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A Study on Modelling Surface Finish in Electrical Discharge Machining Tablet Shape Punches Using Response Surface Methodology

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Abstract: This paper introduces a study on modelling surface finish in EDM (Electrical Discharge Machining) of tablet shape punches when using copper as electrode material. In this study, 27 experiments were performed based on BBD (Box-Behnken Design) and the work-piece material was 9CrSi steel. The input process parameters were the current, the pulse on time, the pulse off time and the voltage. The effects of the input parameters on the surface finish were evaluated by analysing variance. Besides, from the results of the experiments, a regression equation for determining the surface roughness is introduced. Also, the optimum input parameter values were found in order to get the minimum surface roughness.

Key words: EDM (Electrical Discharge Machining), EDM sinking, surface roughness, RSM (Response Surface Methodology), BBD (Box-Behken Design).

1. Introduction

EDM (Electrical Discharge Machining) is the process for removing electrically conductive materials by using precisely controlled sparks that occur between an electrode and a work-piece in a dielectric fluid. It is one of the most effective non-traditional machining processes for working with difficult-to-machine materials as well as for producing blank cavities in products. Therefore, many researches have been done for optimizing the EDM process in order to find the optimum input parameters.

Until now, there are many studies on the modeling of EDM process as well as on the finding optimum input parameters. Barenji, R. V., et al. [1] carried out an optimum study to optimize the material removal rate and tool wear ratio when machining tool steel. Kaneko, T. and Onodera, T. [2] carried out a study on fuzzy control in order to maintain the stability of the EDM process. The characteristics of EDM debris were understood by Murray, J. W., et al. [3]. Thiyagarajan, S., et al. [4] introduced an experimental research on the influences of three different work-piece materials on the aerosol emission rate and the material removal rate. Torres, A., et al. [5] investigated the influences of EDM parameters on the surface roughness, the electrode wear and the material removal rate. Annamalai, N., et al. [6] carried out a study on the effect of process parameters when machining 4340 steel by electrolytic copper electrode. Guu, Y. H., et al. [7] investigated the influences of the process parameters on the surface textures when machining Fe-Mn-Al alloy. Ekmekci, B. [8] introduced a study on the effects of dielectric fluid and the electrode materials on the white layer structure by using X-ray diffraction method.

It can be learned from previous studies that there were many researches on EDM processes. However, most of the previous studies were done with work-pieces in the types of blank cavities or shaped holes. This paper introduces a study on the modelling

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surface finish in EDM tablet shape punches using RSM (Response Surface Methodology). In the study, the effects of input parameters were investigated by analysing variance when EDM is with graphite electrode on the surface finish of 9CrSi steel. Moreover, a regression equation for calculation of the surface roughness is proposed. Besides, the optimum values of EDM parameters for minimum surface roughness were found.

2. Experimental Work

The experiments were designed based on the BBD (Box-Behnken Design) of RSM. In the experiments, four input parameters were selected and three levels of factors were considered. The experimental set-up is as:

- Machine: sinker EDM model CNC-AG40L from Sodick Europe Ltd. (UK);
- Work-piece material: 9CrSi steel;
- Electrode materials: graphite;
- Dielectric fluid: EDM oil HD-1;
- Input parameters: gap voltage (U); pulse on time (T_{on}); pulse off time (T_{off}); pulse current (I). (The levels of the input parameters were shown in Table 1);
- Number of experiments: 27.

After processing, the surface roughness was measured by a strain gage transducer contact SJ-301 (Mitutoyo, Japan). The various levels of input parameters and the results of the output response (the surface roughness Ra) are described in Table 2.

3. Results and Discussion

Fig. 1 presented the results of regression analysis for the surface roughness. From the results, it was found that the highest composition of the regression model was statistically significant (p value was 0.051). Also, as the p value of the lack-of-fit (0.871) in RSM is much larger than the normal value 0.05, the second order is suitable and the model fits quite well.

Eq. (1) was found for determination of the surface roughness:

$$R_a = 4.34 + 0.105 \cdot T_{on} - 0.085 \cdot T_{off} - 0.1025 \cdot U - 0.50583 \cdot I$$
$$+0.53 \cdot T_{on} \cdot I - 0.1175 \cdot T_{off} \cdot U + 0.2875 \cdot T_{off} \cdot I +$$
$$+0.38 \cdot U \cdot I - 0.09042 \cdot U^2 + 0.19542 \cdot I^2 \quad (1)$$

The relation between the surface roughness with the pulse current and the gap voltage is shown in Fig. 2. Also, the contour plot of the surface roughness and the pulse current and the gap voltage is presented in Fig. 3. From the contour plot, it was found that the minimum value of the surface roughness was R_a = 2.52935 when

Table 1 Input parameters and their levels.

Parameter	Level 1	Level 2	Level 3
Pulse on time	30	35	40
Pulse off time	15	20	25
Gap voltage	40	45	50
Pulse current	4	6	8

Table 2 Experimental plans and output response.

