Study the effects of Process Parameters on Overcut of Al6061 Alloy by (Fe₂O₃) Nano- Powder-Mixed Micro-EDM

Nagwa Mejid Elsiti
Benghazi University,
Industrial and Manufacturing
System Engineering
Benghazi, Libya

Abstract: The effect of process parameters on micro-EDM namely current (I), voltage (V) and pulse on time (TON) were studied based on Tool Overcut (OC). The effect of Fe₂O₃ nano-powder mixed dielectric on the overcut for AL6061 alloy was studied using a Die Sinking (EDM) Machine. Effect of the process parameters was examined by 2-Level Factorial Design using Design of Experiment (DOE) software, whereas the level of importance was statistically evaluated using ANOVA. The results indicate discharge current and pulse on time significantly influenced the EDM process compared to voltage. It was also concluded that the use of Fe₂O₃ nano-powder mixed micro-EDM decreased the overcut values.

Keywords: Fe₂O₃ Nano-powder; Micro-EDM; Overcut, Al6061 alloy

1. INTRODUCTION

Electrical discharge machining (EDM) has become the workhorse of the tool making industry due to the precise machining of the workpiece that conducts electricity. It plays a major role in machining of dies, tools and other products manufactured from difficult-to-machine materials [1]. In principle, the material erosion mechanism employed in EDM is largely based on the conversion of electrical energy to thermal energy. This is accomplished by the release of discrete electric charges between the electrode (tool) and the workpiece immersed in a dielectric fluid [2]. The repetitive spark discharge generates considerably high temperatures in the spark zone which melts and vaporizes the workpiece material during EDM [3]. However, in Micro-EDM (scaled-down version of EDM), the range of process parameters is lowered to ensure spark discharge in a micro-joule range. This reportedly improves the machining of hard-to-machine materials in micro domain (chip or debris size in microns)[4]. The technique has a number of unique advantages such as exerting a small force between the work piece and tool electrode essential for fabricating hard-to-cut materials [5].

Despite its unique advantages, Micro-EDM has some drawbacks one of which is overcut. The overcut is the clearance per side between the electrode and workpiece. It is also defined as the difference between the magnitude of the electrode and the cavity created during machining. As a result, it is essential to minimize overcut to ensure the dimensional accuracy of finished products [6]. In order to improve the performance output of EDM, like the low material removal rate (MRR) and relatively poor surface finish, a modified process using suspended powder particles in dielectrics has been developed. The addition of the powder improves MRR and reduces the tool wear rate (TWR), however, it may result in increased overcut size. The powder addition process in conventional EDM is called powder mixed EDM (PMEDM) [7, 8]. Numerous studies has been carried out to improve the performance of EDM. The parameters typically examined

include; MRR, TWR, EWR, EW, SR, SF, taper and very few for overcut, dimensional precision, surface quality, RCL, HAZ, depth of the micro cracks and HV [9]. Pradhan [10]; investigated the effect of material removal rate (MRR), tool wear rate (TWR) and overcut(OC) with AISI D2 tool steel on EDM performance. The weights of the responses were analyzed by GRA, PCA and response surface methodology (RSM). Similarly, Belgassim et al.,[11]; examined and optimized EDM parameters using L9 orthogonal array based on the Taguchi method and Analysis of Variance (ANOVA). The EDM parameters investigated included; pulse current (Ip), pulse on time (T_{on}), pulse off time (T_{off}), and gap voltage (V_g). In addition, machining responses based on surface roughness, machined surface and overcut were examined. Consequently, the optimum surface finish of the EDM surface was deduced from the input parameters investigated in the study. Kumar et al.,[12] investigated overcut using reverse polarity and powder metallurgy tool electrodes based on the Taguchi method. The results demonstrated that overcut and pulse-on time are maximized by applying minimal current. Likewise, the findings demonstrated that overcut can be improved at average values of duty cycle and gap voltage.

The review of literature demonstrates that there is limited research on the size of overcut during PMEDM. Therefore, the objective of this work is to investigate the effect of process parameters namely; current (C), Voltage (V), Pulse ON-time and nano-powder mixed dielectric on the size of overcut (OC) during the process of PMEDM.

