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Experimental investigation of surface roughness of EN 353 on EDM with hollow tool

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Abstract— **Electrical discharge machining (EDM) is one of the earliest non-traditional machining, extensively used in industry for processing of parts having unusual profiles with reasonable precision. In the present work, an attempt has been made to model Surface Roughness (SR) through Response Surface Methodology (RSM) in a die sinking EDM process. The optimization was performed in two steps using one factor at a time for preliminary evaluation and a Box-Benken design (BBD) involving three variables (Pulse on-Time, Pulse off-Time and Pulse Current) with three levels for determination of the critical experimental conditions. A copper electrode having tubular cross section was employed to machine holes of 8 mm height and 12 mm diameter on EN 353 Steel alloy workpiece. The results of analysis of variance (ANOVA) indicated that the proposed mathematical models obtained can adequately describe the performances within the limits of factors being studied. The experimental results reveal that interaction effect of Pulse Current and Pulse Off Time on SR yielding a wide range from 4.28 to 10.16 µm, while Pulse Current remains the most contributing factor. Surface topography is revealed with the help of scanning electron microscope (SEM) micrographs.**

Index Terms— **EDM, hollow tool, response surface methodology, surface roughness, SEM.**

INTRODUCTION

Electric Discharge machining is a nonconventional machining process extensively used in industry for processing of parts having unusual profiles with reasonable precision [1]. Steel is a widely used engineering material. There are a variety of steels used for numerous applications. The steel is being divided as low carbon steel, medium carbon steel, high carbon steel on the basis of carbon content. Low carbon steel has carbon content of 0.15% to 0.45%. It is the most common form of steel as it's provides material properties that are acceptable for many applications [2]. EN353 steel is cheaply available and widely used alloy. It is low alloy case carburized steel, predominantly used for manufacturing heavy-duty gears, shaft and pinions, especially crown wheel and pinion [3].

S. Murugesan [4] optimized that Discharge current was most significant controlling parameter in machining Al-15% SiC MMC using multihole electrode by Grey relational analysis while, taguchi method was employed to determine the relations between the machining parameters and process characteristic surface roughness. *F.L Amorium* [5] concluded that the best results of Surface texture for Duty Factor of 0.5 were obtained with tungsten-copper electrodes, no matter the machining conditions while machining copper-beryllium ASTM C17200 alloy. Kerosene decomposes at higher temperature due to larger discharge energy and produces carbon particles that adhere to the electrode surface and this phenomenon restricts rapid tool wear during machining than deionized water [6]. *A.T Bozdana* [7] demonstrated that Globules of debris, pockmarks and melted drops were observed on the surfaces of blind holes were more dispersed and pronounced. *Pichai* [8] showed that increase in discharge current increased the micro cracks density on machining tungsten carbide with graphite electrode. *M. Boujelbene* [9] showed that increasing discharge energy increases instability and therefore, the quality of the workpiece surface becomes rougher and the white layer thickness increases. Also the amount of particles in the gap becomes too large and form electrically conducting paths between the tool electrode and the workpiece causing unwanted discharges, which become electric arcs (arcing). These electric arcs damage the electrodes surfaces (tool and workpiece surfaces) and can occur microcracks. *A.K Kanra* [10] reported that during EDM, a significant amount of workpiece material was found to transfer from workpiece surface to tool surface and vice-versa. A continuous burning of cutting fluid takes place which would give out a carbon residue, a visual black layer on machined surface, which decreases the EWR. *H.K Kansal* [11] had investigated the surface roughness on EN-31 tool steel with copper electrode and reported that best surface finish is obtained at the lower level of Peak Current and Pulse On Time. *T.Y Tai* [12] reported that increasing the Pulse Current or reducing the Pulse-On Duration suppresses the formation of surface cracks in the SKD11 machined surface and hence improves the fatigue life. *Anish Kumar* [13] revealed that peak values of Pulse On Time and Peak Current produced intense heat conditions in the machining zone (followed by rapid cooling) that yielded higher crack densities and surface roughness while machining Titanium. Also the crater size was larger along with a higher frequency of the globules of debris on the machined surface than that observed on the other materials such as steel. Mathematical modeling of process using Response Surface Methodology shows that the developed model can achieve reliable prediction of experimental results within acceptable accuracy [14]. *Ulas Cydas* also added that RSM is an economical way for obtaining information for any system with the fewest number of experiments [15]. Box-Behnken design gives us robustness to the unavailability of data over central composite design [16]. Reversing the polarity of sparking alters the material removal phenomenon with an appreciable amount of electrode material depositing on the workpiece surface [17]. Due to its structural integrity, Copper can produce very fine surface finishes, even without special polishing circuits. It also makes Copper electrodes highly resistant to DC arcing in poor flushing situations [18]. *S.Rajesha* [1] demonstrated that use of hollow tool is particularly useful for drilling holes with low tool wear rate. It was found that, while machining the same length of the Inconel 718 with a solid tool, it takes approximately 40% more machining time, than taken by a hollow tool. Hollow tool also helps in minimizing the dielectric fluid degradation. Consequently, the approach light is cost effective with higher yield, and reduced material and energy loss.