No.	T_{on} (μ/s)	T_{off} (μ/s)	U (V)	I (A)	R_a (μm)
1	35	20	40	8	7.33
2	30	20	50	6	4.04
3	35	15	45	8	3.90
4	35	20	40	4	4.31
5	40	20	50	6	3.90
6	35	15	40	6	3.76
7	35	20	50	4	5.61
8	35	25	45	8	4.36
9	30	20	45	4	2.97
10	30	20	45	8	3.02
11	40	25	45	6	3.42
12	30	20	40	6	3.89
13	40	15	45	6	3.14
14	35	25	45	4	2.90
15	35	25	40	6	3.24
16	40	20	40	6	2.81
17	40	20	45	4	2.73
18	40	20	45	8	2.74
19	35	15	50	6	2.57
20	35	20	45	6	2.78
21	30	15	45	6	3.14
22	35	20	50	8	2.70
23	35	20	45	6	2.76
24	35	20	45	6	2.40
25	35	25	50	6	2.56
26	35	15	45	4	2.43
27	30	25	45	6	2.37

Response Surface Regression: Ra versus Ton, Tof, U, I

The analysis was done using coded units.

Estimated Regression Coefficients for Ra

Term	Coef	SE Coef	T	P
Constant	4.34000	0.3630	11.957	0.000
Ton	0.10500	0.1815	0.579	0.047
Tof	-0.08500	0.1815	-0.468	0.038
U	-0.10250	0.1815	-0.565	0.013
I	-0.50583	0.1815	-2.787	0.016
U*U	-0.09042	0.2722	-0.332	0.032
I*I	-0.19542	0.2722	-0.718	0.037
Ton*I	0.53000	0.3143	1.686	0.018
Tof*U	-0.11750	0.3143	-0.374	0.015
Tof*I	0.28750	0.3143	0.915	0.028
U*I	0.38000	0.3143	1.209	0.025

S = 0.628671   PRESS = 27.0141
R-Sq = 55.49%   R-Sq(pred) = 0.00%   R-Sq(adj) = 92.74%

Analysis of Variance for Ra

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	14	5.9116	5.91157	0.42226	1.07	0.002
Linear	4	3.4155	3.41548	0.85387	2.16	0.043
Ton	1	0.1323	0.13230	0.13230	0.33	0.047
Tof	1	0.0867	0.08670	0.08670	0.22	0.038
U	1	0.1261	0.12608	0.12608	0.32	0.013
I	1	3.0704	3.07041	3.07041	7.77	0.016
Square	4	0.2965	0.29654	0.07413	0.19	0.003
U*U	1	0.0038	0.04360	0.04360	0.11	0.032
I*I	1	0.2037	0.20367	0.20367	0.52	0.037
Interaction	6	2.1995	2.19955	0.36659	0.93	0.002
Ton*I	1	1.1236	1.12360	1.12360	2.84	0.018
Tof*U	1	0.0552	0.05523	0.05523	0.14	0.015
Tof*I	1	0.3306	0.33062	0.33062	0.84	0.028
U*I	1	0.5776	0.57760	0.57760	1.46	0.025
Residual Error	12	4.7427	4.74273	0.39523		
Lack-of-Fit	10	4.6561	4.65613	0.46561	10.75	0.883
Pure Error	2	0.0866	0.08660	0.04330		
Total	26	10.6543				

Fig. 1 Anova results for surface roughness.

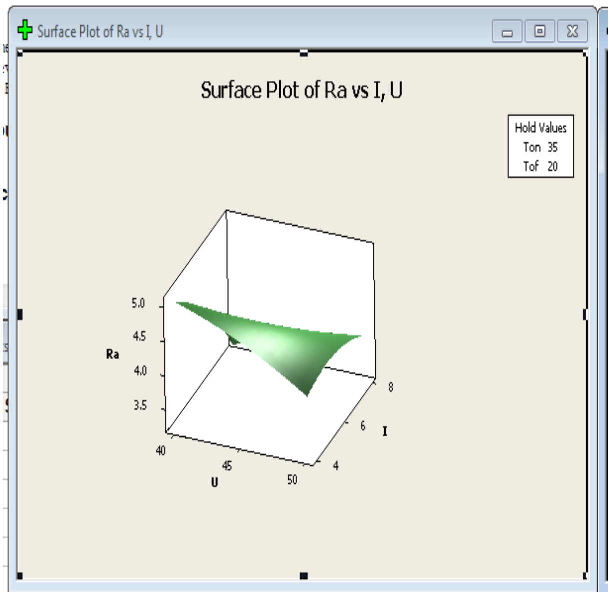

Fig. 2 Surface roughness versus I and U.

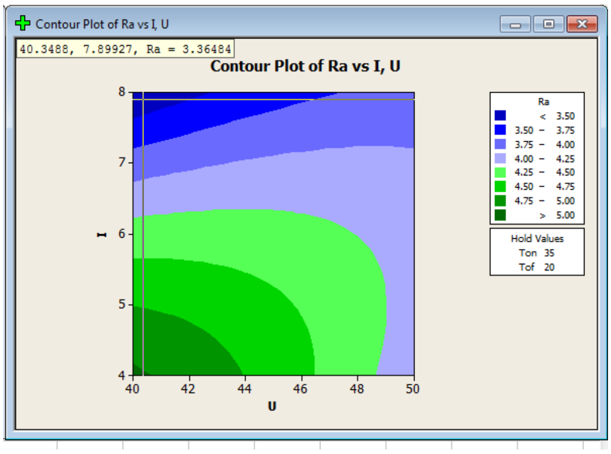

Fig. 3 Contour plot of surface roughness versus I and U.

the gap voltage was 45.6002 and the pulse current was 5.82945.

4. Conclusion

A study on modelling surface finish in EDM of tablet shape punches was presented. The effects of the input EDM process parameters on the surface roughness were investigated by experiments designed by BBD. From the results of the study, a regression equation for calculating the surface roughness was proposed. Besides, the optimum values of input parameters for getting the minimum surface roughness were given.

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