Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia CIRP 6 (2013) 401 – 406

www.elsevier.com/locate/procedia

The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM)

Influence of ECM pulse conditions on WC alloy micro-pin fabrication

W.Natsu[a,*], D.Kurahata[a]

[a]*Tokyo university of Agriculture and Technology, 2-24-16 Nakacho, Koganei City, Tokyo 184-8588, Japan*
* Tel/Fax: 0081-42-388-7776 . *Email: summer@cc.tuat.ac.jp* .

Abstract

Micro-pins with a large aspect ratio are required for micro tools and micro parts. We have proposed to use a neutral and less harmful electrolyte, $NaNO_3$ aqueous solution to fabricate tungsten-carbide (WC) alloy micro-pins with ECM. The workpiece rotation and ultrasonic flushing were adopted during processing in order to obtain a higher machining accuracy and removal rate. However, it was found that oxidized substances adhered to the pin surface, which decreased the removal rate and machining accuracy. In order to reduce the oxidized substance adhesion to the WC alloy surface under the $NaNO_3$ aqueous solution condition, bipolar pulses was then used, since it has been reported that a negative current has the effect to generate NaOH which can dissolve the oxide. Experiments were carried out by changing the pulse condition to investigate the influence of the positive and negative pulse width on the machining characteristics. The results show that a micro-pin with the diameter about 20 μm was obtained in a very short time of 2.5 min. It is also found that using the bipolar pulse power supply is an effective way to reduce the adhesion of oxidized substances to the pin surface, and there exists an optimized pulse period for the micro-pin fabrication.

Selection and/or peer-review under responsibility of Professor Bert Lauwers

Keywords: ECM, micro-pin, electrolyte, byproduct, bipolar pulse

1. Introduction

Since metallic materials can be processed regardless of their hardness, Electrochemical machining (ECM) is widely used for the machining of metal parts with complex shapes and made of difficult-to-cut metallic materials. Recently, many reports have been published on ECM applications in micro machining, which uses pulse power supply, electrolyte with lower concentration, etc. [1-3]. Tungsten carbide alloy (WC alloy), composed of tungsten carbide particles and a cobalt metal binder, is a typical one among difficult-to-cut materials. These days, micro WC alloy pins are of wide application to micro cutting tools and micro die/mold components. Up to now, there were a lot of researches about the micro-pin fabrication by using non-traditional machining methods, such as EDM, ultrasonic machining. For example, the following methods are proposed to fabricate micro-pins in EDM: wire electro discharge grinding (WEDG) [4], machining with self-drilled holes [5], and scanning EDM [6]. However, main defects for the above mentioned machining methods are the low removal rate and high tool wear. Especially, when a micro-pin of tungsten carbide alloy is fabricated, the tool wear becomes much intensive in EDM and ultrasonic machining. However, these two big issues of the intensive tool wear and low removal rate can be overcome with electrochemical machining, since ECM is featured by no tool wear and high productivity regardless of the material hardness.

Up to now, there were several reports about the micro-pins fabrication with ECM [7-8]. In order to reduce the environmental impact caused by the harmful acidic and alkaline electrolytes, our group has proposed a method to fabricate WC alloy micro-pins with mineral water [9-10] and neutral $NaNO_3$ aqueous solution. However, it was also found that oxidized substances adhered to the pin surface, which decreases the removal rate and accuracy. Meanwhile, it has been reported that a bipolar power supply is effective to reduce the oxidized substance adhesion to the WC alloy surface in ECM

Selection and/or peer-review under responsibility of Professor Bert Lauwers
doi:10.1016/j.procir.2013.03.093

with the neutral $NaNO_3$ aqueous solution [11-12]. In this research, the WC alloy micro-pin was fabricated by means of a bipolar pulse power supply and $NaNO_3$ electrolyte, and the oxidized substance adhesion to the surface was observed. In addition, the influences of the pulse period and pulse width were experimentally investigated.

