CIRP Annals - Manufacturing Technology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

CIRP Annals - Manufacturing Technology

journal homepage: http://ees.elsevier.com/cirp/default.asp

Electrochemical machining using porous electrodes fabricated by powder bed fusion additive manufacturing process

Tomohiro Koyano[a], Akira Hosokawa[a], Ryota Igusa[b], Takashi Ueda (1)[c,*]

[a] *Faculty of Mechanical Engineering, Institute of Science and Engineering, Kanazawa University, Japan*
[b] *Division of Mechanical Science and Engineering, Graduate School of Natural Science and Technology, Kanazawa University, Japan*
[c] *Department of Mechanical Science and Engineering, Graduate School of Engineering, Nagoya University, Japan*

ARTICLE INFO

Keywords:
Electro chemical machining (ECM)
Selective laser sintering (SLS)
Electrode

ABSTRACT

A new tool electrode having a porous structure is developed for electrochemical machining (ECM), in which electrolyte fluid can be forced through its permeable structure. This electrode can be easily fabricated using a laser sintering technique of additive manufacturing. Small pores and large porosity can be obtained using a higher laser scanning speed, which increases the flow rate of the electrolyte. ECM results show that a nearly flat surface of the machined hole is obtained and small pores are less likely to cause protrusions on the machined surface. Moreover, the machining speed can be increased as the flow rate increases.

1. Introduction

In electrochemical machining (ECM) [1], the anodic electrode (workpiece) is chemically dissolved and the dissolved metal ions form hydroxides in the electrolyte. Hydrogen is produced at the surface of the tool electrode. The progress of dissolution is hindered by the dissolution products and gas bubbles. Moreover, the electrolyte starts to boil because of rise in its temperature due to Joule heating. Therefore, the electrolyte should be circulated through the machining gap at a high velocity in order to remove the electrochemical products and prevent the electrolyte from boiling. Normally, the electrolyte is supplied through holes or slots made in the tool electrode. However, the holes or slots cause protrusions or ridges on the surface of the workpiece. These have to be removed by a secondary process such as milling.

Shibayama and Kunieda [2] developed a diffusion-bonded tool electrode for electrical discharge machining (EDM), which has micro-holes for jetting the dielectric liquid. As the outlets of the micro-holes were sufficiently small, they were not replicated on the machined surface. Jiang et al. [3] used a porous material as the tool electrode in EDM, which was fabricated by high-temperature sintering of copper particles with diameters in the order of millimeters. The dielectric liquid was supplied through the outlets of pores existing on the entire surface of the electrode.

In this study, a new tool electrode having the porous structure shown in Fig. 1 is developed, in which electrolyte fluid can be forced through its permeable structure. The shape of the pore is not expected to be replicated on the surface of the workpiece if the pore size is sufficiently small between several tens of micrometers to several hundred micrometers. This electrode with several tool geometries and porosities is easily fabricated using an additive manufacturing (AM) laser sintering technique [4]. The use of AM process to fabricate a tool electrode of EDM has been reported [5]. On the other hand, our electrode is characterised by its porous structure as a channel of electrolyte for ECM process. It is possible to make such small pores or holes by other machining processes such as micro-EDM. However, this will require substantial time and cost. In this paper, the machining characteristics of ECM using porous electrodes are described. Porous electrodes were fabricated under different laser irradiation conditions, and the flow rate of the electrolyte through the porous structure was measured. In addition, the influence of the porous structure on the machining surface was examined. The influence of the flow rate of the electrolyte on the machining speed was also investigated.

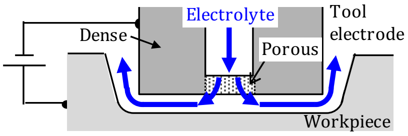


Fig. 1. Electrochemical machining using porous electrode.

2. Porous electrodes

2.1. Fabrication of porous electrodes using AM

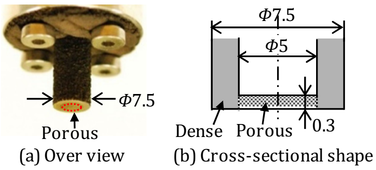
In the proposed electrode, the porous structure can be fabricated only in the essential part, that is central in this study as shown in Fig. 1. The presence of pore outlets on the entire surface of the tool electrode can cause stagnation of the electrolyte, which may result in an unstable electrochemical dissolution. The size and shape of porous part should be determined by analysing the electrolyte fluid flow based on the shape of the tool electrode. The porous electrode was formed using a metal powder bed fusion AM

---

* Corresponding author.
E-mail address: ueda@mech.nagoya-u.ac.jp (T. Ueda).

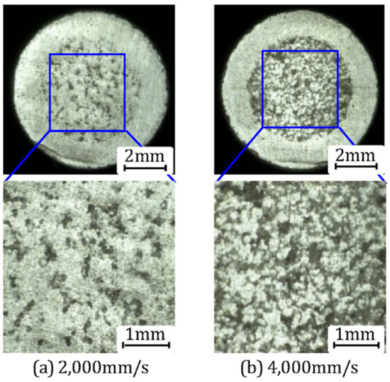
http://dx.doi.org/10.1016/j.cirp.2017.04.127
0007-8506/© 2017 Published by Elsevier Ltd on behalf of CIRP.

Please cite this article in press as: Koyano T, et al. Electrochemical machining using porous electrodes fabricated by powder bed fusion additive manufacturing process. CIRP Annals - Manufacturing Technology (2017), http://dx.doi.org/10.1016/j.cirp.2017.04.127



(a) Over view (b) Cross-sectional shape

Fig. 2. Cylindrical porous electrode.



