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A Study of Dimensional Accuracy on Die Sinking Electrical Discharge Machining of Ti-6AL-4V

Nurezayana Zainal[1]*, Azlan Mohd Zain[1], Safian Sharif[2] and Haza Nuzly Abdul Hamed[1]

[1]Soft Computing Research Group, Faculty of Computing, Universiti Teknologi Malaysia, Skudai - 81310, Johor, Malaysia; ezayana@gmail.com
[2]Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Skudai - 81310 Johor, Malaysia

Abstract

Objectives: In this work, an investigation of dimensional accuracy (DA) on the die sinking electrical discharge machining (EDM) of Ti-6AL-4V titanium alloy with positive polarity of copper-tungsten (Cu-W) electrode has been carried out. **Methods/Analysis:** Pulse on time (ON), pulse off time OFF), peak current (IP) and servo voltage (SV) were selected as the cutting parameters. The experiments have been conducted upon the two levels of full factorial design with added four center points Design of Experiments (DOE). A mathematical model is developed to associate the effects of these four cutting parameters with DA of the work piece. Multiple linear regression modelling technique was performed in the mathematical modelling process. Furthermore, Analysis of Variance (ANOVA) technique was performed to determine the significance of the cutting parameters. **Findings:** Based on the results, ON, IP and SV were found to be the significant cutting parameters contributes to the DA. This finding also indicates the model developed is observed to be in good simultaneous with the experimental results.

Keywords: Copper Tungsten, Dimensional Accuracy, Electrical Discharge Machining, Titanium Alloy

1. Introduction

Electrical Discharge Machining (EDM) is a modern machining method which is generally being utilized in the industry. The process involved material removal in EDM is depends on the series of electrical discharge (spark) created a temperature in the range 8000°C–12000°C between a work piece and an electrode, which are both submerged in a dielectric fluid[1]. In the meantime, high temperature produced during the discharge removes material from the electrodes by melting and vaporization processes[2,3]. The EDM spark debris which created because of machining process is required to be evacuated to keep the sparking zone clean. Or else, the debris concentration will bring about an abnormal discharge, which prompting to unstable machining and harsh surface. The EDM can be used to machine all types of traditional machining operations. Moreover, EDM process can be employed to cut complex, detailed contours or cavities within parts and fabrication.

Titanium is artificially responsive with all cutting tool materials and it is low thermal conductivity and low modulus of adaptability. Basically, the utilization of titanium and its alloys is expanding in numerous modern and business applications. It is because of its favourable which high temperature strength, high strength–weight ratio and biological compatibility[4]. Ti-6Al-4V has a decent machinability include and superb physical and mechanical properties[5]. In addition, Ti-6Al-4V is a titanium alloy that has higher erosion resistance.

Over the past few years, titanium alloys have been expanding popular in the aviation segment because of the expanded effectiveness and higher working temperature of air gas turbine motor[4-6]. Also, the excellent quality weight proportion of titanium composites gives a lessening of airplane weight and, hence, a diminishment in fuel utilization and emanations. However, titanium alloy is immensely difficult-to-machine due to their toughness, low warm conductivity, strength at high temperatures

*Author for correspondence

and chemical reactivity with apparatus materials for more material removal processes. Thus, according to the advantages of EDM process as above, it can be seen that titanium alloy can be adequately machined by EDM[7].

Copper-tungsten electrodes provide a superior surface finish and furthermore longer life instead of other graphite electrodes[8]. Copper-tungsten is suitable for the use in the EDM process because of its thermal properties. Normally, its Cu part gives a high thermal conductivity, while its W segment gives a better start disintegration resistance[9]. Moreover, copper-tungsten has a low thermal extension coefficient and has a high running temperature. Then, it has a decent wear resistance properties and great thermal conductivity due to the presence of Cu and its high tungsten content[7-9].

The main goal of the present study is to optimize the cutting parameters in die sinking EDM with positive polarity of copper-tungsten electrode to investigate the parameters affecting Dimensional Accuracy (DA) by applying the full factorial design of experiments, which has generally been used in the past. The cutting parameters considered are Pulse on Time (ON), Pulse off Time (OFF), Peak Current (IP) and Servo Voltage (SV). The outcome of these cutting parameters is analysed using Analysis of Variance (ANOVA).

