RSM and ANN Modeling of Micro Wire Electrical Discharge Machining of AL 2024 T351

P.Sivaprakasam, P.Hariharan and S.Gowri

***Abstract*—This paper presents modeling and analysis of machining characteristics of Micro Wire Electro Discharge Machining (Micro-WEDM) process on Aluminium alloy (AL 2024 T351) using the Response Surface Methodology (RSM) and Artificial Neural Network (ANN). The input variables of Micro-WEDM process were voltage, capacitance and feed rate. The surface roughness and material removal rate are considered as a response variables. Experiments were carried out on Aluminium alloy using Central Composite Design (CCD). The RSM and ANN models have been developed based on experimental designs. Analysis of variance (ANOVA) has been employed to test the significance of RSM model. It has been found out that all the three process parameters are significant and their interaction effects are also significant on the surface roughness and material removal rate. Finally predicted values were compared with ANN.**

Keywords: Modeling; Micro WEDM; ANOVA; ANN; RSM .

I. INTRODUCTION

RECENTLY, miniaturization and improvement of products in industry are advancing at a rapid pace, leading to increasing demands for micro-parts and micro-metal molds. Needs for micro-EDM are consequently growing stronger and stronger. In order to create in micro components in micro scale, fabrication by micro machining has unique advantage in creating 3D components using variety of engineering materials. Micro Electrical discharge machining (EDM) is especially suitable for manufacturing micro-components due to its thermal material removal mechanism, which allows an almost process-force free machining independently of the mechanical properties of the processed material. High-precision Micro-EDM can process functional materials like hardened steel, cemented carbide and electrically conductive ceramics with sub-micron precision. Micro EDM is recognized as an effective machining technique in the production of micro parts and components used in wide range application namely aerospace, biomedical, electronics, environmental, communications and automotive.

This research aims to develop mathematical model for predicting machining performance of Micro-WEDM process on of difficult to cut material Aluminium alloy (AL 2024 T351) for improving and enhancing the performance of Micro-WEDM. Experimental investigation on feasibility of achieving fine surface finish and better material removal rate will investigate the machining of AL 2024 T351 Micro-WEDM process. Comparative studies were conducted on the performance of Micro-WEDM using artificial neural network.

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TABLE I. INPUT FACTORS AND THEIR LEVELS

Variable	Symbol	Levels-1	0	1
Voltage,(V)	A	80	90	100
Capacitance (F)	B	0.01	0.1	0.4
Feed Rate (m sec)	C	5	10	15

II. RESPONSE SURFACE METHODOLOGY (RSM)

RSM is a collection of statistical and mathematical techniques useful for design of experiments and optimizing process parameters [1]. RSM used for determining and representing the cause and effect relationship between the responses and input control variables influencing the responses as a two- or three-dimensional hyper surface.[2] Y. C. Lin [3] evaluated the machining characteristic of micro EDM using response surface methodology. RSM based on the CCD could efficiently be applied for the modeling of Micro-EDM [4].

III. EXPERIMENTATION

DT-110 is a 3-axis automatic multi process integrated machining system for micromachining. A Variety of materials; metallic and non-metallic can be machined to a very precision. The experimental studies were performed on a DT-110 a 3-axis automatic multi process integrated machining system using Micro-WEDM setup. Different machine settings parameter of voltage, Capacitance and feed rate were used in the experiments as given in Table 1.Twenty different combinations of machining parameters were determined by using a response surface methodology using central composite design method to estimate the effects of machining parameters on surface roughness and material removal rate. Zinc coated copper wire with diameter of 70m was used as electrode materials. Aluminium alloy (AL 2024 T351) was used as work piece material with 50 mm length, 10 mm width and 0.65 mm thickness. Surface roughness value, Ra was measured with a non contact surface roughness tester supplied by Taylor Hobson. The cutoff length was set at 0.250 mm with an evaluation length of 0.8mm and roughness values were the average of three measurements per specimen. The material removal rate calculated using equation 1.