The literature reveals that, no extensive work has been done with tubular hollow electrode. Also there is a little work has been carried out regarding the modelling and analysis of the EDM process on EN 353 steel alloy material with the SR as the machining performances. In this study, mathematical models have been developed using Response Surface Methodology, while Analysis of variance (ANOVA) is used to check the validity of the models. Surface topography is revealed with the help of scanning electron microscope (SEM) micrographs.

EXPERIMENTAL PROCEDURE

Experiments were conducted on a die sinking EDM machine, model Electronica Xpert 1 CNC. In this study, EN 353 steel selected as the work material. Chemical composition of the workpiece material is given in Table 1. A cylindrical electrode with tubular section having 12 mm external and 9 mm internal diameter cooper was used as the electrode (tool). Fig. 1 show a CNC EDM machine with typical copper electrode used in the experimentation trials. Kerosene was used as a dielectric

Table 1 The composition of EN 353 Steel alloy

Compo-sition									
Contents	C	Si	Mn	Cr	Mo	S	P	Al	Ni
Percentage	0.18	0.22	0.66	0.89	0.13	0.033	0.034	0.026	1.06

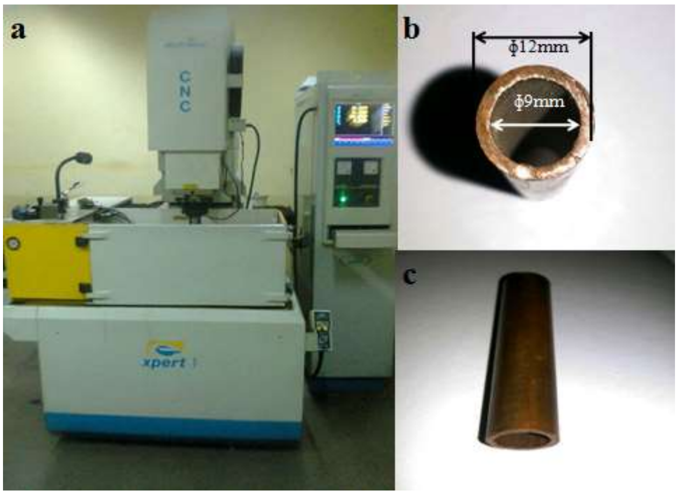

Figure 1(a) CNC Die sinking EDM; (b and c) cross-sectional view of electrode

Table 2 Factors and their levels

S.No.	Symbols	Input factors	Levels			Units
			1.	2.	3.	
1.	A	Pulse on Time	100	340	580	μs
2.	B	Pulse off Time	4	16	25	μs
3.	C	Peak current	5	25	45	A

The process parameters and their levels for the main experiments were decided on the basis of the pilot experiments conducted using one-factor-at-a-time approach as shown in Table 2.