2. Materials and Methods

2.1 Experimental Setup

The experiments were performed on the AG40L Sodick model of die-sinking electrical discharge machine. The machine and experimental setup were illustrated in Figure 1. Ti-6Al-4V titanium alloy workpiece material

Figure 1. Figure of the machine **(a)** Machine **(b)** Experimental setup for EDM process.

was used in the experimental study. The electrode material used was copper-tungsten. The work piece was cut to a size of 100mm × 60mm × 5mm for experimental and machined using 8mm diameter of the electrodes. Moreover, oil was utilized as dielectric fluid. The work piece was EDMed at 1.5mm depth of hole. Meanwhile, the cutting parameters with their designation, units and respective levels are listed in Table 1.

Full factorial design of experiment methodology was employed for designing the experimental with added four center points which resulted in a total number of 20 runs. The combinations of cutting parameters by fractional were obtained using Design Expert 6.0.4 software. The organization of the experiment's parameters was noted as coded terms; the low level (–), center point (cp) and high level (+) as shown in Table 2. The experimental run orders and their results were shown in Table 3.

2.2 Measuring and Test Equipment

The variations of the diameter of EDMed work pieces were investigated in this study. The hole diameter produced were measured by using the digital microscopy image analyser. The work piece material will be placed under the microscopy tools and some adjustments were needed as to get the clear picture of the holes. The image of the diameter of each hole will be obtained and calculated through the screen of the computer. And so, the following equation as in (1) was used to specify the dimensional accuracy:

$$Dimensional\ Accuracy = \frac{DH_E - DH_W}{DH_E}\ x\ 100\% \quad (1)$$

Where, DH_E is the diameter hole for electrode in mm and DH_W is the diameter hole for work piece in mm.

2.3 Determination of Regression Analysis Model for Dimensional Accuracy

A mathematical model was developed using multiple regression analysis method. Regression analysis employs

Table 1. Factor and level for EDM parameters of titanium alloy

Symbol	Name	Units	Level	
			Low (−1)	High (+1)
ON	Pulse on time	μs	150	230
OFF	Pulse off time	μs	60	90
IP	Peak current	A	10	12
SV	Servo voltage	Volt	30	60

Table 2. Two level full factorial experiments with four factors and four center points

Std	ON (µs)	OFF (µs)	IP (A)	SV (Volt)
1	–	–	–	–
2	+	–	–	–
3	–	+	–	–
4	+	+	–	–
5	–	–	+	–
6	+	–	+	–
7	–	+	+	–
8	+	+	+	–
9	–	–	–	+
10	+	–	–	+
11	–	+	–	+
12	+	+	–	+
13	–	–	+	+
14	+	–	+	+
15	–	+	+	+
16	+	+	+	+
17	cp	cp	cp	cp
18	cp	cp	cp	cp
19	cp	cp	cp	cp
20	cp	cp	cp	cp

a model that describes the connections between the dependent and independent variables in a simplified mathematical form[10]. In this investigation, a whole analysis was done using the experimental data in Table 3. Regression analysis was performed to predict the dimensional accuracy by using Design Expert 6.0.4 software. The general model to predict the DA over the experimental region can be expressed as in (2).

$$\bar{y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_1 x_2 + \beta_6 x_1 x_3 + \beta_7 x_1 x_4 + \beta_8 x_2 x_3 + \beta_9 x_2 x_4 + \beta_{10} x_3 x_4 \quad (2)$$

Where $\bar{y}$ is the estimated responses, x_n are the variables for cutting parameters and β_n are regression coefficients.

3. Results and Discussions

The effects of individual cutting parameters on DA in EDM of Ti-6AI-4L titanium alloy are discussed in this part. Design Expert 6.0.4 software was performed to carry out the ANOVA results. Additionally, the machining layout of the work piece, electrodes and the images of the diameter of the holes are shown in Figure 2, Figure 3 and Figure 4, respectively.

