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Realization of eco-friendly electrochemical micromachining using mineral water as an electrolyte

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ABSTRACT

This paper presents a new electrochemical micromachining method, which uses everyday mineral water as an electrolyte. The advantages of the new method include totally green machining, high precision, high efficiency, and low-cost. In this paper, practical experiments and results that focus on the fabrication of micro pins and micro hole drilling as well as a more detailed theoretical analysis to explain the phenomena concerned are presented.

1. Introduction

Electrochemical micromachining (ECMM) has several advantages over other machining methods; these advantages include no tool wear, no residual force, no cracks, high machining rate, and the capability of fabricating complex 3D geometries. Because the principle of electrochemical machining (ECM) involves dissolving an anodic workpiece in the form of atoms, ECM can be utilized as a microscale or nanoscale machining method. With an increasing need for microscale parts, such as medical implants, microscale batteries, and fuel cells, micro holes for fiber optics, micro nozzles for high-temperature jets, optical lenses, and inkjet printers or other MEMS, more and more attempts are being made to use ECM for micromachining [1]. The application of ultra-short-pulse power supplies makes ECMM with sub-micrometer precision possible. Schuster et al. [2] reported that local etching of copper and silicon is possible by applying ultra-short voltage pulses, since the electrochemical reactions are confined to electrode regions in close proximity during nanosecond pulses.

In ECMM, fabrication of micro pins and micro holes, and generation of 3D features are generally carried out. Micro pins are usually machined by WEDG, EDM, chemical etching, or ECM processes. The WEDG method used for micro pin fabrication provides high precision but is time-consuming [3], and the unavoidable tool wear may influence the accuracy of the process. In previous attempts of ECM machining of micro pins, low voltages and high-concentration alkali solutions are utilized. Fan and Hourng [4] investigated micro pin fabrication by electrochemical machining. A 510 μm tungsten rod was used as the anode and nickel plates were used as the cathode to fabricate the micro pin used in STM by electrochemical polishing. By applying low voltage, a high-concentration electrolyte, and an appropriate rotation of the electrode, micro pins with a diameter of 100 μm were fabricated. Choi et al. [5] fabricated a tungsten carbide (WC) micro-shaft in the way of electrochemical etching using a H_2SO_4 solution as the electrolyte. Using their approach, a WC rod that was 200 μm in diameter and 2.5 cm long was reduced to 5 μm in diameter and 3 mm in length using an electrolyte of 1.5 M H_2SO_4, and an applied voltage of 4.1 V with a machining time of 210 s. As for surface generation, Kim et al. [6] used a 10 μm diameter platinum wire electrode and a 0.1 M H_2SO_4 solution to machine various 3D features on a stainless steel plate.

From the above review, it can be seen that ECMM has significant potential for micromachining. However, the environmental measure still remains a big issue, because the acid and alkaline electrolytes used are dangerous to operators and cause environmental problems.

To solve the environmental problems and expand the application range of ECMM, this study presents an environmentally friendly, high precision, and low-cost method of ECMM using mineral water as the electrolyte instead of the traditionally used acid or neutral solutions, such as H_2SO_4 and $NaNO_3$ [7]. In addition, a brand new method of micro pin fabrication by applying a high-voltage power supply and monitoring the change in the inter-electrode voltage is proposed, and the effectiveness of the method is verified

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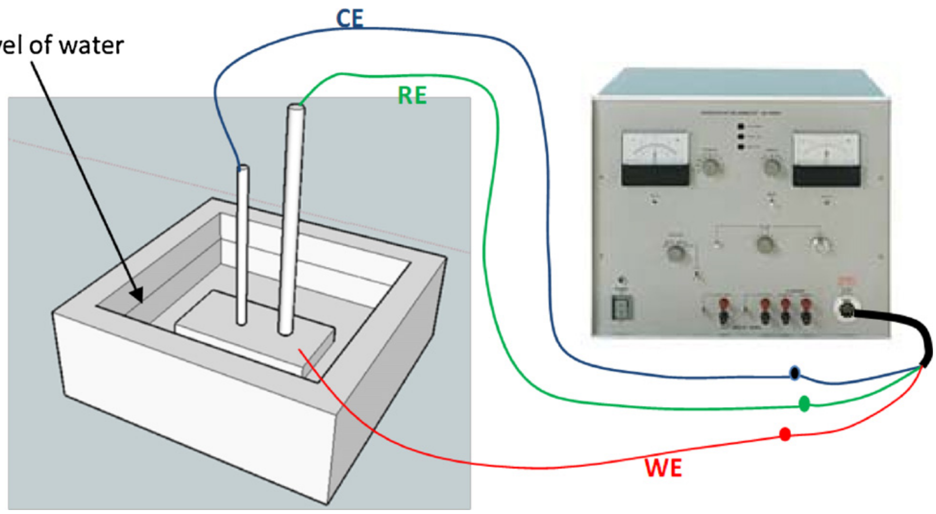

Fig. 1. Electrochemical cell used for measuring the polarization curve.

experimentally. Furthermore, the characteristics of hole drilling in mineral water is investigated and the influence of electrolyte concentration on machining characteristics is discussed.