2. Method and setup for micro-pin fabrication

Since Tungsten carbide alloy is a mixture of WC particles and the Co binder, in order to obtain a good surface finish, the two components of the WC and Co must be removed at the same rate. However, when WC alloy is machined under a direct current and $NaNO_3$ aqueous solution, the following reactions will occur on the anode surface [11-12].

$$Co \rightarrow Co^{++} + 2e \quad (1)$$
$$WC + 6OH^- \rightarrow WO_3 + C + 3H_2O + 6e \quad (2)$$
$$WC + 6OH^- \rightarrow WO_3 + CO_2 + 5H_2O + 10e \quad (3)$$

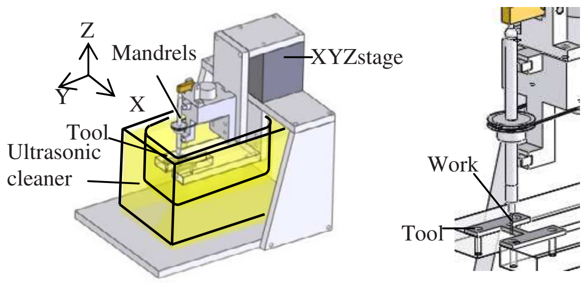
The oxide film WO_3 on the workpiece surface prevents the dissolution of WC. It has been reported that a bipolar pulse power supply is effective to dissolve both WC particles and Co binder in the machining with $NaNO_3$ aqueous solution [11-12], and the principle is as follows. In the positive half-cycle which means the WC alloy is set to the anode, Co is dissolved into the solution, while WC is anodized and WO_3 is generated on the anode surface as expressed by equations (1) to (3). Meanwhile, in the negative-cycle which means the WC alloy is set to the cathode, NaOH is generated and it reacts with WO_3 as expressed with equations (4) and (5).

$$2Na^+ + 2H_2O + 2e \rightarrow 2NaOH + H_2 \quad (4)$$
$$WO_3 + 2NaOH \rightarrow Na_2WO_4 + H_2O \quad (5)$$

Thus, the WC and Co will be dissolved with $NaNO_3$ aqueous solution and a better surface finish is expected to be obtained.

The schematic of the system for micro-pin fabrication is shown in Fig.1. The end of the cylindrical workpiece, made of WC alloy, was positioned at the same height as the bottom surface of the plate tool, made of stainless steel SUS304. The relative position between the plate tool and the cylindrical workpiece was controlled by an XYZ stage. During the machining, the workpiece rotated at a speed of 2825 rpm and there was no tool feeding. This rotational speed was determined by the equipment, and its influence on the machining characteristics was not investigated in this research. A bipolar power supply (BWS 120-2.5, made by Takasago. Ltd.), and a digital function generator (DF1906, made by NF Corp.) were used to supply the machining current. In experiments, the constant current mode was used, which means the peak current of the pulse was kept the same while the voltage between the two electrodes varied according to the gap conditions.

In order to effectively remove the bubbles and other by-products from the inter-electrode area, and stabilize the fabrication process, a commercially available ultrasonic washing machine was used to vibrate and flush the electrolyte during machining. Since by-products and oxidized substance adhering to the surface could not be fully flushed from the workpiece surface during machining, further ultrasonic washing operation was carried out for about 10 min after machining.



(a)Overall view (b)Enlarged view

Fig.1 Experimental device

3. Effect of pulse period on micro-pin formation

Experiments were conducted by using the current waveform of bipolar pulse shown in Fig.2. The period when the polarity of workpiece is set to the anode is called the positive pulse width, while the period when polarity of workpiece is set to the cathode is called the negative pulse width, and the sum of these two pulse widths is called the pulse period in this research.

In order to investigate the effect of the pulse period on the micro-pin formation, experiments were carried out by changing the pulse period from 250 μs to 500 ms under the conditions shown in Table 1. The initial gap is the distance between the surfaces of the pin workpiece and the plate electrode before machining. The initial eccentricity of the micro-pin was under 20 μm. The positive and negative pulse widths were the same. The experimental procedure is shown in Fig.3. After the electrolytic processing for 10 to 20 seconds, the pin surface was observed with a microscope. Next, the micro-pin was washed with the ultrasonic washing machine for about 10 minutes and then the surface was observed again and the diameter at the position 1 mm from the pin end was measured. The reason to measure the diameter at this position is that the obtained micro-pin has a tapered shape and the diameter changes with the position. The reason for the tapered pin shape will be discussed later. After that, the pin was machined again. This process was repeated until the rod part of 1 mm from the original rod end disappeared due to dissolution.