IV. RESULTS AND DISCUSSION

The effect of the machining parameters such as voltage, capacitance and feed rate of Micro-WEDM were investigated

TABLE II. EXPERIMENTAL RESULTS FOR SURFACE ROUGHNESS AND MATERIAL REMOVAL RATE

Experimental Run	Block	Factor 1	Factor 2	Factor 3	Response 1	Response 2
		A:Voltage V	B: Capacitance F	C:Feed Rate m /sec	Surface Roughness m	MRR (mm3/min)
1	Block 1	1	1	1	1.94	0.0308
2	Block 1	1	1	-1	3.66	0.0134
3	Block 1	1	-1	1	0.97	0.0218
4	Block 1	0	0	0	2.59	0.0173
5	Block 1	-1	1	-1	2.46	0.0129
6	Block 1	0	0	0	2.15	0.0172
7	Block 1	-1	1	1	2.97	0.0222
8	Block 1	-1	-1	-1	0.87	0.0102
9	Block 1	0	0	-1.681	2.59	0.0114
10	Block 1	0	1.681	0	3.28	0.0204
11	Block 1	-1	-1	1	1.06	0.0161
12	Block 1	0	0	0	2.43	0.0177
13	Block 1	0	0	1.681	2.13	0.0219
14	Block 1	-1.681	0	0	2.12	0.0171
15	Block 1	0	0	0	1.98	0.0178
16	Block 1	0	0	0	2.88	0.0186
17	Block 1	0	0	0	1.78	0.0180
18	Block 1	1	-1	-1	1.26	0.0116
19	Block 1	1.681	0	0	2.12	0.0189
20	Block 1	0	-1.681	0	1.11	0.0154

using a CCD. The experimental results of response parameters surface roughness and material removal rate values are presented in Table 2, using a series of experimental runs. The statistical analysis indicates that the model is adequate; no significant lack of fit and well fits with the actual data. The ANOVA Table for the reduced quadratic model for surface roughness and MRR are shown in Table 3 and Table 4 respectively. The second-order polynomial equation is used to express the Surface Roughness (YSR) and MRR(YMRR) of Micro-WEDM process with operating parameters for the Micro-WEDM, namely voltage (A), capacitance (B), feed rate (C).The relationship between the responses (SR and MRR) and machining parameters are obtained using Design Expert Software for a coded unit as follows.

Model equation for Surface Roughness

$$Y_{SR} = +2.11750 + 0.034415 * A + 0.7702 * B - 0.1525 * C - 0.33875 * A * C \quad (1)$$

Model equation for MRR

$$Y_{MRR} = 0.018 + 0.001408 * A + 0.002051 * B + 0.004427 * C + 0.00155 * A * C + 0.001325 * B * C \quad (2)$$

Based on ANOVA Table 3; it is found that the discharge voltage (A), capacitance (B),feed rate(C), interaction term voltage and feed rate (AC) have significant effect on the surface roughness. Fig 1 shows the estimated response surface for the SR parameter, according to design parameters of discharge voltage and feed rate. It shows that when discharge voltage increases, the SR parameter tends to increase noticeably. It is also found that the SR parameter

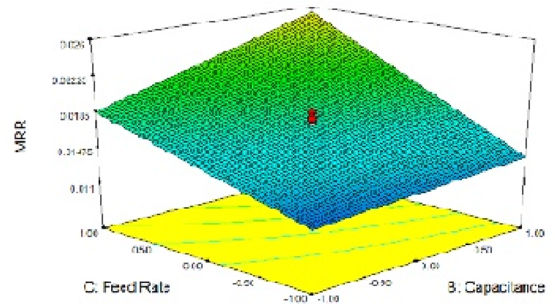

Fig. 1. Surface response of SR (A, C)

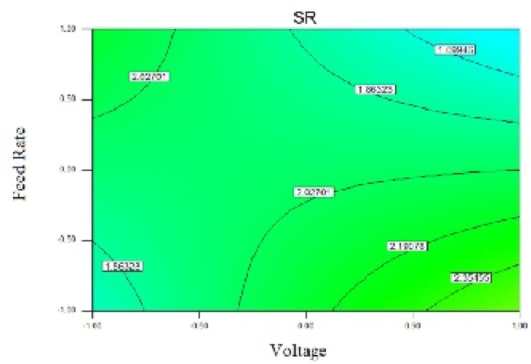

Fig. 2. Contour plot of SR (A, C)

