is also proportional to the total machining time with rate of energy supplied.

V. CONCLUSION

This study highlights the development of a comprehensive mathematical model for correlating the interactive and higher order influences of various electrical discharge machining parameters through response surface methodology (RSM), utilizing relevant experimental data as obtained through experimentation. The research findings of the present study based on RSM models can be used effectively in machining of AISI 1045 steel in order to obtain best possible EDM efficiency.

- MRR and TWR are found to have an increasing trend with the increase of current and pulse on time Maximum MRR 32.9670 mm^3/min achieved at 21 amp Current and 60 µs Pulse on time. Pulses off time have very little effect on MRR and TWR.
- MRR is reduced significantly by increasing the Pulse off time.
- TWR is found to have an increasing trend with the increase of pulse on and pulse off time. This establishes the fact that TWR is also proportional to the total machining time with rate of energy supplied.

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