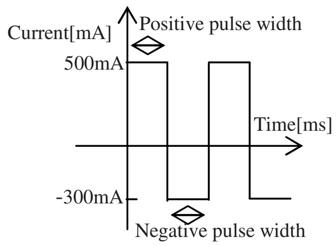


Fig.2 Current waveform

Table 1 Machining conditions

Electrolyte	10% $NaNO_3$ aq
Positive current (mA)	500
Negative current (mA)	-300
Initial gap width (μm)	350
Work material	WC alloy with 300 μm diameter
Tool material	SUS304 with 2mm thickness

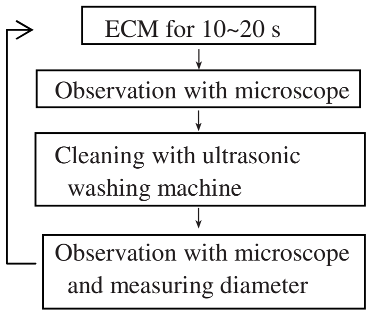
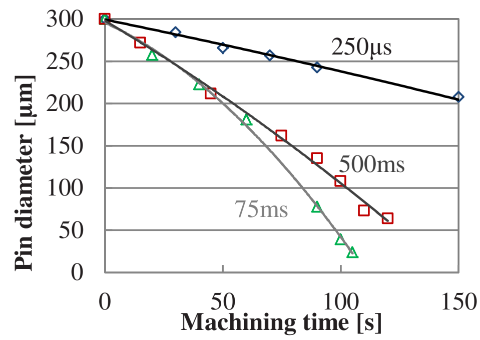
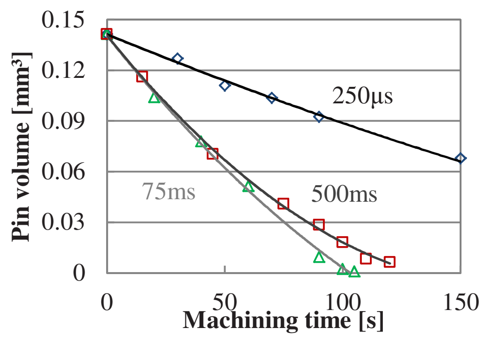


Fig.3 Experimental procedure

The pin diameter change under the pulse period of 250 μs, 75 ms and 500 ms are shown in Fig.4 (a). Although the pin's volume change is more suitable to represent the material removal rate, the pin has a tapered shape and it is difficult to calculate the pin volume. Therefore, the diameter change is mainly observed. To roughly show the relationship between the pin diameter and the pin volume change, the pin volume is calculated under the assumption that the diameter is the same along the length of 2 mm, the same as the thickness of the plate tool. The result is shown in Fig.4 (b). As the inclination of each diameter change in Fig.4 (a) represents the diameter removal rate, the inclination under each pulse period was obtained from experimental results and plotted in Fig.5. The figure shows that there exits an optimized pulse period for the diameter removal rate and the pulse period of 100 ms is the optimized one under the conditions used in experiments. The observed results of the pins formed with different pulse period are shown in Fig.6. It is found that more oxidized substances and by-products adhere to the pin surface in the case of pulse period of 250 μs, 5 ms, 250 ms and 500ms, while oxidized substances and by-products become much less in the case of pulse period around 100 ms. This may be the reason for that the optimized pulse period is around 100 ms, because of less by-products which disturbs the current flow.



