A Study on Fabrication and Application of Micro Tool by using High Speed Chemical Etching

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1. Introduction

The method of micro tool fabrication has been studied in the fields of micro-machining, electronics, optics and medical instruments. Y. Yamagata [1], T. Waida[2], and T. Masuzawa [3] fabricated micro shaft using turning, grinding and WEDG (Wire Electro-Discharge Grinding) method, respectively. But grinding and turning method leaves mechanical damage layer to the tool and WEDM method requires complicated system.

In this study, the tool was fabricated by fluid-energy-enhanced chemical etching method to prevent th material from mechanical damage and shape accuracy degradation. The experimental setup was composed of high speed motor, chemical solution and several mm rod. A part of the rod was dipped in chemical solution and the rod rotated with high speed (1000-10000rpm). The main factors of diameter control are chemical concentration, reaction time, rpm and temperature. The surface of chemical solution around the rotating rod is pulled up by balance of surface tension and centrifugal force. This phenomenon makes a difficulty in getting clear shape of micro shaft. As a result, the lower part of the material to be the micro tool was fabricated in diameter of tens of µm with high speed rotation. And then, the micro shaft was finished by electropolishing method. The electrolyte was mixed b H_3PO_4(phosphoric acid), H_2SO_4(sulfuric acid), H_2O(water) 50%, 20%, 30%, respectively [4].

This type of micro shaft can be used in manufacturing one dimensional structures such as hole and lines in size of tens of µm. Thus the fabricated micro tool was applied to make a line with 30 µm width. In this research, this process has the advantages of low cost and superior machine-ability for micro tools. The fluid-energy-enhanced etching method was successfully applied to make micro tool and the integration of the kinetic energ of circumference and the effect of etching, takes less time to fabricate the micro shaft than any other conventional methods.

2. Mechanism of corrosion erosion

Erosion corrosion phenomenon is corrosive property by the velocity difference between caustic liquid and interface of the metallic material. The shear force is increasing in surface of material by increasing of the caustic fluid velocity. When the shear force approaches the breakaway velocity, the chemical reacted layer of the material is removed the leakage part by cavitation phenomenon. The cavitation phenomenon is caused b metamorphosis of pressure difference between chemical fluid and surface of the metallic material. The burst pores break the immovable oxidation layer of the metallic material. The pressure difference is ruled b Bernoulli's law. And then, the lower part of the removed layer is appeared in the chemical solution. Thi phenomenon is continuously occurred interface of the material and chemical solution as shown Fig.1. Th material to be micro tool was rotated with high speed (1,000~10,000rpm) to add the surface active energy. The experimental set-up is shown Fig.2. The micro shaft was fabricated several micrometers in the diameter by the high speed rotation, the cavitation and chemical attack.

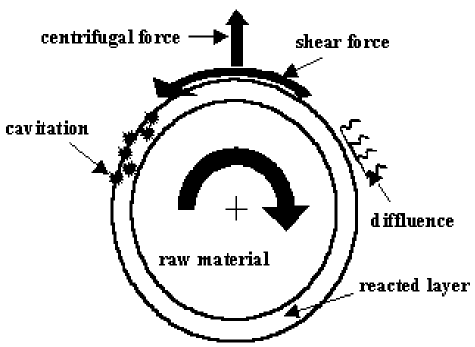

Fig. 1 mechanism of corrosion erosion

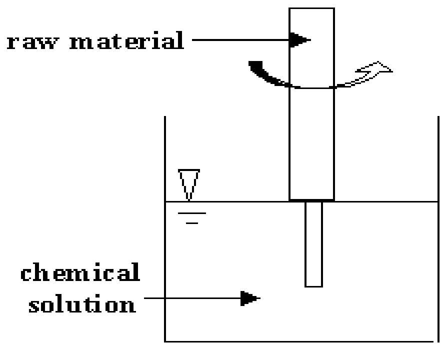

Fig. 2 schematic of micro tool fabrication

3. Fabrication of micro shaf

The micro shaft can be fabricated several micrometer in the diameter only using machining the chemical reactions of atoms level, and the shape of micro shaft is cleared as well. The process is removed not anisotropic machining but isotropic machining. Most of all, the system is not only simplified but also very low cost.

