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Electrochemical Machining of Tungsten Carbide Microshaft

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텅스텐 카바이드 미세축의 전해가공

이강희*

Abstract

Tungsten carbide microshaft is used as micro punch, electrode of micro electro discharge machining, and micro tool because of its high hardness and rigidity. In this research, tungsten carbide microshaft was fabricated using electrochemical machining. H_2SO_4 solution was used as the electrolyte because it can dissolve tungsten carbide and cobalt simultaneously. Experimentally studied were the effects of electrolyte concentration, machining time, and machining voltage on material removal rate and the shape of the microshaft. To eliminate the effects of bubbles and metal corrosion layer on microshaft shape, the machining was performed below the electrolysis voltage. Three step electrochemical process was suggested to fabricate the straight tungsten carbide microshaft. As a result, a straight tungsten carbide microshaft of 30μm in diameter and 500μm in length was obtained through the proposed three step electrochemical process.

본 연구에서는 전해가공을 이용해서 직경이 균일한 텅스텐 카바이드 미세축을 제작하는 실험을 수행하였다. 전해가공을 통해 미세축으로 사용 가능한 형상을 얻기 위한 최적의 가공 조건에 대해 고찰하였다. 이 과정에서 미세축의 형상에 영향을 주는 여러 인자들을 적절하게 조절하여 최적의 형상을 얻을 수 있었다. 그리고, 가공된 미세축을 이용하여 적절한 조건으로 2차, 3차 가공을 수행하여 초미세축을 가공할 수 있음을 보였다. 그리하여 실험 결과 직경 30μm, 길이 500μm의 텅스텐 카바이드 미세축을 제작하였다.

Key Words : Electrochemical machining(전해가공), Electrolysis voltage(전해전압), Electrolyte concentration(전해집중), Tungsten Carbide microshaft(텅스텐 카바이드 미세축)

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1. Introduction

Demand for techniques capable of machining micro-scale products is increasing as miniaturization is proceeding in various industrial products.

Especially, the needs for fabrication of microshaft increase in machining of micro products. Electrochemical machining (ECM) is based on the electrochemical dissolution of a metal and is one of the very useful techniques to fabricate microshaft. In ECM, mechanical force does not act between the tool and workpiece and there are not deformation and residual stress in workpiece and wear in tool. Also the machined surface is very smooth. In addition, ECM can be applied easily to mass production of parts because of its simple mechanism of machining process. These advantages make ECM suitable for machining of the micro metallic products. But, in ECM, it is difficult to control the shape and dimension of the products accurately and to avoid the effect of bubbles induced from the electrolysis of water.

Many research works have been conducted for electrochemical machining of tungsten. Muller and Tsong(1) made a probe of FIM (Field Ion Microscopy) using ECM. Other research works concentrated on fabrication of the micro probes used in AFM (Atomic Force Microscopy), STM (Scanning Tunneling Microscopy), and testing card of semiconductor using ECM(2~4). Lim et al.(5) fabricated a tungsten microshaft with uniform diameter using electrochemical process.

Tungsten carbide has high hardness and high rigidity. Therefore, tungsten carbide microshaft can be used as a micro punch to make micro holes of ink jet printer nozzle and fuel injection nozzle of vehicle, a electrode of micro electro-discharge machining and a tool of ultrasonic micro machining. Human et al.(6) studied the wear characteristics of tungsten carbide in electrochemical etching. Kang(7) suggested a method to fabricate the tungsten carbide microshaft with uniform diameter using electrochemical machining. He showed that the concentration of metal removal at sharp end edge and metal corrosion layer affect the shape of the microshaft. Kim(9) suggested a method to fabricate the various 3-D shapes using ultra-short pulse.

In this research, a three-step electrochemical machining process was proposed to fabricate the straight tungsten carbide microshaft. Experimentally studied were the effects of various machining parameters such as machining voltage, electrolyte concentration, and machining time on the material removal rate and microshaft shape. To obtain the uniform shaped microshaft, generation of the metal corrosion layer and bubbles induced from electrochemical reaction was suppressed by machining below the electrolysis voltage of water. A tungsten carbide microshaft of 30μm in diameter and 500μm in length was fabricated through the proposed three-step electrochemical machining process.