(a) Change in the pin diameter



(b) Change in the pin volume

Fig.4 Change in the pin diameter and pin volume with the machining time under different pulse period

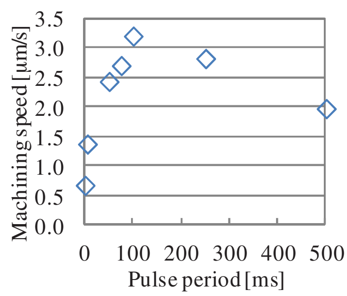


Fig.5 Relationship between diameter machining speed and pulse period

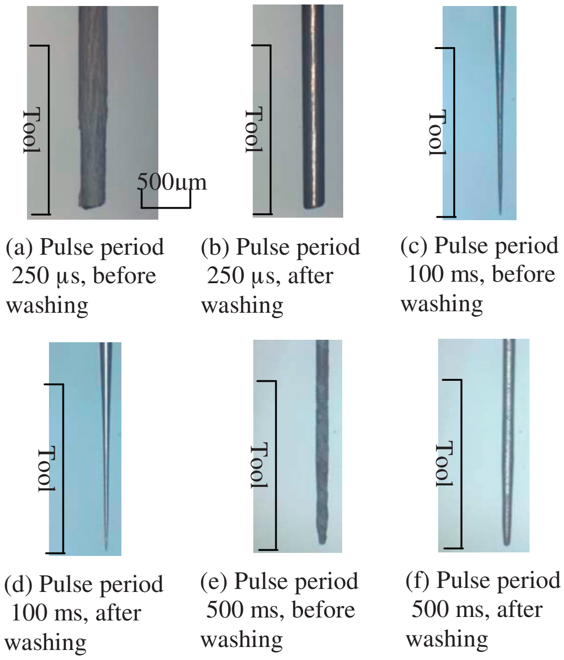


Fig.6 Micro-pin fabricated under different pulse period

The photos in Fig.6 show that tapered micro-pins instead of cylindrical ones were fabricated. The pointed pin end can be considered to be caused by the big curvature, where the current tends to concentrate. However, the reason for the tapered shape apart from the pin end is not clear now and needs further investigation. One possible reason is the influence of bubbles in the gap area, since more bubbles exit in the upper part of gap area and hinders the current flow there.

Since the oxide on the workpiece surface is dissolved by NaOH which is generated in the negative-cycle [12], the oxidized substances and by-products are therefore thought to be influenced by the negative pulse width. If the negative pulse width is too short, most oxidized substances and by-products cannot be removed from the workpiece surface. Thus the removal rate of the WC alloy decreases. On the other hand, the oxidized substances and by-products are generated during the positive pulse width. When the pulse period is too long, the amount of oxidized substances and by-products adhering to the workpiece becomes too much and difficult to be removed from the surface during the negative pulse width. Thus, the removal rate also decreases. This is the reason for the optimized pulse period.

Meanwhile, during the period of polarity change when a bipolar power supply is used, the additional electroplating on the cathodic workpiece may happen and the wear of the anodic tool electrode cannot be avoided. In this research, although the electroplating did not happened, the wear of the plate tool electrode was observed. However, since the experiment was carried out under a constant current mode, the current value was kept the same while the voltage between two electrodes increased a little with the tool wear.

4. Effect of pulse width on micro-pin formation

In the above mentioned experiments, the pulse width of the positive and negative current was the same. In order to investigate the different influence on the adhesion of the by-products and the removal rate, pin formation when changing the positive or negative width was carried out.

4.1 Effect of positive pulse width on pin formation

First, the positive pulse width was changed from 50 to 150 ms, while the negative pulse width was fixed at 50 ms. The other conditions are the same as those shown in Table 1. Fig.7 shows the change in the pin diameter for different positive pulse width. It is found that except for 150 ms positive width, the change in the pin diameter is nearly the same. The reason for the lower removal rate for 150 ms pulse width is thought that the more oxidized substances and by-products adheres to the pin surface when a longer positive pulse width is used, which can be seen from Fig.8.