In this study, the chemical solution is mixed water(90wt%) with $FeCl_3$ (10wt%) to make the micro shaft. Th material to be micro shaft is steel, and stainless steel. Discharging on the anode and the cathode, th anode(steel) is dissolved in the state of ionization, and the cathode generates the hydrogen gas. The ionized steel generates a ferrous hydroxide as a bonding state of hydroxyl ions. The ferric hydroxide is also resulted from reacting the ferrous hydroxide, water, and oxygen gas. The reaction between steel and the chemical solution is representatively shown (1) ~ (3). The SEM(Scanning Electron Microscope) of shafts is respectively shown as Fig. 3,4, and the experimental conditions are shown as table 1.

$$2Fe(s) + O_2(g) + 2H_2O(l) \rightarrow 2Fe(OH)_2(s) \qquad (1)$$

$$6Fe(OH)_2(s) + O_2(g) \rightarrow 2Fe_3O_4 \bullet H_2O(s) + 4H_2O(l) \qquad (2)$$

$$Fe_3O_4 \bullet H_2O(s) \rightarrow H_2O(l) + Fe_3O_4(s) \qquad (3)$$

Table 1 experimental conditions of fabrication of micro shaft

Raw material	Steel, stainless steel
Rpm	1,000 ~ 10,000
Chemical solution	Water(90wt%) + $FeCl_3$ (10wt%)
Temperature	Room temperature
Machining time	10 min

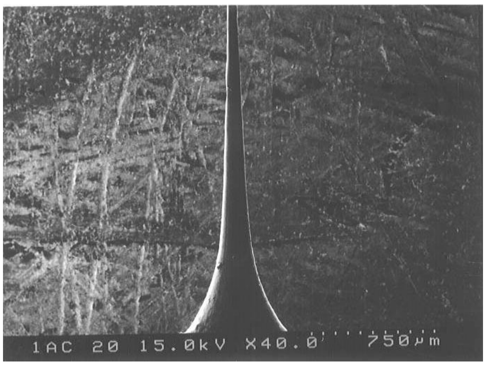

Fig. 3 shape of micro shaft(stainless steel)

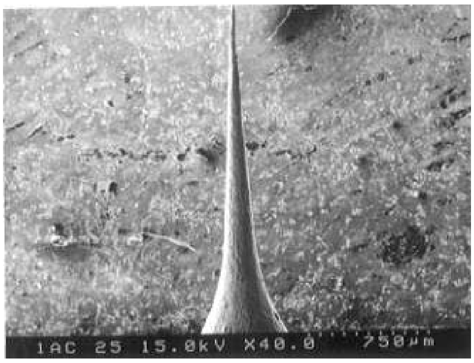

Fig. 4 shape of micro shaft(steel)

4. Electropolishing

Electropolishing is decided by electrochemical dissolution between the anode and the cathode of atomic weight of materials, current, and machining time. The cathode is not change the shape but only expose the hydrogen gas. In the electropolishing process, the removal volume of the material is defined by Farada 's law.

$$m = \frac{AIt}{zF}.$$

where A : atomic weight, I : current, t : machining time, z : valence, F : Farada 's constant(96500C)

Thus, the removal rate per machining time is defined below equation.

$$m' = \frac{AIt}{zF}.$$

Especially, A/z(electrochemical equivalent) is a important factor in electropolishing process. The current efficiency is defined ;

$$\text{Current efficiency} = \frac{m'}{(A/zF)I}.$$

The current efficiency is affected by passivation, gas generation, etching, electrode gap distance, and electrolyte. The electropolishing is a super passivation process. Thus, the oxidation chromium layer appears on the material, and the current efficiency is resulting in decreasing, and the surface roughness is not made progress any more.