2. Proposed use of mineral water as an electrolyte

Compared with the traditional acid or neutral solutions, as far as the environmental impact and maintenance of the machine setup are concerned, mineral water is totally clean, eco-friendly, and non-corrosive. Also, since water is low-cost and easily available, machining costs can be reduced considerably. However, the electrical conductivity of water cannot be compared with that of acid or neutral chemical solutions, even with dilute solutions, because the amount of ions existing in common mineral water is rather low. The concentration of mineral water is approximately 10^{-7} mol/L, and it has a pH value of around 7. To guarantee consistency and comparability, commercial mineral water of the same brand is chosen as the electrolyte in all our experiments. The detailed chemical–physical properties and substances in mineral water are listed in Tables 1 and 2.

Although the electric conductivity of mineral water is much lower than that of the conventional electrolytes, the data in the tables show that the electric conductivity of mineral water is better than both the ultrapure and the vaporized water because there are still a few ions such as H_3O^+, OH^-, and Na^+ in mineral water.

To determine if mineral water has a potential to be used as an electrolyte for ECMM, the polarization curve was investigated. In general, a polarization curve is measured either in potentiostat mode or galvanostat mode. In this study, the polarization curve is measured in potentiostat mode. A high-power potentiostat, which can provide a maximum voltage of 300 V between the tool electrode and the workpiece, is used in the experiments. This specialized potentiostat has an advantage over the common potentiostats for high-resistance studies. A schematic of the apparatus used for measuring the polarization curve is shown in Fig. 1.

In the electrochemical cell, the working electrode (WE) is connected to the workpiece, which is a SUS304 plate. The reference electrode (RE) or the auxiliary electrode is a standard Ag/AgCl electrode, and the counter electrode (CE), corresponding to the tool electrode in ECM, is a tungsten carbide (WC) rod with a diameter of 0.3 mm. The electrolyte flowing between the electrodes is mineral water. The voltage is measured between WE and RE, and the current flows through CE and WE. The measured polarization curve of the electrochemical cell composed of the stainless steel workpiece, WC tool, and mineral water are shown in Fig. 2.

Compared with the polarization curve of a dilute acid electrolyte [8], the initial overpotential found for mineral water is not much different. However, the applied voltage between the anode and the cathode electrodes differs significantly because it is divided into several portions, as shown in Fig. 3, and expressed with Eq. (1)

$$V_{\mathrm{Applied}} = V_{\mathrm{Adl}} + V_{\mathrm{E}} + V_{\mathrm{Cdl}} \quad (1)$$

where, V_{Applied} is the total power supply on both the electrodes, V_{E} is the voltage drop on the bulk electrolyte, V_{Adl} and V_{Cdl} stand for voltage drops on the anodic and cathodic double layer, respectively.

Table 1
Chemical–physical properties of the mineral water used in the experiment.

Brand	Morimizu (Coca-Cola Japan Company)
Electric conductivity	0.014 S/m
pH	7
Water hardness	33.1

Table 2
Composition of the mineral water (mg/L).

Na	12.5
Ca	8.5
K	1.0
Mg	2.9

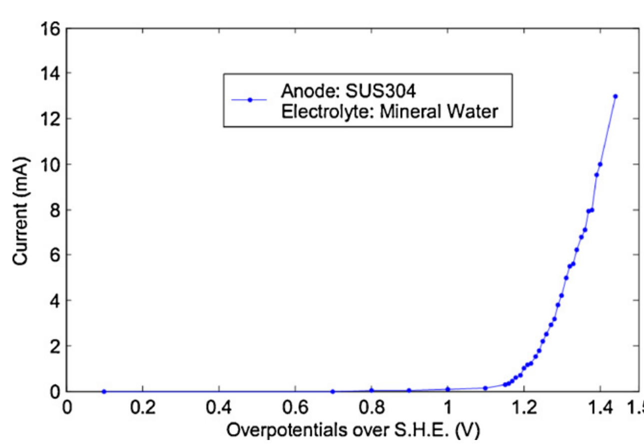

Fig. 2. Polarization curve of the electrochemical cell (anode – SUS304 board; electrolyte – mineral water; cathode – WC rod; RE – standard Ag/AgCl electrode).