2. Electrolyte and Experimental setup

Tungsten carbide is a compound of tungsten carbide and cobalt. Hence, the electrolyte must dissolve tungsten carbide and cobalt simultaneously for electrochemical machining of tungsten carbide microshaft. It is known that H_2SO_4 solution and mixed solution of NaCl and NaOH can dissolve tungsten carbide and cobalt simultaneously(8). When H_2SO_4 solution is used as the electrolyte, however, the machined surface is more even and machined shape can be controlled more easily through conditioning the concentration and voltage. Therefore, the authors selected H_2SO_4 solution as the electrolyte.

Fig. 1 shows the experimental setup for electrochemical machining of tungsten carbide microshaft. The workpiece, tungsten carbide shaft of 200μm in diameter, is attached on a duralumin jig. The duralumin jig is installed in Z axis of precision stage (Parker MSA6705). To control the dipping length of tungsten carbide shaft into H_2SO_4 electrolyte, the feed of Z axis is manipulated by PMAC controller interfaced with PC. Tungsten carbide shaft is connected to the anode of d.c. source and platinum electrode is connected to the cathode of d.c. source.

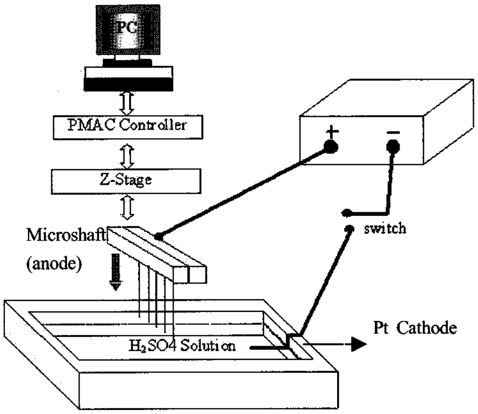

Fig. 1 Experimental Set-up

3. Effects of machining parameters on shape and diameter of microshaft

The machining voltage, electrolyte concentration, and machining time are the most important machining parameters to determine the shape and diameter of the machined microshaft in electrochemical machining. So, the effects of such parameters on the shape and diameter of machined microshaft were studied experimentally.

3.1 Effects of machining voltage on microshaft shape

It is known that the electrolysis voltage of water is about 1.23 V and the value can change in the range of 0.2~0.3 V according to the metal electrodes.

Fig. 2 shows the current variation between the anode and cathode according to applied voltage in H_2SO_4 electrolyte. Above 1.3 V, the current increased rapidly according to the increase in voltage and bubbles induced from oxygen due to electrolysis of water appeared above 1.5 V. In electrochemical machining of tungsten carbide shaft using H_2SO_4 electrolyte, tungsten carbide is oxidized and dissolved at anode and hydrogen generates at cathode when applied voltage is below the electrolysis voltage. In experiment, bubbles due to hydrogen appeared at cathode only below 1.5 V. However, when the applied voltage was above 1.5 V, oxygen generated in addition to oxidized tungsten carbide and bubbles appeared due to oxygen at anode. Then the bubbles interfere with the exchange of electrons between tungsten carbide shaft and electrolyte, so the surface of machined microshaft becomes uneven. If higher voltage applies, material removal rate increases, but metal corrosion layer forms around the shaft and interfere with the electrochemical reaction between the shaft and electrolyte. The thickness of metal corrosion layer is thicker at lower part of the shaft than at upper part of the shaft, so the machined microshaft has reverse taper form.

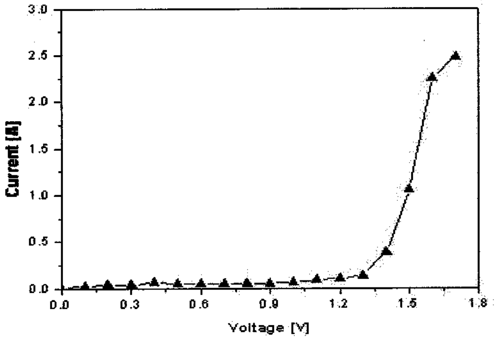

Fig. 2 The current variation

Below electrolysis voltage, the machined shaft has even surface since oxygen does not generate at anode and the effect of bubbles on microshaft shape is eliminated. In addition, interference of metal corrosion layer in electrochemical reaction between the shaft and electrolyte does not exist because diffusion rate of metal ions into electrolyte is faster than the oxidized rate of metal at anode. Consequently, machining below the electrolysis voltage is advantageous over that above electrolyte voltage to obtain a straight microshaft with even surface although the machining time increases. The microshaft machined below electrolysis voltage showed better straightness than that machined above electrolysis voltage. However, below 1.4 V, the material removal rate was very low because the variation of the current was very small. Hence, in this research, electrochemical machining of tungsten carbide shaft was conducted at 1.45 V considering the material removal rate and quality of the machined microshaft.