The relation of electrolyte and stainless steel is shown chemical reaction equation (4) ~ (6).

$$Cr(s) + O_2(g) + 2H_2O(l) \rightarrow Cr(OH)^-(aq) + 2H_2(g) \quad (4)$$
$$Cr(s) + H_3PO_4(aq) \rightarrow Cr(PO_4) + H_2(g) + H^+(aq) \quad (5)$$
$$Cr(s) + 3H_2SO_4(aq) \rightarrow Cr_2(SO_4)_3 \bullet + 3H_2(g) \rightarrow Cr_2O_3(s) \quad (6)$$

The electropolishing mechanism and the experimental set-up are shown as Fig. 5,6, respectively. The electrolyte used is mixed H_3PO_4(phosphoric acid), H_2SO_4(sulfuric acid), H_2O(water) 50%, 20%, 30%, respectively. The anode is the micro shaft, and the copper plate is used as the cathode. The condition of electropolishing is followed as table 2. According to the table 3, the electrochemical equivalent is calculated as the value of 27.52 (table 4). In the electropolishing process of the stainless steel, the experimental and theoretical removal rate values are compared in the table 5. As the results, the removal rate is to be estimated. From the results of relation the electrode gap and the surface roughness the electropolishing, the gap is related to the current efficiency. The surface roughness of the stainless steel is fine neither low current density(≥0.5 A/ $cm^{2)}$, nor high current density(≤1.5 A/ cm^2). The good electrode gap is 1mm as shown Fig. 7. From these results, the micr shaft was made a good shape and corrosion resistance (Fig.8).

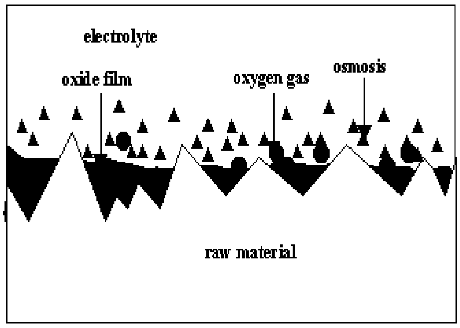

Fig. 5 Mechanism of electropolishing

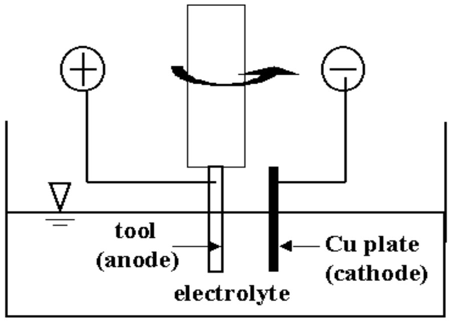

Fig. 6 schematic of electropolishing

Table 2 conditions of electropolishing (steel, stainless steel)

Power output	DC
Current	200 mA
Voltage	30 V
Pulse time (τ on, off)	5 μs
Polishing time	2 minute
Electrolyte	H_3PO_4 : 50wt%+ H_2SO_4 : 20wt%+ H_2O : 30wt%
Electrode gap	1 mm
Tool material	SUS 316L, steel (SKD 11)

Table 3 chemical properties and composition of stainless steel

Metal	Atomic weight	Valence	Weight %
Chromium	51.99	2	17.80
Iron	55.85	2	66.24
Manganese	54.94	2	0.80
Molybdenum	95.94	3	2.28
Nickel	58.71	2	12.19
Silicon	28.09	4	0.62

Table 4 A value of electrochemical equivalent for stainless steel

Element	Fe	Si	Mn	Ni	Cr	Mo
Chemical equivalent(A/z)	27.93	7.02	27.47	29.36	26.0	31.98
Quotient X/(A/z)	2.37	0.09	0.03	0.42	0.68	0.07
$(A/z)_{stainless\ steel}$	27.24					

Table 5 Experimental, theoretical removal rates and current efficiencies for stainless steel

