Investigation of Micro-EDM in Deionized Water Using Nanosecond Pulse Power Supply

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Abstract

Deionized water (DIW) is an eco-friendly dielectric fluid for micro-electric discharge machining (micro-EDM). Comparing with hydrocarbon oil, micro-EDM using DIW has higher material removal rate, lower tool wear and less debris formation. However, due to its slight conductivity, DIW causes a weak electrochemical reaction during micro-EDM. This leads to unexpected removal of material which affects machining shape and quality. This study aims to suppress electrochemical reaction in micro-EDM using DIW by employing short pulse power supply. Experiments to fabricate micro-holes were performed using the developed nanosecond pulse circuit with different pulse parameters. It was found that the affected area caused by electrochemical reaction was effectively eliminated when the pulse duration was reduced to a certain value. Besides, Energy-dispersive X-ray (EDX) spectroscopy analysis showed that the machined surface using DIW was less suffered from material migration in comparison to hydrocarbon oil.

1 Introduction

Micro-EDM has been a favourable process in micro-machining because there is no cutting force applied on the electrode and workpiece. It can be used to fabricate micro-holes, micro-nozzles as well as micro-moulds. DIW has been used as dielectric fluid in micro-EDM and it brings higher MRR, lower tool wear and less debris formation than hydrocarbon oil [1]. However, there is a weak electrochemical reaction during machining due to the slight conductivity of DIW. This leads to unexpected material dissolution affecting machining shape and degrading material quality [2]. This study aims to suppress this material dissolution by applying short voltage pulse. Micro-holes were fabricated with different pulse parameters using self-developed nanosecond pulse power supply.

2 Experimental details

The experiments were carried out on a specially developed integrated multi-process machine tools DT-110. DIW with 0.23MΩ.cm resistivity was used as dielectric fluid. A new short pulse generator employing high frequency switching MOSFET has been designed to control the pulses given to micro-EDM. The ∅200µm tungsten electrode was used to minimize tool wear. The 100µm thickness workpiece was made from carbon steel which is highly susceptible to material dissolution.

Table 1: Machining parameters

Voltage (V)	45
Resistor (Ω)/Capacitor (pF)	220/265
Frequency (kHz)	0 (DC regime), 100, 200,300,400,500
Duty cycle (%)	15, 20, 30, 40, 50

3 Results and discussions

3.1 Influence of pulse parameters on the qualities of micro-holes

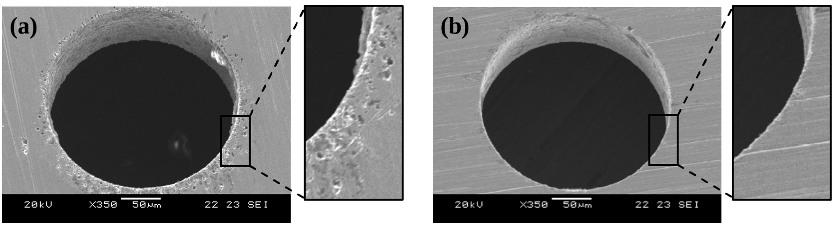


Figure 1: Micro-holes machined using DC-regime (a) and 300ns pulse (b)

Fig. 1a shows the micro-hole machined using DC regime. It was observed that the material dissolution appeared around the rim. It was not uniformly distributed but led to formation of pits. This indicates that the material was locally dissolved. The main reason causing this phenomenon is the variation in homogeneity of material. At micro-scale, the heterogeneity of metal surface can be seen with the presence of various phases. Each phase has different electrode potential. The phase with lower potential will serve as the anode in the electrochemical reaction and will be dissolved. The phase with higher potential remains behind leading to formation of pits.

From experimental results, it was found that when pulses from 100kHz to 500kHz with 50% duty cycle were applied, the affected area reduced. The higher the frequency used, the smaller the affected area was. With the same duty cycle, this means that pulse-on time was shorter. Therefore, experiments were carried out at the same 300kHz frequency with different pulse-on time: 1.6µs, 1.3µs, 1µs, 500ns and 300ns. When reducing the pulse-on time from 1.6µs to 500ns, the number of defective pits along the rim of micro-hole decreased significantly. Especially, when the pulse-on time was reduced to 300ns only, the rim was found to be free of pits as shown in Fig.1b. It shows that the pulse-on time is the main factor that affects the material dissolution.