(a) 2,000mm/s (b) 4,000mm/s

Fig. 3. End surface of porous electrode.

equipment (LUMEX Advance-25, Matsuura Machinery Corp.), which utilizes a Yb fiber laser. This AM process can control the porosity of the consolidated structure by changing the laser irradiation conditions [6]. A partially porous structure can be produced at any location on the consolidated structure using a low-energy density laser beam. Fig. 2(a) shows a cylindrical porous electrode fabricated in this study. The metal powder used to fabricate the electrode is a mixture of 70 wt% alloy steel (42CrMo4), 20 wt% copper-phosphorous alloy (CuSn8), and 10 wt% nickel powder. The average particle diameter of the powder mixture is 25 μm. The diameter of the porous electrode is 7.5 mm. The diameter of the porous part is 5 mm and its thickness is 0.3 mm, as shown in Fig. 2(b). The porous structure was fabricated by increasing the laser scanning speed to 2000 mm/s and 4000 mm/s at a constant laser power of 200 W. The outer circumference of the porous part was consolidated without pores under full melting conditions at a lower scanning speed of 500 mm/s. Fig. 3 shows the end surface of the porous electrode fabricated at 2000 mm/s and 4000 mm/s. Pores of sizes smaller than 300 μm were generated under both laser scanning speeds. However, the number of small pores with sizes smaller than 100 μm was greater when the laser scanning speed was 4000 mm/s. In addition, the porosity of the electrode was also higher. This is because the structure failed to consolidate at the higher scanning speed due to lower energy density of the laser.

2.2. Flow rate

The flow rate of the electrolyte through the porous structure was measured using the electrolyte supply equipment, as shown in Fig. 4. The electrolyte was supplied using a gear pump. The supply pressure of the electrolyte was controlled by changing either the speed of rotation of the gear pump or the flow rate of the electrolyte through the valve. The flow rate and supply pressure were measured using a flow meter and a pressure gauge, respectively. The electrolyte was a 10 wt% sodium nitrate aqueous solution. Fig. 5 shows the relation between the supply pressure and flow rate in the porous electrode fabricated under the different laser scanning speeds. The flow rate per unit area of the porous structure is also shown in Fig. 5. The flow rate increased with an increase in supply pressure. The flow rate in the porous structure fabricated at the laser scanning speed of 4000 mm/s was higher than that at 2000 mm/s because of higher porosity.

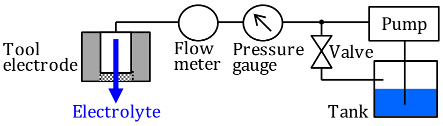


Fig. 4. Electrolyte supply equipment.

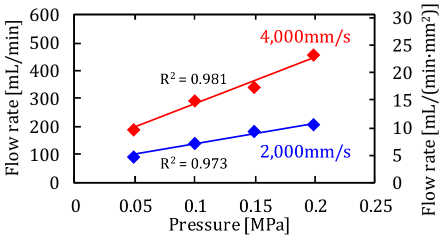


Fig. 5. Relation between flow rate and pressure.

3. Observation of cavitation

It is known that cavitation occurs near the outlets of the electrolyte because the pressure near the outlets can be negative [7,8]. Cavitation tends to occur when the flow velocity is high. The clear flow marks are formed on the electrochemical machined surface due to cavitation because bubbles generated due to cavitation impede the current flow. As described later in Section 4.3, flow marks were formed on the machined surface of the porous electrode when the flow rate of the electrolyte was high and gap distance was small. Therefore, the occurrence of cavitation was observed using a high-speed camera. Fig. 6 shows the experimental setup for observing the electrolyte flow. The tool electrode was placed opposite to the transparent acryl with a constant gap width of 0.1 mm. The mirror was placed below the acryl and the flow over the end surface of the tool electrode was observed through the mirror. The laser scanning speed of the porous structure was 4000 mm/s. The flow rates were set at 200 mL/min and 600 mL/min. The frame rate of the high-speed camera was 1000 fps.

Fig. 7 shows the observation results for one-fourth of the end surface of the electrode at both flow rates. Cavitation was not observed at the smaller flow rate of 200 mL/min. When the flow rate was increased to 600 mL/min, the flow line was observed at the outer circumference of the porous part. This was probably due to cavitation. This was one of the reasons why flow marks, described later, were formed on the machined surface.

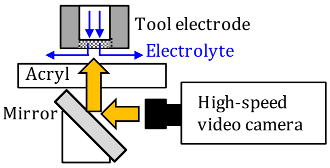
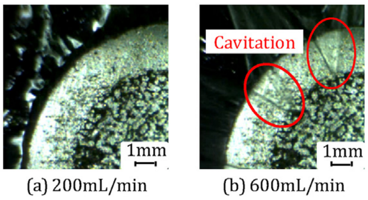


Fig. 6. Experimental setup for flow observation.



(a) 200mL/min (b) 600mL/min

Fig. 7. Observation results of flow at end surface.

4. ECM using a porous electrode

4.1. Comparison with conventional electrodes

ECM was performed using a porous electrode and the machined shape was compared with a conventional electrode that had a

Please cite this article in press as: Koyano T, et al. Electrochemical machining using porous electrodes fabricated by powder bed fusion additive manufacturing process. CIRP Annals - Manufacturing Technology (2017), http://dx.doi.org/10.1016/j.cirp.2017.04.127