The Box–Benken design (BBD) was used for planning and executing the subsequent main experimentation, as shown in Table 3. In this study, an effort has been made to model the empirical relationship between machining parameters by using Response Surface Methodology. The workpiece was connected to the positive polarity while the tool electrode was maintained at negative polarity. Side flushing method was employed for the dielectric fluid. A hole depth of 8 mm and diameter of 12 mm was machined throughout, for each run. The process parameters and depth of cut was programmed in the NC controlled unit. Once the experimentation was completed, the workpieces were cleaned thoroughly using acetone and the final individual weight was measured. Surface roughness measurements were carried out at the side wall of the holes using a Brand- Mitutoyo Surftest, Model- SJ-301.

Table 3 Factors and their response

Factors				Response
Run no.	*Pulse off Time T_{OFF} (μs)*	*Pulse on Time T_{ON} (μs)*	*Pulse Current I_P (A)*	*Surface Roughness SR (μm)*
1.	28	340	5	5.39
2	4	340	5	6.3
3	16	340	25	7.22
4	28	340	45	6.25
5	16	340	25	7.45
6	16	340	25	7.57
7	4	580	25	10.12
8	4	100	25	5.42
9	16	340	25	7.23
10	16	580	45	10.16
11	16	100	5	4.28
12	16	580	5	9.15
13	16	100	45	5.34
14	28	100	25	4.33
15	16	340	25	7.43
16	4	340	45	7.73
17	28	580	25	9.2

RESULTS AND DISCUSSION

Effect on Surface Roughness

The mathematical relationship for correlating the Surface Roughness and the considered process variables is obtained as follows in Eq. 1:

$$Surface\ Roughness = 2.88516 + 5.88455E - 003 * T_{ON} + 0.072066 * T_{OFF} + 0.099094 * I_P + 6.09809E - 006 * T_{ON^2} - 3.22049E - 003 * T_{OFF^2} - 1.24687E - 003 * I_{P^2} - 5.93750E - 004 * T_{OFF} * I_P \qquad (1)$$

Based on ANOVA as shown in Table 6, The Model F-value of 550.62 implies the model is significant. There is only a 0.01%

chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, A^2, B^2, C^2, BC are significant model terms.

Table 4 The analysis of variance for main and interaction effects of parameters on SR

Source	**SS**	**D**	**MS**	**F value**	**Prob>F**	**At 95% CI**	**%C**
Model	53.68	7	7.67	550.62	<0.0001	S	
A	46.37	1	46.37	3329.21	<0.0001	S	86.17
B	2.42	1	2.42	173.75	<0.0001	S	4.49
C	2.38	1	2.38	170.61	<0.0001	S	4.42
A²	0.52	1	0.52	37.30	0.0002	S	0.96
B²	0.91	1	0.91	65.02	<0.0001	S	1.69
C²	1.05	1	1.05	75.20	<0.0001	S	1.95
BC	0.081	1	0.081	5.83	0.0389	S	0.15
Lack of Fit	0.034	5	6.75E -003	0.29	0.8937	NS	
R²	0.9977						
Adjusted R²	0.9959						
Predicted R²	0.9921						

The "Lack of Fit F-value" of 0.29 implies the Lack of Fit is not significant relative to the pure error. There is a 89.37% chance that a "Lack of Fit F-value" this large could occur due to noise. The ‘‘Pred. R²’’ of 0.9921 is in reasonable agreement with the ‘‘Adj. R²’’ of 0.9959. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 73.433 indicates an adequate signal. This model can be used to navigate the design space.

Figure 2 (a) shows the contour plot, while Figure 2(b, c) three-dimensional interaction response surfaces for SR in relation to the input parameters of Peak Current and Pulse Off Time. From the contour plot and response surface, it was observed that minimum SR 4.29 µm with the value of Peak Current at 16 A and Pulse Off Time at 100µs. In addition to this, Figure 2(d - f) shows that the normal plot of residuals data are normally distributed and all the experimental results are in the region very near to the predicted values, and hence, the developed model can be effectively used to predict the surface roughness in EDM of EN 353. At higher Peak Current, the discharge energy per pulse increases, which produces the deeper and wider overlapping craters, globules of debris and

