Precision Engineering xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Precision Engineering

journal homepage: www.elsevier.com/locate/precision

Wire electrochemical grinding of tungsten micro-rods using neutral electrolyte

Wei Han*, Masanori Kunieda

Department of Precision Engineering, The University of Tokyo, Tokyo 113-8656, Japan

A R T I C L E I N F O

Keywords:
Electrochemical machining
Wire electrochemical grinding
Electrostatic induction
feeding method
Tungsten
Micro-rods

A B S T R A C T

A new method, wire electrochemical grinding(WECG), is proposed for machining tungsten micro rods with neutral electrolyte and bipolar current. The inevitable problem of tool wear due to the bipolar current can be eliminated by using a running wire as the tool electrode with this method. In this study, three kinds of wire guides were used for feeding the workpiece rod in the axial direction: cylindrical cemented tungsten carbide (WC) guide, cylindrical zirconium oxide (ZrO_2) guide, and disk-shaped cemented WC guide, to investigate the influence of materials and configurations of the guide on the machining characteristics. The experimental results showed that the disk-shaped WC wire guide can realize higher machining accuracy because of less influence of stray current flowing through the gap formed between the machined micro-rod and wire guide. Even if the ZrO_2 material has a much lower electrical conductivity than that of the cemented WC, the machining process was still influenced by the stray current between the micro-rod and wire guide. Furthermore, micro-rods were also machined by feeding the rod workpiece in the radial direction. Compared to when the workpiece is fed in the axial direction, the current was higher, which was clarified by the simulation of the current density distribution. However, the machining time was much longer than that with the workpiece fed in the axial direction because more machining steps were necessary to obtain a smooth side surface. With the workpiece fed in the axial direction method, a tungsten micro-rod of 35 μm in diameter was machined to the length of 163 μm. The results confirmed that the new method is capable of miniaturization equivalent to micro electrical discharge machining (EDM).

1. Introduction

Demands for the fabrication of micro-rods are increasing, because micro-rods are widely used as tools for micro-drilling and micro-milling 3D structures [1] and probes for measuring system such as the atomic force microscopy (AFM). Electrochemical machining (ECM) is a promising method for machining micro-rods because it is an anodic dissolution process [2] which is free of residual stress and surface cracks inevitably generated in thermal processes such as electrical discharge machining (EDM) and laser machining. In the application, tungsten is widely used as micro-rod material because of the high erosion resistance, high electrical and thermal conductivity, and high stiffness, which are significantly important especially for micro-rods with high aspect ratios. However, the electrochemical machining of tungsten is difficult because tungsten oxide layer is generated on the anode tungsten surface, blocking the electrolytic current. Hence, Fan and Hourng [3] and Lim and Kim [4] used NaOH and KOH aqueous solution, respectively, as the electrolyte to fabricate tungsten rods. However, since these strongly alkaline electrolytes are highly harmful to the environment, use of neutral electrolytes is desirable. Maeda et al. [5] reported that cemented tungsten carbide can be machined with a neutral electrolyte such as sodium nitrate ($NaNO_3$) aqueous solution using a bipolar current, because NaOH is generated when the tungsten carbide electrode is in negative polarity, thereby removing the oxide layer from the surface of tungsten carbide. Thus, Natsu and Kurahata [6] machined cemented tungsten carbide (WC) rods successfully using a $NaNO_3$ aqueous solution. However, the machining accuracy was not sufficiently high to obtain micro-rods with diameters equivalent to that which can be obtained by EDM, because the bipolar current resulted in a significantly large tool wear. Furthermore, since the pulse duration of the machining current was as long as several tens to several hundreds of ms, the electrochemical reaction could not be localized in a small gap width. Nevertheless, it is considered that pure tungsten can also be machined using a neutral electrolyte and bipolar current based on the same mechanism reported by Maeda et al. [5] and Natsu and Kurahara [6].

On the other hand, Schuster et al. [7] found that electrochemical micromachining can be performed when ultra-short pulse current of

* Corresponding author at: Room 833, Engineering Building 14#, Department of Precision Engineering, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan.
E-mail addresses: hanwei_wh@edm.t.u-tokyo.ac.jp (W. Han), kunieda@edm.t.u-tokyo.ac.jp (M. Kunieda).

https://doi.org/10.1016/j.precisioneng.2018.02.006
Received 5 November 2017; Received in revised form 17 January 2018; Accepted 31 January 2018
0141-6359/

Please cite this article as: Han, W., Precision Engineering (2018), https://doi.org/10.1016/j.precisioneng.2018.02.006

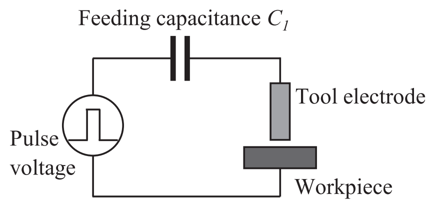

Fig. 1. Electrostatic induction feeding ECM.