Table 3. Experimental design and results for DA

Std.	Run	Machining parameters				Machining response
		ON (µs)	OFF (µs)	IP (A)	SV (Volt)	DA (%)
1	16	150	60	10	30	0.019
2	3	230	60	10	30	0.022
3	2	150	90	10	30	0.020
4	9	230	90	10	30	0.022
5	15	150	60	12	30	0.021
6	12	230	60	12	30	0.024
7	11	150	90	12	30	0.022
8	8	230	90	12	30	0.022
9	13	150	60	10	60	0.015
10	5	230	60	10	60	0.018
11	6	150	90	10	60	0.019
12	4	230	90	10	60	0.020
13	10	150	60	12	60	0.018
14	1	230	60	12	60	0.021
15	7	150	90	12	60	0.017
16	14	230	90	12	60	0.022
17	19	190	75	11	45	0.020
18	18	190	75	11	45	0.021
19	17	190	75	11	45	0.020
20	20	190	75	11	45	0.020

3.1 Analysis of Dimensional Accuracy

Checking the lack of fit of the model may be needed for the process of analysis of data. The checking of an adequacy of the model incorporates test for significance of regression model and lack of fit[11]. For this reason, ANOVA is performed where is the F value is tested. The P value is an indication of the F value is larger than the calculated F value due to the noise[12]. The significance of corresponding term is presented when the P value is less than 0.05. Also, the P value of lack of fit must be greater the 0.05[11,12].

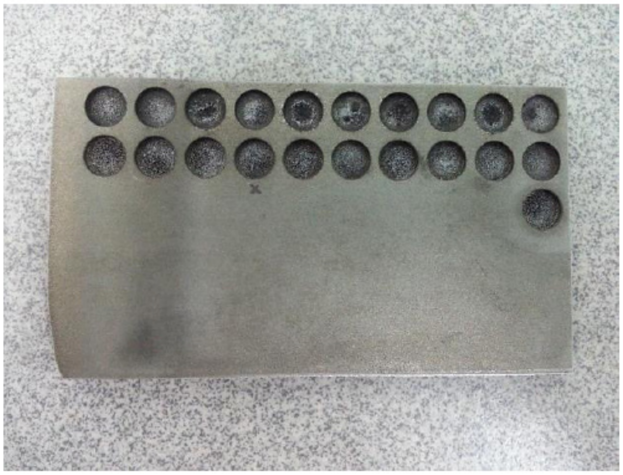

Figure 2. Ti-6AI-4L titanium alloy work piece after machining.

Figure 3. Copper-tungsten electrodes after machining.

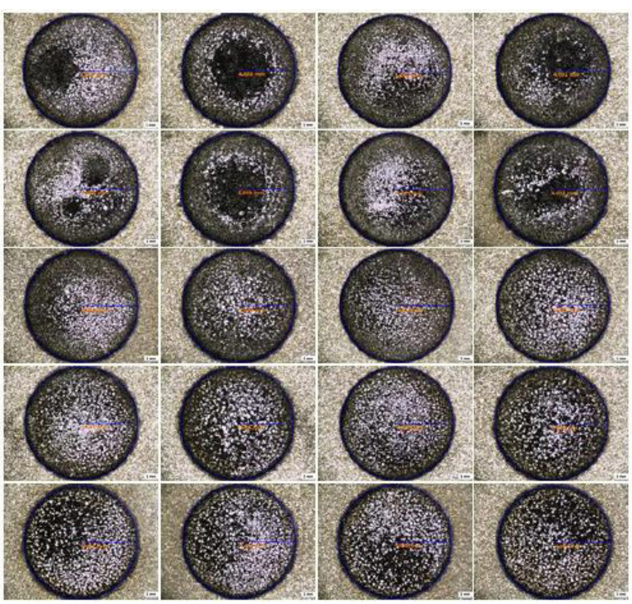

Figure 4. Images of diameter of the holes.

The developed model is fitted when the value of lack of fit is insignificant. As presented in Table 4, the suggested regression model is statistically significant model which is 0.0015 while the lack of fit is statistically insignificant (0.1212). Furthermore, it shows that ON, IP and SV are statistically significant in affecting DA. The rest factors show insignificant with the P value larger than 0.05. The coefficient of determination (R-Squared) value indicates the adequacy of the model[13]. The value of R-squared for the model is calculated as 0.9085, which indicate the high significance of the model (very close to 1). It shows that 90.85% of the variance in the metal removal rate is assigned to process parameters and the variation which cannot explain by model is 9.15%. Moreover, normality of residuals was checked using normal probability plot. It can be seen from Figure 5 that all the residuals are falling on the straight line. It shows the errors are normally distributed, which satisfy the normality test conditions. Hence, the model developed is adequate and valid.