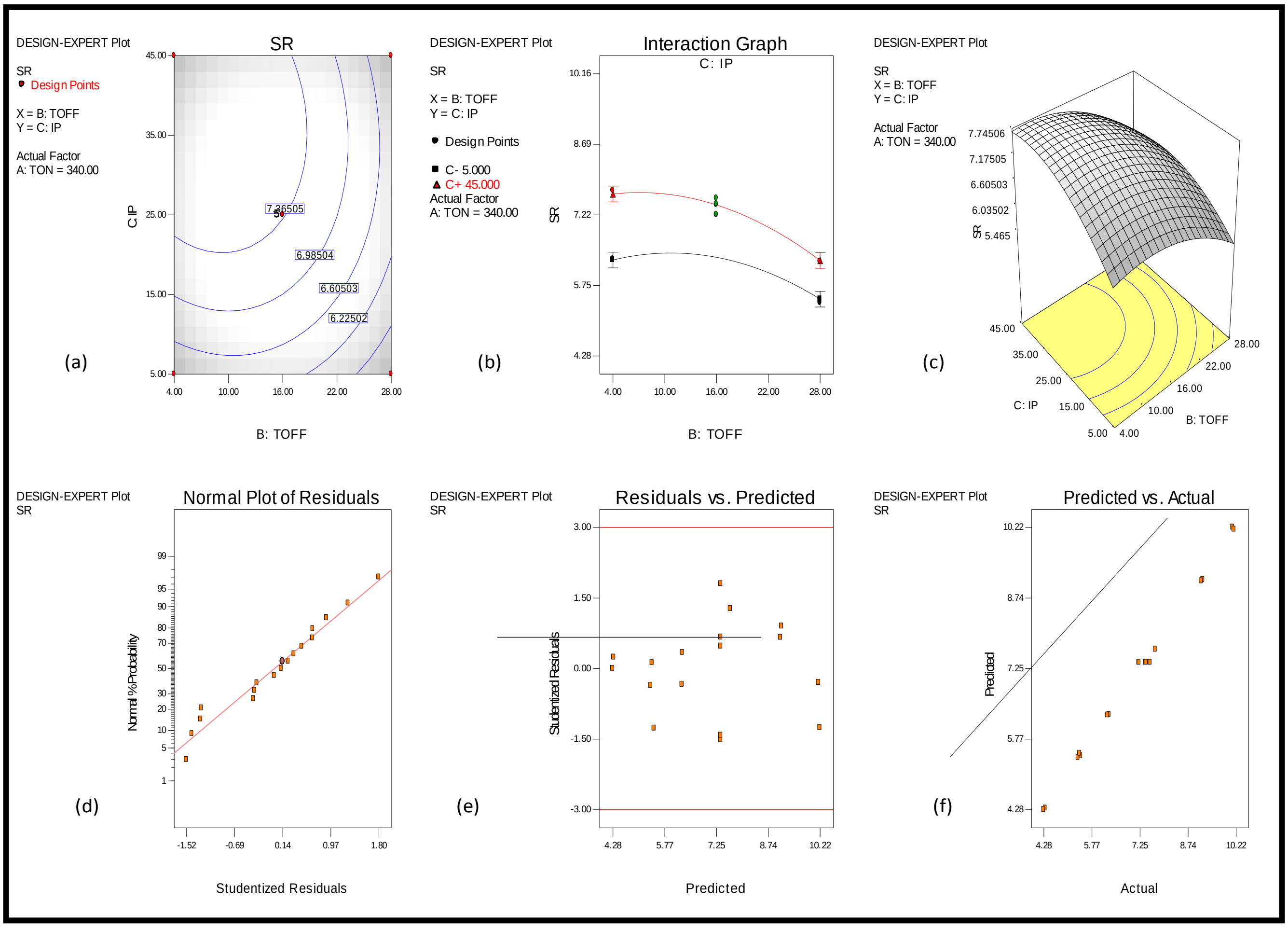

Figure 2 Response surface plot for SR: (a) contour plot, (b and c) interaction plot at Pulse On Time = 340 µs, (d) normal plot residuals; (e) residuals versus predicted values and (f) predicted versus actual.