2. EXPERIMENTAL PLAN AND PROCEDURES

The experiments in the current research were performed by an AG40L Sinker EDM (Fig.2), and the material of workpiece samples was Al6061 alloy. The samples were cut into slides with dimensions of 50mm x 90mm x 1mm, and the electrode was copper with 6mm length and 500µm diameter. The dielectric fluid was mixed with 4g/l percentage of Fe₂O₃ nano-powder. The

PMEDM experiments were carried out in the working tank with dimensions; 46cm × 35cm × 24cm fabricated from 1.5mm thick stainless steel sheets as illustrated in figure 2. During each test, a stirrer was employed to maintain the homogeneity of the Fe₂O₃ nano-powder suspension in the tank. The selected input variables of the study were; current, voltage, and pulse-on time.

Figure 1. AG40L Sodick electrical discharge machine

Figure 2. Working tank

The Design of Experiment (DoE) was carried out using 2 Level Factorial Design comprising 8 points (2³), and 3 center points as presented in table 1. Consequently, a total of 11 experimental runs were conducted as outlined in table 2.

Table 1. Selected Machining Process Parameters

Symbol	Input Factors	Unit	level	
			Low	High
A	Current	A	4	6
B	Voltage	V	4	15
C	Pulse On	μs	10	120

The overcut (OC) was calculated for all experimental runs according to Eq. 1;

$$OC = DW/2 \quad (1)$$

Where the terms DW= D₁ – D; and D₁ represents the diameter of the entry hole and D – the diameter of the electrode (tool).

Table 2. Design of Experimental and Responses

no	Level parameters			Results	
	current	voltage	Pulse-ON time	(OC1) Free powder	(OC2) Fe ₂ O ₃ 4g/l
	Amp	v	s	mm	mm
1	4	4	10	17.78	1.04
2	6	4	10	119.61	9.32
3	4	15	10	23.74	2.98
4	6	15	10	157.87	15.26
5	4	4	120	40.29	4.56
6	6	4	120	119.45	7.24
7	4	15	120	46.63	9.75
8	6	15	120	125.61	14.27
9	5	4.5	65	38.39	6.71
10	5	4.5	65	94.18	7.24
11	5	4.5	65	99.22	9.97

3. RESULTS AND DISCUSSIONS

3.1 Effect of Process Parameters on OC

Figures 3- 4 presents the variation of overcut of micro-holes produced by various process parameters during machining. The main effect plots of OC1 and OC2 demonstrate the overcut of the micro-holes increase sharply with peak current. The minimum overcut was obtained at the corresponding discharge current of 4 A. In addition, it was observed that the peak current increased with increase in discharge energy density resulting in breakdown of debris into smaller particles. As a result, the smaller sized debris particles obtained easily seeped through the narrow passage between the micro-tool and wall of the micro-hole. This phenomena decreases the chances of a second spark and mechanical scratching of the internal walls of micro-hole resulting in lower overcut (OC) [13]. At higher peak current settings of 6A, the overcut was observably high. This is attributed to the ejection of large sized of debris from the micro-hole at high discharge energy. This may also be ascribed to the occurrence of the secondary sparking phenomenon and materials entering the side hole wall [13, 14]. The results also demonstrated that pulse-on time significantly influenced OC2. When the values of pulse on time increase the overcut values increase. However, the effect of voltage on OC1, was not significant, while it has a significant effect on OC2. The OC2 had a small value when voltage was 4v.

Figure. 3 Variation of OC1 with process parameters

Figure. 4 From (a-d) variation of OC2 with process parameters

3.2 ANOVA Analysis and Optimal Conditions

The accuracy and relative significance of the process responses OC1 and OC2 were examined by Analysis of Variance (ANOVA). Tables 3 – 4 present ANOVA test results for the defined responses. From the ANOVA tables, it can be concluded that peak current had a significant contribution to OC1 and OC2. However, the pulse on time and voltage had a significant effect on only OC2.

Table 3. Analysis of Variance (ANOVA) test for (OC1)

Source	SS	DF	Mean Sq	F-value	P-value
A(current)	19414.35	1	19414.35	45	0.0002
Curvature	36.84	1	36.84	0.077	0.7889
Residual	3846.2	8	480.78	--	--
Lack of fit	1566.8	6	261.13	0.23	0.9324
Total	23297.4	10			

$$R^2 = 83.33\% \quad R^2_{\text{adjusted}} = 81.48\% \quad R^2_{\text{predicted}} = 77.01\%$$

Table 4. Analysis of Variance (ANOVA) test for (OC2)

Source	SS	DF	Mean Sq	F-value	P-value
A(current)	96.33	1	96.33	36.16	0.0018
B(voltage)	50.50	1	50.50	18.96	0.0073
C(pulse)	6.52	1	6.52	2.45	0.1786
AC	22.31	1	22.31	8.37	0.034
Curvature	0.014	1	0.014	0.000513	0.9457
Residual	13.32	5	2.66		
Lack of fit	7.2	3	2.4	0.78	0.6026
Total	188.99	10			

$$R^2 = 92.94\% \quad R^2_{\text{adjusted}} = 88.24\% \quad R^2_{\text{predicted}} = 73.30\%$$

3.3 Effect of Fe_2O_3 nano-powder on Overcut

Figure 5 shows the effect of Fe_2O_3 powder concentration on the magnitude of overcut. The results clearly indicate the size of the overcut decrease with increasing powder concentration.