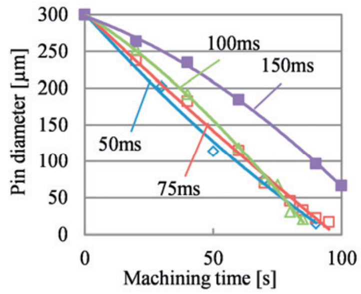
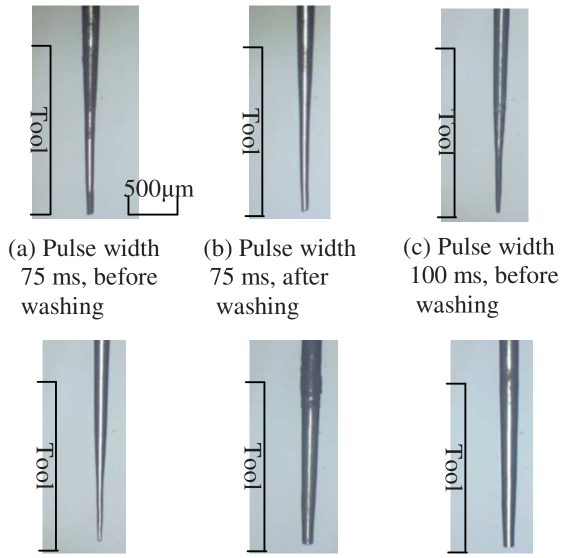


Fig.7 Relationship between pin diameter and machining time under different positive pulse width

4.2 Effect of negative pulse width on pin formation

Experiments were carried out when the negative pulse width was changed from 5 to 75 ms, while the positive one was fixed at 50 ms, in order to investigate the effect of the negative pulse width on the removal rate and by-products adhesion to the pin surface. Fig.9 shows the change in the pin diameter with the time for different pulse widths, and Fig.10 shows the observation results of the pin surface. It is found that few oxidized substances and by-products adhere to the pin surface in the case of pulse width 50 ms and 75 ms, while adhesion is observed in the case of pulse width 10 ms. This result means that a negative pulse width longer than 50 ms is necessary to prevent the adhesion of oxidized substances and by-products to the pin surface. Meanwhile, Fig.9 shows that the removal rate of WC alloy decreases with the increase in the negative pulse width. This is because a longer negative pulse width reduces the period when the positive pulse is applied in a certain period. The material of WC alloy only is dissolved during the positive pulse period. It can also be found from Fig.9 and Fig.10 that a micro WC alloy pin with the diameter around 20 μm and with few oxidized substances on the surface can be obtained by using a bipolar pulse whose negative pulse width is longer than 50 ms, in a very short time of 2.5 min.



(a) Pulse width 75 ms, before washing
(b) Pulse width 75 ms, after washing
(c) Pulse width 100 ms, before washing
(d) Pulse width 100 ms, after washing
(e) Pulse width 150 ms, before washing
(f) Pulse width 150 ms, after washing

Fig.8 Micro-pin fabricated under different positive pulse width

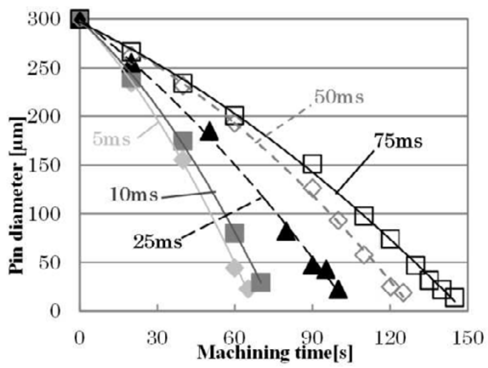
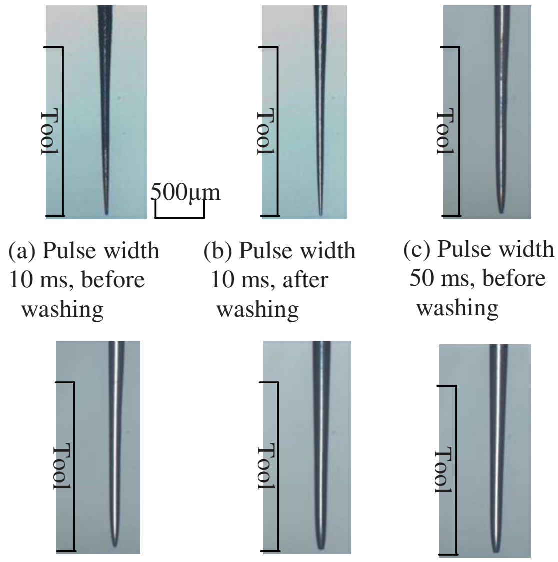


