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Modelling of tool wear and recast layer thickness in die sinking EDM process

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Abstract
This work focuses on the modelling of tool wear (TW) and recast layer thickness (RLT) in a die-sinking EDM process using response surface methodology (RSM). A central composite rotatable design (CCRD) involving three variables with five levels has been used to establish a mathematical model between the input parameters and responses. Pulse on-time, duty factor and pulse current were varied during the experimentation. 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 predicted values agrees reasonably weel with the experimental results in the range selected.

EDM, Tool wear, Recast layer thickness, ANOVA

1. Introduction

In EDM, the workpiece and the shaping tool are the electrodes separated by a liquid dielectric (i.e. no physical contact) and therefore; no rnechanical stress is placed on the workpiece, so this is an ideal method to shape hard metals and alloys in aerospace, automotive and die industries. During machining, the discharge energy produces very high temperatures at the point of the spark on the surface of the workpiece removing the material by melting and vaporization [1-3]. The top surface of the workpiece subsequently resolidifies and cools at a very high rate. This resolidified layer has been called the recast layer, and it contains numerous pock marks, globules, cracks and microcracks, whose thickness and density depends on the process conditions [4]. In addition to the molten workpiece surface, electrode wear occurs during the EDM process, leading to a lack of machining accuracy in the geometry of workpiece [5-7].

Many investigations [8-10] have been conducted on TW and RLT in the EDM process. It was noted that the electrode erosion rate in EDM is related to the melting points of the electrode materials and the TW increased with increasing pulse current. On the other hand, many qualitative relationships between process parameters and the resulting recast layer thickness have been reported by several authors [11–13]. All these researchers showed that increasing pulse energy will result in an increase in the dimension of the discharge crater, cracks, the density and RLT. It is evident from above that little research has been carried out regarding the modelling of the EDM process with the tool wear and recast layer thickness as the machining performance. In this study, mathematical models have been developed to predict the tool wear and recast layer thickness using RSM.

2. Experimentation

The CCRD is chosen to determine the relationship between three operating variables namely, pulse on-time, duty factor and pulse current and responses (TW and RLT) for this study. Experiments were conducted on a die sinking EDM machine. Kerosene was used as a dielectric. In this study, AISI4340 was selected as the work material. Chemical composition of the workpiece material is given in Table 1.

Table 1 Chemical composition of the workpiece material
(AISI 4340) by weight

Fe	Ni	Mn	Cr	C	Si	Mo
95.7	1.83	0.87	0.72	0.41	0.28	0.21

Figure 1 (a) and (b) shows the experimental system and the main conditions were illustrated in Table 2. A Cu-W electrode with 2 mm diameter was used to machine AISI4340 alloy. The RLT was measured by using a stereo zoom microscope.

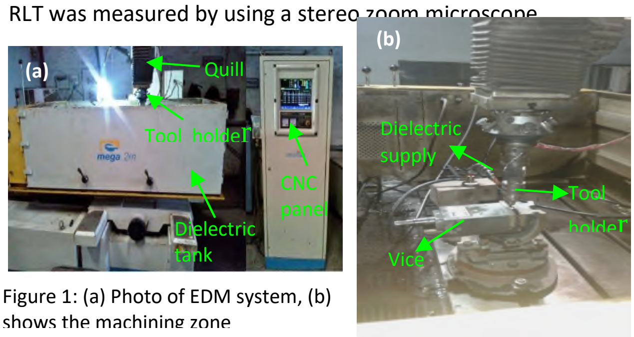


Figure 1: (a) Photo of EDM system, (b) shows the machining zone

Table 2 Machining condition & description in EDM

Voltage	Tool polarity	Generator	Dielectric	Dielectric flushing	Flushing pressure
130 V	Negative	3 phase 380 V 6.5kW	Kerosene	Side flushing with pressure	0.4 MPa Constant

3. Results and discussion

The independent variables and their levels for the CCRD used in this study are shown in Table 3. Using the relationship in Table 3, the coded and actual levels of the variables for each of the experiments in the design matrix of CCRD is caliculated. Experiments have been

Table 3 Input parameters and their levels for CCRD

Variables	Units	Limits				
		-2	-1	0	+1	+2
I	A	2	5	8	11	14
t_i	μs	10	15	20	25	30

τ	-	0.5	0.6	0.7	0.8	0.9

conducted using CCRD matrix and the mathematical models has been derived, based on observed values of TW and RLT. As per ANOVA technique, models are adequate as if the calculated *F* ratio of the developed models do not exceed the standard tabulated values of *F* ratio for desired level of confidence (98% and 96% for TW and RLT, respectively). Futher based on *p*-values (probability values of the given models), the models are found significant. The final models are

$$TW = -1.9907 + 0.048\, t_i + 0.0125\, \tau + 0.01978\, I + 0.04109\, I^3 - 0.00139\, \tau I \quad \text{------------- (1)}$$

$$RLT = 8.1283 - 0.00783\, t_i + 0.0298\, \tau - 0.4928\, I + 0.19801\, I^3 - 0.00698\, \tau I \quad \text{------------- (2)}$$