Figure. 5 Comparison between Overcut values

4. CONCLUSION

In the present study, attempts were made to machine micro-holes on Al6061alloy with lower overcut (OC) using EDM and Fe_2O_3 nano-powder mixed dielectric at different concentrations. The following conclusions were made;

- The ANOVA analysis for OC1 and OC2 responses indicated current, voltage and pulse on time were

significant factors. The lowest OC was obtained at 4A (current), 4V (voltage) and 10 μ s (pulse-on time).

- The overcut (OC) decreased when Fe₂O₃ nano-powder was added to dielectric liquid.
- Lower overcut (OC) was observed at Fe₂O₃ nano-powder concentration of 4g/l.

5. REFERENCES

1. Sharma, R. and J. Singh, Effect of Powder Mixed Electrical Discharge Machining (PMEDM) on Difficult-to-machine Materials – a Systematic Literature Review, in Journal for Manufacturing Science and Production 2014. p. 233.
2. Kolli, M. and A. Kumar, Effect of Boron Carbide Powder Mixed into Dielectric Fluid on Electrical Discharge Machining of Titanium Alloy. Procedia Materials Science, 2014. **5**: p. 1957-1965.
3. Dwivedi, A.P. Comparative Assessment of MRR, TWR and Surface Integrity in Rotary and Stationary Tool EDM for Machining AISI D3 Tool Steel. 2015. (01.07.2015).
4. Jahan, M.P., M. Rahman, and Y.S. Wong, A review on the conventional and micro-electrodischarge machining of tungsten carbide. International Journal of Machine Tools and Manufacture, 2011. **51**(12): p. 837-858.
5. Moghanizadeh, A., Reducing side overcut in EDM process by changing electrical field between tool and work piece. The International Journal of Advanced Manufacturing Technology, 2016: p. 1-8.
6. Vikas, et al., Effect and Optimization of Machine Process Parameters on MRR for EN19 & EN41 Materials Using Taguchi. Procedia Technology, 2014. **14**: p. 204-210.
7. Talla, G., S. Gangopadhyay, and C.K. Biswas, Effect of Powder-Suspended Dielectric on the EDM Characteristics of Inconel 625. Journal of Materials Engineering and Performance, 2016. **25**(2): p. 704-717.
8. Batish, A., A. Bhattacharya, and N. Kumar, Powder Mixed Dielectric: An Approach for Improved Process Performance in EDM. Particulate Science and Technology, 2014. **33**(2): p. 150-158.
9. Choudri, P.B., Experimental Investigations into the Effect of Process Parameters on Performance Measures of Sink EDM Process- A Review till the year 2010 and Future Work. International Journal of Latest Trends in Engineering and Technology (IJLTET), 2016. **6**: p. 504-511.
10. Pradhan, M.K., Estimating the effect of process parameters on MRR, TWR and radial overcut of EDMed AISI D2 tool steel by RSM and GRA coupled with PCA. The International Journal of Advanced Manufacturing Technology, 2013. **68**(1-4): p. 591-605.
11. Belgassim, O. and A. Abu-Saada, Optimization of EDM Parameters in Machining AISI D3 Tool Steel by Grey Relational Analysis. Applied Mechanics and Materials, 2013. **330**: p. 747-753.
12. Dinesh Kumar, N.B., Anil kumar, Study Of overcut during electric discharge machining of hastelloy steel with different electrodes using the taguchi method. International Journal of advanced engineering technology, 2011(E-ISSN 0976-3945).
13. Shivakotia, I., et al., Multi-objective optimization and analysis of electrical discharge machining process during micro-hole machining of D3 die steel employing salt mixed de-ionized water dielectric. journal of computational and applied research, 2013. **3**: p. 27-39.
14. Zhao, F.L., H. Wang, and Z.Z. Lu, Calculating the Overcut in Electro-Discharge Machining. Key Engineering Materials, 2005. **291-292**: p. 561-566.