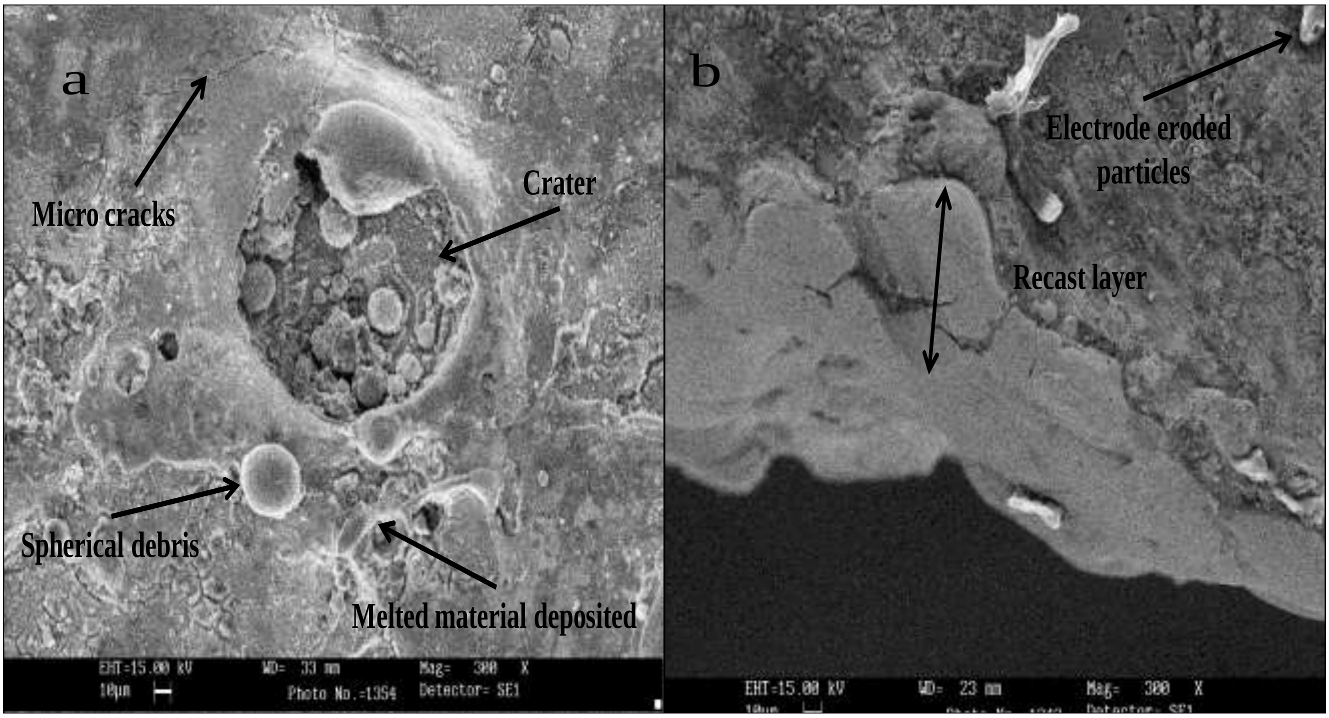

Figure 3 (a) Exp No. 3, at T_{on} = 340 µs, T_{off} = 16 µs and I_p = 25 A; (b) Exp No. 3, at T_{on} = 340 µs, T_{off} = 16 µs and I_p = 25 A.

micro cracks on the machined samples as seen in SEM micrographs (Figures 3).

CONCLUSION

In this study, the influence of significant EDM process parameters like Peak Current, Pulse On Time and Pulse Off Time on response parameter SR while machining the EN 353 steel has been investigated. Experimentations were planed and conducted according to the Response Surface Method. Results were analyzed using analysis of variance (ANOVA). Following major conclusion were drawn from this study are:

- EDM is an adequate process to do machining of EN 353 Steel with good Surface Roughness.
- Lowest SR while EDMing the EN 353 steel alloy is 5.34µm, which is majorly influenced by all the three factors Peak Current and Pulse off Time. In order to obtain better surface finish set Peak Current and Pulse on Time at low levels.
- The optimized value of Surface Roughness is 4.16 µm obtained at optimum setting of parameters Pulse On Time, Pulse Off Time and Peak Current at 147.01 µs , 26.69 µs and 9.03 A respectively.

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