3.1. Effect of variables on responses

Figure 1 shows the main effect plots of three factors on TW and RLT. It could be seen from the figures that pulse current is the most important factor on TW and RLT while duty factor is the least. This is due to the fact that an increase in pulse current leads to an increase in the rate of heat energy, which is subjected to both of the electrodes, and in the rate of melting and evaporation [15]. Therefore, more heat is transferred into the workpiece as the pulse current increases, and the dielectric is increasingly unable to clear away the molten material, causing it to build upon the surface of the parent material. During off-time, this molten material resolidifies to form recast layer and the thickness of recast layer depends on the volume of molten material [16]. The effects of pulse on time are straighter than the current because the attached molten workpiece material protects the tool surface against wear. The TW is increased approximately 1.21 mg/min with pulse-on duration and decreased 0.9 mg/min with duty factor in the range of factors. These changes are very small since the Cu-W electrode has very high vaporized point and can be assumed negligible. However, as shown in Fig. 2 the RLT is increased approximately 5.8 µm with pulse duration. The combination of high pulse current and low duty factor leads to larger tool wear. Three-dimensional (3D) response surface plots were also formed based on the quadratic models Eqs. (1) & (2) to assess the change of response surface as shown in Figs. 3 & 4. The relationship between the variables and responses can be also further understood by these plots. The effects of t_i and τ , t_i and I , and τ and I on responses, while keeping the other parameter at center level, are shown in Figs. 2(a–c) and 3(a–c).It could be clearly seen that an increase in pulse current leads to a sharp increase in TW and RLT, rather than the other parameters. In addition, the responses depend more on the pulse on-time rather than on the dury factor.

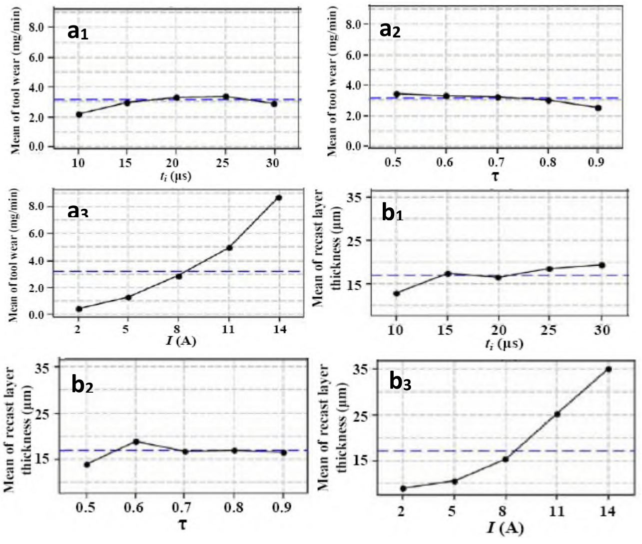
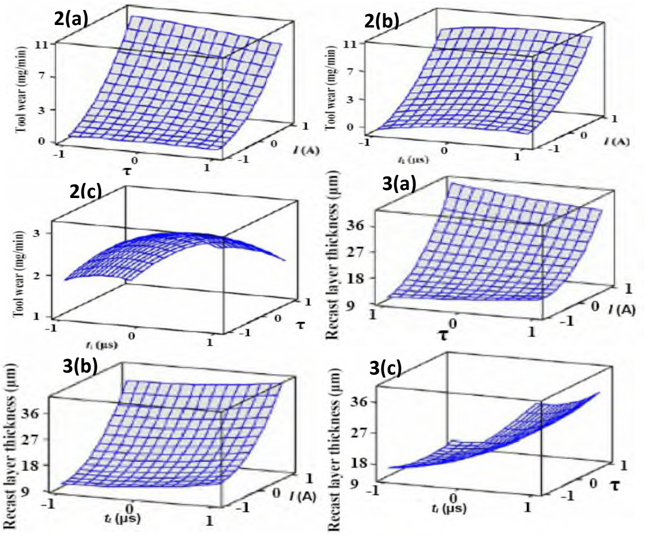


Figure 2. Plots of main effects of three variables on TW and RLT (a_1 & b_1: Pulse on-time; a_2 & b_2: duty factor; a_3 & b_3: pulse current)



Figures 3 & 4. 3D response surface plots showing the effects of two variables on TW and RLT. (a. duty factor and pulse current; b. Pulse on-time and pulse current; c: pulse on-time and duty factor)

4. Coclusion

The present study reveals that: (i)The predicted values of TW (approx. 3.9565 mg/min) & RLT (22.074 µm) agrees the experimental values of TW (approx. 3.962 mg/min) & RLT (22.077µm) reasonably well, with R^2 of 0.98 for TW and R^2 of 0.96 for RLT. (ii) Pulse current was found to be the most important factor affecting the both TW and RLT, while duty factor has no significant effect on both responses (iii) The main effect and 3D response surface plots provided a better understanding of individual and interactions of variables on responses (iv) RSM can be successfully used for modelling the machining parameters for TW and RLT (v) Model developed not only makes AISI4340 a more commercially viable material for industrial applications, but also turns a spotlight on the EDM of AISI4340 as a promising field for further advancements.

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