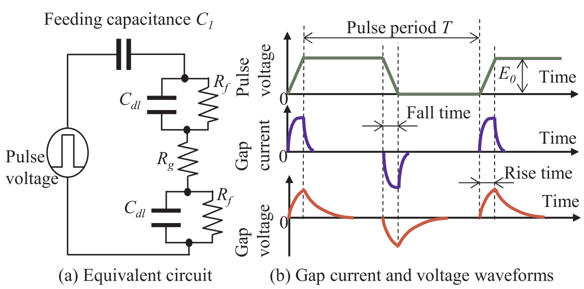

Fig. 2. Principle of electrostatic induction feeding ECM.

several tens of ns in duration is used. In order to easily obtain such an ultra-short pulse current in ECM without using an expensive ultra-short pulse generator, Koyano and Kunieda [8] developed the electrostatic induction feeding ECM as shown in Fig. 1. Fig. 2 shows the equivalent circuit of this method and gap current and voltage waveforms. When the pulse voltage is supplied across the working gap, the electric double layer is formed on the surface of electrodes, which can be expressed as C_{dl}. Then, the working gap can be modeled as the Faraday impedance R_f, resistance of electrolyte in the machining gap R_g and C_{dl} [9]. Since the pulse voltage with a constant pulse duration is coupled to the tool electrode by a feeding capacitance C_1, current only flows at the instance when the pulse voltage changes to high or low as shown in Fig. 2. Hence, the current pulse duration is nearly equal to the rise and fall time regardless of the pulse on-time of the pulse voltage. In addition, the current is bipolar, and this is advantageous to tungsten machining using a neutral electrolyte. With this method, a pulse duration shorter than several tens ns can easily be obtained. Hence, Han and Kunieda [10] fabricated tungsten micro-rods successfully with a neutral electrolyte, $NaNO_3$ or NaCl aqueous solution, and bipolar current. They used an ultra-short pulse current of 20 ns to 40 ns in their research, and thus successfully fabricated a micro-rod with a diameter of 7.1 μm and aspect ratio of 14 by localizing the electrochemical dissolution in a significantly small working gap. To obtain such a high accuracy, however, they used a platinum tool electrode to avoid tool electrode wear. Thus, this process was costly.

A wire tool electrode was first used in micro EDM by Masuzawa et al. [11] to fabricate micro-rods without the influence of tool wear due to discharge, known as the wire electro-discharge grinding (WEDG) method. In WEDG, to avoid the wire vibration, which normally occurs in wire EDM, the wire is supported by a cylindrical guide which is circumferentially grooved on the edge. Since the present work aims to machine tungsten micro-rods electrochemically with a high accuracy equivalent to WEDG using a bipolar current, the same tool electrode system as WEDG was introduced and named as wire electrochemical grinding (WECG). This method is therefore able to solve both the problems of the tool electrode wear and wire vibration. Three kinds of wire guides were used in this study, namely the cylindrical cemented tungsten carbide (WC) guide, cylindrical zirconium oxide (ZrO_2) guide, and disk-shaped WC guide. The ZrO_2 was used as guide material because of its significantly low electrical conductivity, which may reduce the stray current during the electrochemical process, compared with cemented tungsten carbide. The cylindrical and disk-shaped wire guides form different gap areas during machining because of their different surface areas with different geometries. Micro-rods can be machined with the workpiece fed either in the axial or radial directions, and because the wire tool electrode is running during machining, tool wear which is inevitably generated by the bipolar current does not influence machining accuracy.

2. Wire electrochemical grinding (WECG) method

The WECG method is shown in Fig. 3. The micro EDM machine (Panasonic, MG-ED72W) was converted to the micro ECM machine by replacing the EDM pulse generator with the circuit in Fig. 1. The tool electrode, which is kept running during machining, is commercial brass wire with a diameter of 100 μm and held by a wire guide. Since the wire tool electrode is running during machining, the influence of tool wear caused by the bipolar current on machining accuracy can be eliminated. The rod workpiece is fed toward the wire tool electrode during machining and rotates with a speed of 3000 rpm. The feed distance in the axial direction determines the rod length while the cut depth in the radial direction determines the rod diameter. The electrolyte is jetted into the working gap by a nozzle 210 μm in inner diameter placed near the working gap. The ultra-short-pulse bipolar current is supplied by the electrostatic induction feeding method.

The three kinds of wire guides used in this study are shown in Fig. 4: the cylindrical cemented WC guide, cylindrical ZrO_2 guide, and disk-shaped cemented WC guide. All their diameters were set to 10 mm. The guides in Fig. 4(a) and (c) are made of a material with a high electrical conductivity, but have different geometries, while (b) is made of ZrO_2 which has a much lower electrical conductivity. Table 1 shows the properties of the materials used for the guides [12]. Fig. 5 shows the brass wire held by one of the wire guides. Since the brass wire is running off the edge of the wire guide by 75 μm, the cut depth in radial direction must be made smaller than 75 μm to avoid the wear of the wire guide due to electrochemical dissolution, because current can flow through the gap between the shoulder surface of workpiece and the top surface of the wire guide as shown in Fig. 3.

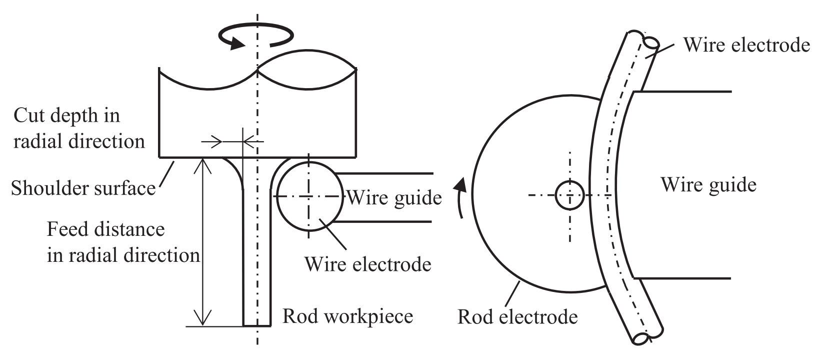

Fig. 3. Wire electrochemical grinding method.