Fig.9 Relationship between pin diameter and machining time under different negative pulse width



(a) Pulse width 10 ms, before washing
(b) Pulse width 10 ms, after washing
(c) Pulse width 50 ms, before washing
(d) Pulse width 50 ms, after washing
(e) Pulse width 75 ms, before washing
(f) Pulse width 75 ms, after washing

Fig.10 Micro-pin fabricated under different negative pulse width

5. Conclusions

In this research, fabricating micro-pin of WC alloy was conducted with a bipolar pulse power supply and the influence of machining conditions on the removal rate and the adhesion of oxidized substances and by-products on the pin surface was investigated. The following conclusions were obtained from experiments and discussions.

(1) A micro WC alloy pin with the diameter around 20 μm and with few oxidized substances on the surface can be obtained by means of a bipolar pulse power supply in a very short time of 2.5 min.
(2) The removal rate changes with the pulse period and there exists an optimized pulse period.
(3) A negative pulse width longer than 50 ms is necessary to prevent the adhesion of oxidized substances to the WC alloy pin surface.

Acknowledgment

This work was supported by Grant-in-Aid for Scientific Research (B), JSPS (No.23360064).

References

[1] Rajurkar, K.P., Levy, G., Malshe, A., Sundaram, M.M., McGeough, J., Hu, X., Resnick, R., DeSilv, A., 2006. Micro and Nano Machining by Electro-Physical and Chemical Processes, Annuals of the CIRP 55(2), p. 643.

[2] Bhattacharyya, B., Mitra, S., Boro, A.K., 2002, Electrochemical Machining: New Possibilities for Micromachining, Robotics and Computer Integrated Manufacturing 18, p.283.

[3] Chung, D. K., Shin, H. S., Park, M. S., Kim, B. H., Chu, C. N., 2011, Recent Researches in Micro Electrical Machining, International Journal of Precision Engineering and Manufacturing 12(2), p.371.

[4] Masuzawa, T., Fujino, M., Kobayashi, K., Suzuki, T., 1985, Wire Electro-Discharge Grinding for Micro-Machining, Annals of the CIRP 34(1), p.431.

[5] Yamazaki, M., Suzuki, T., Mori, N., Kunieda, M., 2004, EDM of Micro-rods by Self-drilled Holes, Journal of Materials Processing Technology 149, p.134.

[6] Tani, T., Gotoh, H., Lee, J. K., Mohri, N., 2009, Micro-pin Forming Method by Scanning EDM, Journal of The Japan Society of Electrical Machining Engineers, 43(104), p.187. (in Japanese)

[7] Lim, Y. M., Kim, S. H., 2001, An Electrochemical Fabrication Method for Extremely Thin Cylindrical Micopin, International Journal of Machine Tools and Manufacture 41, p.2287.

[8] Choi, S.H., Ryu, S.H., Choi, D.K., Chu, C.N., 2007, Fabrication of WC Micro-shaft by Using Electrochemical Etching, The International Journal Advanced Manufacturing Technology 31(7-8), p.682.

[9] Yang, Y., Natsu, W., Zhao, W., 2011, Realization of Eco-friendly Electrochemical Micro-machining by Using Mineral Water as the Electrolyte, Precision Engineering 35(2), p.204.

[10] Shibuya, N., Natsu, W., 2012, Fabrication of Tungsten Carbide Alloy Micro-pin with Environment-Responsive ECM Using Ultra-low Concentration Electrolyte, International Journal of Electrical Machining 17, p.32.

[11] Sato, T., 1973. Electrolytes for different metals, in "*Electrochemical Machining and Chemical Processing*", Asakura Publishing, Tokyo, p.65. (in Japanese)

[12] Masuzawa, T., Kimura, M., 1991, Electrochemical Surface Finishing of Tungsten Carbide Alloy, Annals of the CIRP 40(11), p.199.