Table 4. ANOVA for dimensional accuracy

Source	Sum of Squares	df	Mean Square	F Value	P-value
Model	7.5000E-05	10	7.5000E-06	8.9404	0.0015
A-Pulse on time	2.5000E-05	1	2.5000E-05	29.8013	0.0004
B-Pulse off time	2.2500E-06	1	2.2500E-06	2.6821	0.1359
C-Peak current	9.0000E-06	1	9.0000E-06	10.7285	0.0096
D-Servo voltage	3.0250E-05	1	3.0250E-05	36.0596	0.0002
AB	1.0000E-06	1	1.0000E-06	1.1921	0.3033
AC	2.5000E-07	1	2.5000E-07	0.2980	0.5984
AD	1.0000E-06	1	1.0000E-06	1.1921	0.3033
BC	4.0000E-06	1	4.0000E-06	4.7682	0.0568
BD	2.2500E-06	1	2.2500E-06	2.6821	0.1359
CD	0.0000E+00	1	0.0000E+00	0.0000	1.0000
Residual	7.5500E-06	9	8.3889E-07		
Lack of Fit	6.8000E-06	6	1.1333E-06	4.5333	0.1212
Pure Error	7.5000E-07	3	2.5000E-07		
Cor Total	8.2550E-05	19			
Std. Dev.	0.00092		R-Squared		0.9085
Mean	0.02015		Adj R-Squared		0.8069
C.V. %	4.54545		Pred R-Squared		0.1452
PRESS	0.00007		Adeq Precision		12.6857

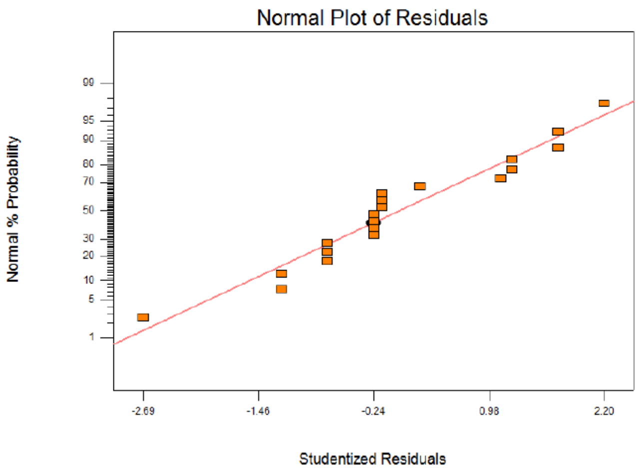

Figure 5. Normal probability plot of residuals for DA.

By using the multiple linear regression analysis equation from (2) with the experimental data, the final regression model for DA can be written as in (3).

$$DA = -0.0095 + (9.375E-06 * A) + 0.0004 * B + 0.0027 * C - 0.0003 * D - (4.167E-07 * A * B) + (3.125E-06 * A * C) + (4.167E-07 * A * D) - (3.333E-05 * B * C) + (1.667E-06 * B * D) - (2.476E-19 * C * D) \qquad (3)$$

Where DA is dimensional accuracy, A is pulse on time in µs, B is pulse off time in µs, C is peak current in Ampere and D is servo voltage in Volt.

4. Conclusions

In this work, the effects of the pulse on time (ON), pulse off time (OFF), peak current (IP) and servo voltage (SV) on the DA of die sinking EDM were studied. The experimental data were collected from AG40L Sodick electrical discharge machine upon the full factorial design of experiment with added four center points. The effect of each machining parameter on the DA was determined using ANOVA technique. Thus, the following conclusions are made.

1. DA has found to be most minimum at the run no. 9 (0.015) which the combinations of the cutting parameters are 150µs of ON, 60µs of OFF, 10A of IP and 60V of SV.
2. The predicted values match the experimental values reasonably well, with R-squared of 0.9085 for DA.
3. ON, IP and SV were found to be the significant parameters in affecting DA.

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