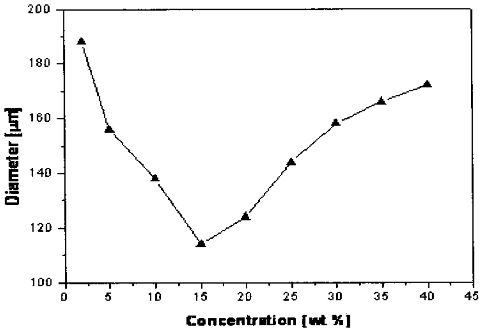

Fig. 3 Diameter of machined microshaft according to the electrolyte concentration

3.2 Effects of electrolyte concentration and machining time on diameter and shape of machined microshaft

Experiments to identify the effect of electrolyte concentration on the shape and diameter of machined microshaft were performed. The electrolyte concentration changed from 2% to 40% at 1.45 V and the machining time was 20 min. Fig. 3 represents the variation of machined diameter according to the electrolyte concentration.

At 15% concentration, the diameter of machined microshaft was minimum, that is, the material removal rate was maximum. In lower range of that concentration, the ions to oxidize the tungsten carbide could not be supplied sufficiently. In higher range of concentration, metal corrosion layer formed around the microshaft and the electrochemical reaction between the tungsten carbide shaft and electrolyte was interfered by the metal corrosion layer. In other voltage ranges, the tendency in MRR was observed similar. Through the experiments, the optimal electrolyte concentration was determined as 15%.

To investigate the effect of machining time on the shape and diameter of machined microshaft, the machining time varied from 5 min to 40 min at constant voltage, 1.45 V and concentration, 15%. The shapes of the microshaft according to the machining time are shown in Fig. 4. Until 30 min, the diameter of the microshaft decreased linearly and straight shape was maintained although the end of the shaft rounded due to concentration of machining. When the machining time was over 30 min, the shape started to taper from the end of the shaft and the length started to shorten and finally the machined shape became a short cone type probe. Therefore, the optimal machining time to obtain uniform shaped microshaft was determined as 30 min.

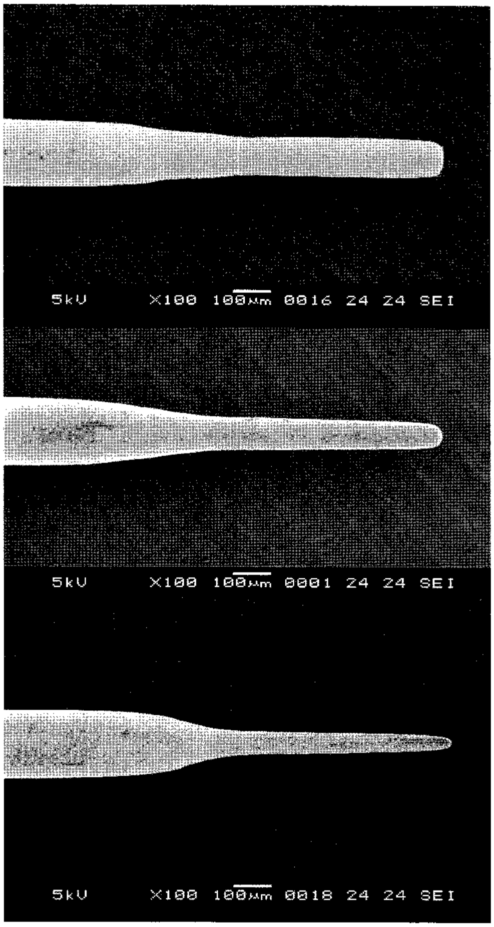

Fig. 4 The shapes of the microshaft according to the machining time (20min, 30min, 33min)