Current density (A/cm^2)	Machining rate ($g\ min^{-1} cm^{-2}$)		
	Theoretical	Observed	Current efficiency(%)
0.5	0.00847	0.00831	98.1
0.7	0.01186	0.01161	97.9
1	0.01694	0.01649	97.3

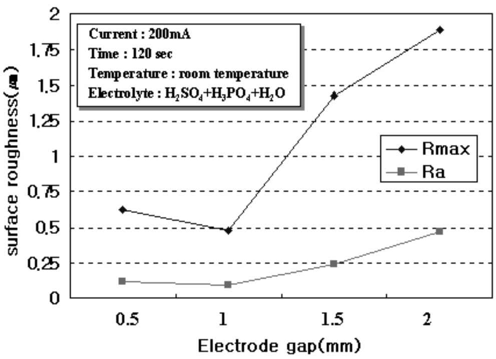

Fig. 7 relation electrode gap and surface roughness(electropolishing)

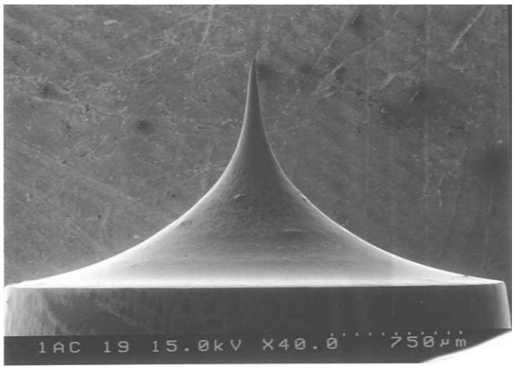

Fig. 8 SEM of micro shaft(after electropolishing)

6. Conclusions

In this study, A new method of micro shaft fabrication was introduced as high speed chemical etching and electropolishing. This method is dependent on the chemical solution, material, and machining time. The electropolishing made the micro shaft that has a very clear shape, and corrosion resistance. Thus, the micro shaft is to be a good micro tool. The micro shaft of the Fig. 9 has the radius of 2.5 µm. The line in the Fig. 10 is applied by the machining of the stainless steel micro tool.

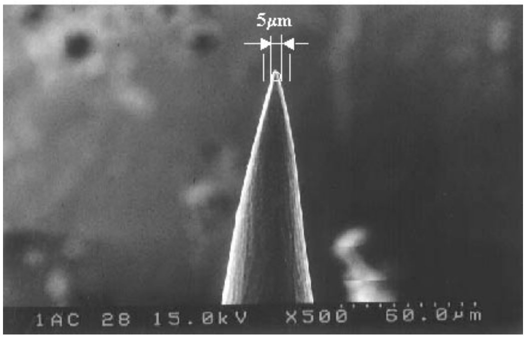

Fig. 9 SEM of micro shaft (radius = 5 µm)

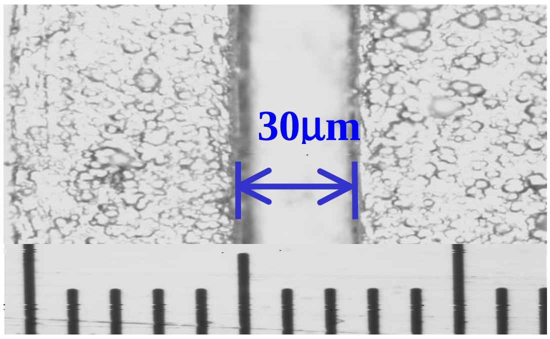

Fig. 10 optic microscope photograph of line machining(x500)

Reference

[1] Y. Yamagata, T. Higuchi, "Three-Dimensional Micro Fabrication by Precision Cutting Technique", JSPE, Vol.61, No.10, pp.1361-1364, 1995.

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[4] J.B. Song, E.S. Lee, J.W. Park, " A Study on the Machining Characteristics of Electropolishing for Stainless Steel ", Vol.23, No.2, pp.279-286, 1999.