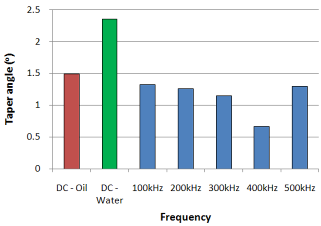
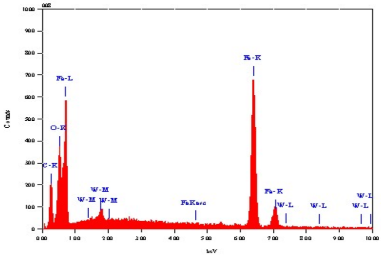


Figure 2: Variation of taper angle corresponding to pulse parameters applied

Taper angle is formed by a small difference between the inlet and outlet diameter of micro-holes. Fig. 2 shows the taper angle of micro-holes under different machining conditions. In DIW, the taper angle was very high when DC regime was used, nearly 2.5°. This is much higher than that of the other micro-holes. The taper angle is mainly contributed by electrode wear and secondary discharges when debris escape machining zone. However, it was reported that the tool wear and debris formation was less when DIW was used. Therefore, this phenomenon can be explained by the dissolution of material caused by the continuous voltage supply in DIW. The upper part of micro-holes had longer facing time with the electrode. Thus, more material was dissolved in the upper zone of the micro-hole. This argument is also consistent with the experimental results. When voltage pulses were applied, the taper angle was significantly reduced as we can see in Fig. 2. Although the electrochemical reaction still occurred but taper angle was even slightly smaller than micro-hole machined by EDM oil.

3.2 Material composition

Fig. 3 shows the composition of surface machined using DIW and EDM oil respectively. In the sample using DIW, it was observed that there appeared 11.36% oxygen element. This can be explained by the rapid oxidation of discharge crater under high temperature and existence of oxygen gas. Under high temperature, water was disassociated into hydrogen and oxygen. The combination of oxygen and high temperature lead to violently oxidation which forms oxide on the machined surface.



(a)

Element	(keV)	mass%	Error%	At%
C K	0.277	19.40	0.07	45.60
O K	0.525	11.36	0.08	20.04
Fe K	6.398	67.43	0.26	34.08
W M	1.774	1.81	0.26	0.28
Total		100.00		100.00

(b)

Element	(keV)	mass%	Error%	At%
C K	0.277	19.93	0.07	54.60
Fe K	6.398	75.78	0.26	44.64
W M	1.774	4.28	0.27	0.77
Total		100.00		100.00

Figure 3: Composition of machined surface using DIW (a) and EDM oil (b)

When EDM oil is used, decomposed carbon increases the debris formation. The debris is not only dislodged from the workpiece but also from the electrode. Some particles are re-solidified on the surface of both electrode and workpiece. As a result, there is the migration of material from workpiece to electrode and vice versa. The increase of debris formation also means that more debris particles would be solidified on the surface. As a result, the amount of migration material would also be higher. This is in accordance with experimental results in Fig. 3. The amount of tungsten (W) element on the sampled machined by oil is 4.28% which is much higher than the sample machined using deionized water, 1.81%.

4 Conclusions

The following conclusions can be drawn from this study:

a. The electrochemical reaction in micro-EDM using DIW can be reduced by using short voltage pulse.
b. Pulse-on time is the main factor affecting the electrochemical reaction rate.
c. When the pulse-on time is under the critical value, dissolution of material from workpiece can be effectively suppressed.
d. The machined surface using DIW was found to be less suffered from material migration due to less debris formation during micro-EDM.

References:

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[2] T Masuzawa et al. (1989) Drilling of Deep Microholes by EDM. CIRP Annals.