4. Three-step machining process for fabrication of tungsten carbide microshaft

In the above sections, the optimal electrolyte concentration, machining voltage, and machining time were determined through experiments. Fig. 5 shows the shape of the tungsten carbide microshaft machined under the optimal conditions as a first step. The diameter of the machined microshaft was $80\mu m$ and machined length was $600\mu m$. To make the microshaft thinner, the machining conditions must change. Changing voltage is easier than changing the electrolyte concentration, so, in the second step machining, machining voltage changed to 1.2 V. Because the electrolysis voltage of water is about 1.23 V, maximum MRR is expected without generation bubbles around the microshaft at 1.2 V. The material removal concentration at the end of the microshaft can be prevented and the microshaft does not taper and shorten through decreasing the machining voltage.

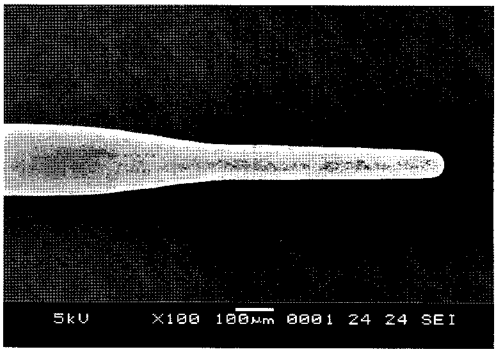

Fig. 5 The shape of the tungsten carbide microshaft machined under the optimal conditions as a first step

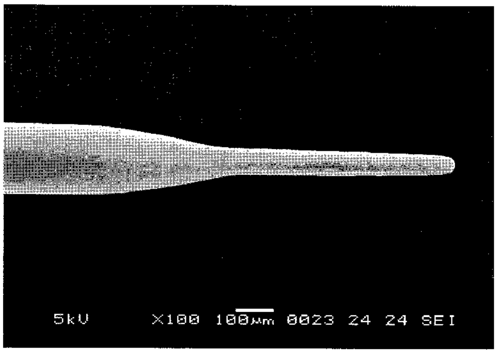

Fig. 6 The shape of the microshaft obtained through the second step machining

The machining time was 15 min. At the longer machining time than 15 min, the micro shaft begins shortening. Fig. 6 shows the shape of the microshaft obtained through the second step machining. The diameter became $60\mu m$. As a final step, the machining voltage changed to 0.75 V and the machining time was 20 min. The shape of the microshaft obtained through the third step machining is shown in Fig. 7. The diameter was $30\mu m$ and the microshaft maintained its straightness and length.

5. Conclusions

Electrochemical machining characteristics of tungsten carbide shaft were investigated to fabricate tungsten carbide microshaft. H_2SO_4 electrolyte showed good performance in electrochemical machining of tungsten carbide. To eliminate the effects of bubbles and metal corrosion layer on the shape of the microshaft, the machining was conducted below the electrolysis voltage.

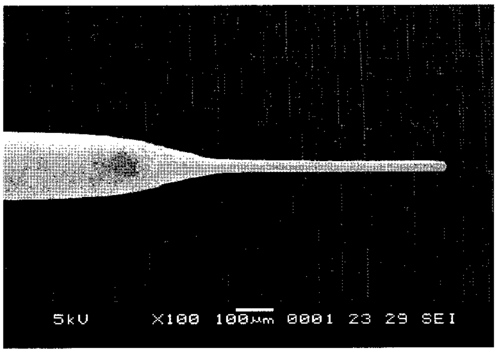

Fig. 7 The shape of the microshaft obtained through the third step machining

Table 1 shows the condinions used in three step machining

Tab. 1 the machining conditions

	concentration of H_2SO_4 electrolyte	Voltage	time
1st step	15%	1.45 V	30 min.
2nd step	15%	1.2 V	15 min.
3rd step	15%	0.75 V	20 min.

Experimentally investigated were the effects of the machining parameters such as electrolyte concentration, machining voltage, and machining time on the microshaft shape and material removal rate. Through the experiments, the optimal electrolyte concentration, machining voltage, and machining time were determined. Three-step electrochemical process was proposed to make the tungsten carbide microshaft. The machining conditions at each step were determined from experiments. A straight tungsten carbide microshaft of 30μm in diameter and 600μm in length was fabricated through the proposed three-step electrochemical machining process.

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