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White layer thickness prediction in WEDM-ANFIS modeling

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ABSTRACT – Wire Electric Discharge Machining (WEDM) is a nontraditional technique by which the required profile is acquired using spark energy. Regarding wire cutting, precision machining is necessary to achieve high product quality. White Layer Thickness (WLT) is one of the most important factors for assessing superior surface finish. In this research, Adaptive Neuro-fuzzy Inference System (ANFIS) was used to predict the WLT in WEDM using coated wire electrode. The predicted data were compared with measured values, and the average prediction error for WLT was 2.61 %.

1. INTRODUCTION

Wire Electric Discharge Machining (WEDM) is among the most well-know and applied nontraditional machining processes in industry today. WEDM can machine difficult-to-machine materials. In WEDM process, White Layer Thickness (WLT) plays a vital role on the operational characteristics of the part (e.g., fatigue, corrosion, creep life, fracture resistance, surface friction, and coating ability). To achieve low WLT value, the part must be machined more than once. Therefore, the desired WLT is usually specified, and proper processes are selected to reach the wanted quality [1].

WEDM is a complex machining process controlled by many process parameters. Any slight variation in one of the process parameters can affect the machining performance measures such as white layer thickness, surface roughness, and cutting rate. The most effective machining strategy is determined by identifying different factors affecting the WEDM process, and seeking different methods of obtaining the best machining condition and performance [2, 3].

To achieve an efficient machining, mathematical modeling between input WEDM parameters and output performance characteristics should be available to the manufacturers [4, 5]. Soft computing techniques are useful when exact mathematical information is not available. In contrast to traditional computing, these techniques suffer from approximation, partial truth, met heuristics, uncertainty, and inaccuracy. ANFIS is one of the soft computing techniques that play an important role in input-output parameter relationship modeling [6].

Hence, the aim of this work is to obtain the best machining parameters (discharging time, charging time, peak current, wire tension, and wire speed) to minimize white layer thickness using ANFIS modeling.

2. EXPERIMENTAL WORK

The experiments were performed using Computer numerical control (CNC) Sodick A500W WEDM machine tool. Coated wire electrode with tensile strength of 875 N/mm2 and diameter of 0.2 mm were used for machining blocks of AISI 1050 carbon steel under specific machining conditions. The raw material with dimension (100x60x20) mm is machined into dimension (5x5x20) mm for each specimen.

In this study, the effect of machining parameters including peak current (I_P), discharging time (T_{on}), charging time (T_{off}), wire speed (W_S), and wire tension (W_T) white layer thickness performance factor was investigated. The machining parameters levels were chosen according to machining recommendations as shown in Table 1. The other machining parameters were kept constant as a fixed value during experiments to optimize the process as spark gap voltage = 20volts; flush pressure = 14kgf/cm²; and water resistivity = $6x10^4$Ω.cm.

Table 1 Levels of machining parameters

Parameter	**levels**		
	1	2	3
T_{on} (μs)	0.2	0.3	0.4
T_{off} (μs)	0.5	0.9	1.3
I_P (A)	16	17	-
W_S (m/min)	2	4	6
W_T (g)	350	550	750

Scanning electron microscope (SEM) was used to examine the surface characteristics of the machined part to measure the WLT. The average WLT was calculated for three different measurements at three different areas. Eighteen sets of data were used for building and training ANFIS model.

3. ANFIS MODEL

Neuro-fuzzy system combines the advantage of fuzzy system which deals with explicit knowledge that can be explained and understood whereas neural network deals with implicit knowledge that can be acquired only through learning [7]. Five network layers were used by ANFIS to perform the following fuzzy inference steps: Layer 1: Each node in this layer performs fuzzification and generates membership grade of linguistic label of an input variable. Layer 2: The output of each node in this layer is obtained by multiplying the incoming signals and represents the firing strength of a rule. Layer 3: Each node calculates the normalized firing strength. Layer 4: Each node output is calculated by the sum of the signals of the third and second layer. Layer 5: The node in this layer calculates the overall output of the ANFIS.

4. MODEL VERIFICATION

Four random readings were used as the testing data set. The plot of 4 measured WLT values versus predicted values using the ANFIS model is shown in Figure 1. Appropriate agreement is obvious between the measured and predicted values. This close agreement obviously displays that the ANFIS model can be used to predict the WLT under consideration.

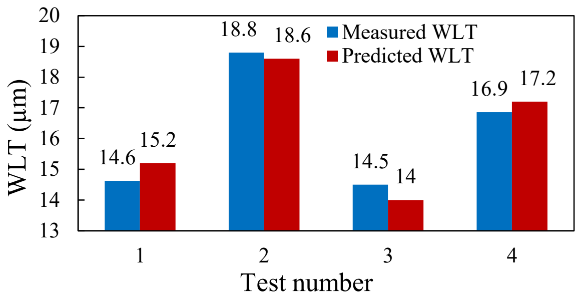

Figure 1 Comparison of measured and predicted WLT for the testing data set

To evaluate the Fuzzy model, the percentage error E_i and average percentage error E_{av} defined in Eqs. (1) and (2), respectively, were used.

$$E_i = \frac{|T_m - T_p|}{T_m} \times 100 \quad (1)$$

$$E_{av} = \frac{1}{m}\sum_{i=1}^{m} E_i \quad (2)$$

Where Tm is the measured WLT; Tp is the predicted WLT; and i=1,2,3 is the sample number. The obtained average percentage error is 2.61 %. The low error level signifies that the WLT results predicted by ANFIS are very close to the actual experimental results. The error values mean that the proposed model can predict WLT satisfactorily.

5. Results and discussion

The ANFIS model shows that the peak current and discharging time are the most significant parameters affecting the WLT. The wire tension and wire speed has minor effect on the WLT. Charging time has moderate effect on the WLT. The ANFIS model shows that minimum WLT is achieved at the lowest levels of peak current and discharging time. The spark energy increases with increasing discharging time and/or peak current. Hence, more heat is produced on the machined surface that leads to a larger WLT on the workpiece.

6. CONCLUSION

ANFIS was used to develop empirical model for predicting the WLT in WEDM. Discharging time, charging time, peak current, wire speed, and wire tension were used as predictor variables. Eighteen measured WLT values, under different cutting conditions, were used as training data set and four values were used as testing data set. The model was verified with test data where the average error was 2.61%. These results indicate that ANFIS model is accurate and can be used to predict WLT in WEDM.

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