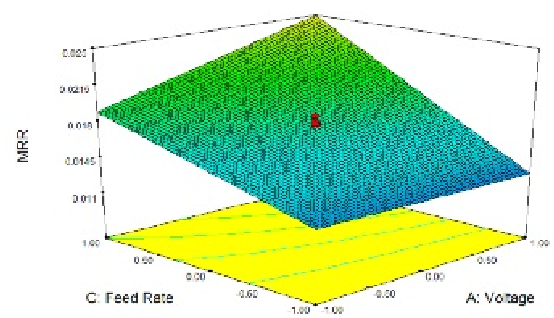

Fig. 3. Surface response of MRR (A, C)

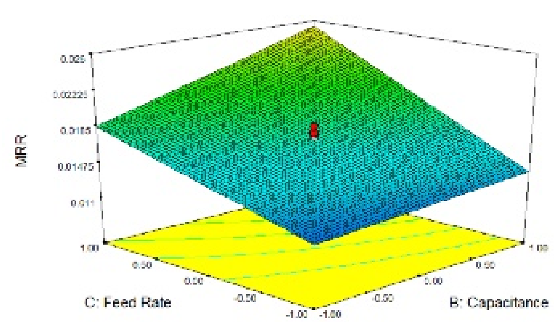

Fig. 4. Surface response of MRR (B, C)

increases when the feed rate is increased. Fig 2 shows the two dimensional contour plot of voltage and feed rate, capacitance remains fixed at 0.1F.The optimum machining condition obtained using desirability function. According to ANOVA Table 4, it is found that the discharge voltage (A), capacitance (B),feed rate(C) , interaction term voltage and feed rate (AC) capacitance and feed rate (BC) have significant effect on the Material removal rate. From the Fig 3 the MRR increase while increasing voltage and feed, similarly noticed that the MRR increasing while increasing capacitance and feed rate shown in Fig 4.

The main goal is minimization of surface roughness and maximization of MRR. The fine surface finish 1.07m and material removal rate 0.02154mm3/min achieved using optimized machining condition voltage 100V, capacitance 0.01F and feed rate 15m / sec. Fig 5 shows the three dimensional surface image using non contact 3D Profiler under the optimized machining conditions.

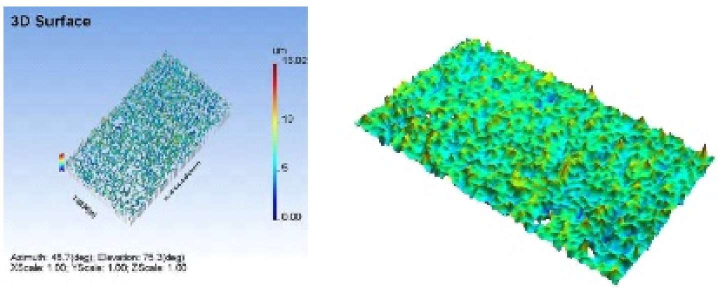

Fig. 5. 3D Surface profile

TABLE III. ANALYSIS OF VARIANCE FOR SURFACE ROUGHNESS

Source	Sum of Square	Degree of freedom	Mean Square	F Value	p-value Prob >F	
Model	9.354953	4	2.3387	15.5728	<0.0001	Significant
A-Voltage	0.016175	1	0.01617	0.1077	0.7473	
B-Capacitance	8.102867	1	8.1028	53.9562	<0.0001	
C-Feed Rate	0.317898	1	0.3178	2.1168	0.1663	
AC	0.918013	1	0.9180	6.1129	0.0259	
Residual	2.252622	15	0.1501			
Lack of Fit	1.419938	10	0.1419	0.8526	0.6133	Not significant
Pure Error	0.832683	5	0.1665			
Cor Total	11.60758	19				

V. ARTIFICIAL NEURAL NETWORK MODELING

[!h] An Artificial Neural Network (ANN) is a flexible mathematical model used for predicting the machining performance, especially non linear optimization with constraints by relating between the input and output parameters. The variety of works has been published with ANN tool for prediction of response process of EDM machining process as well as several experts

TABLE IV. ANALYSIS OF VARIANCE FOR MATERIAL REMOVAL RATE

Source	Sum of Squares	Degree of freedom	Mean Square	F Value	p-value Prob >F	
Model	3.854E-004	5	7.709E-005	32.43	<0.0001	significant
A-Voltage	2.707E-005	1	2.707E-005	11.39	0.0045	
B-Capacitance	5.744E-005	1	5.744E-005	24.17	0.0002	
C-Feed Rate	2.677E-004	1	2.677E-004	112.61	<0.0001	
AC	1.922E-005	1	1.922E-005	8.09	0.0130	
BC	1.404E-005	1	1.404E-005	5.91	0.0291	
Residual	3.328E-005	14	2.377E-006			
Lack of Fit	3.198E-005	9	3.554E-006	13.94	0.0050	significant
Pure Error	1.293E-006	5	2.587E-007			
Cor Total	4.187E-004	19				

TABLE V. TEST SET USED FOR NN ANALYSIS

Exp No	Factor 1	Factor 2	Factor 3	Actual values		ANN		ANN	
	A: Voltage V	B: Capacitance μF	C: Feed Rate μm /sec	SR μm	MRR (mm3/ min)	Predicted SR	Error %	Predicted MRR	Error %
1	1	1	1	1.94	0.0308	1.9406	-0.030	0.0320	-3.8961
2	1	1	-1	3.66	0.0134	3.779	-3.251	0.0152	-13.432
3	1	-1	1	0.97	0.0218	1.003	-3.402	0.0218	0.00
4	0	0	0	2.59	0.0173	2.337	9.768	0.0185	6.936
5	-1	1	-1	2.46	0.0129	2.459	0.040	0.0154	-19.37

used Artificial Neural Networks (ANN) method to train a model for micro-EDM processes [5] [6]. Feed forward neural network model is considered in this study to evaluate the machining performance (Surface roughness) of Micro -WEDM process on machining parameters such as voltage, capacitance and feed rate. The typical ANN model of Micro WEDM process is shown in Fig.6. Among the twenty experiments, fifteen experiments were used for training the network and five experiments were used for testing the experiments.

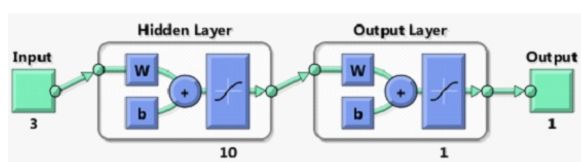

Fig. 6. Architecture of ANN Model

To measure the effectiveness of the developed ANN model, the predicted values were compared with the experimental data shown in Table 5. The predicted average error percentage of SR is 0.624% and MRR is 8.72% in ANN.

VI. Conclusion

The influences of input machining parameters on the machining performance of Micro WEDM process were experimentally investigated. The RSM and ANN models have been developed based on experimental designs for surface roughness and Material removal rate. It has been found out that all the three process parameters (A, B, C) are significant and their interaction effects (AC) significant on the surface roughness and voltage and feed rate (AC), capacitance and feed rate (BC) have significant effect on the Material removal rate. Finally predicted values were compared with ANN. It is found that capacitance is the most significant influencing factor for surface roughness. When increasing the capacitance the surface roughness values is increases, increasing voltage and feed rate decreasing in surface roughness. Capacitance and feed rate more significant influencing factor for material removal rate. The fine surface finish 1.07m and material removal rate 0.02154 (mm3/min) are achieved using optimum machining condition voltage 100V, capacitance 0.01F and feed rate 15m / sec. Finally predicted values and experimental values were compared with ANN. The predicted error percentages are 0.624

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