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Characteristics of electrochemical machining by using electrolyte suction tool with auxiliary anode

Takafumi Tabata [1], Shuhei Kodama [1], Wataru Natsu [1], Guanxian Liu [2]

[1]Tokyo University of Agriculture and Technology, Tokyo 1840012, Japan
[2] Guangdong University of Technology, Guangdong 510006, China

summer@cc.tuat.ac.jp

Abstract

When an electrolyte suction tool is applied to electrochemical machining process to restrain the electrolyte flow and improve machining accuracy, some electrolyte overflows outside the tool, because the electrolyte in the inner-electrode area is contaminated with bubbles and electrolytic by-products generated during machining. The current density becomes lower at the portion of overflowing electrolyte, which leads to a deterioration of the machining accuracy and the surface quality. In this paper, a suction tool with built-in auxiliary anode is designed and applied to stationary and scanning electrochemical machining. Since the function of the built-in auxiliary anode is to further restrain the electric field and lead to a narrower current area in the inter-electrode gap (IEG) in addition to the constrained electrolyte flow, higher machining accuracy and surface quality can be achieved. Based on the tool structure, the numerical simulation of current density distribution was carried out to show the effectiveness of the new tool. Also, characteristics of electrochemical machining with the proposed tool were experimentally investigated. It was found the machining accuracy was greatly improved, especially in the case of tool scanning.

Keywords: electrochemical machining, electrolyte suction tool, auxiliary anode, machining characteristics

1. Introduction

Conventional electrochemical machining (ECM) is conducted with the tool and the workpiece immersed in the electrolyte solution. Therefore, anodic dissolution occurs on the whole workpiece surface contacting the electrolyte, resulting in a lower machining accuracy [1]. In order to solve this problem, an electrolyte suction tool, confining the electrolyte solution just under the tool tip, was proposed by Yamamura [2] and Endo et al [3]. By using this suction tool, the machining area is limited in the workpiece surface just under the tool tip, and the electrolyte tank immersing a workpiece is no longer needed. Meanwhile, in the machining with the suction tool, the volume increase of electrolyte solution due to by-product and bubble generation causes the leakage of electrolyte to the outside of the tool [4]. The distance between the workpiece and the tool electrode in the leakage area is a little longer than that in the other area, reducing the current density in the leakage area. Machining accuracy and surface quality then decrease in the leakage area due to the low current density causing poor surface quality in ECM.

In order to solve the problem of the conventional suction tool, the new electrolyte suction tool with an auxiliary anode of the same voltage as the workpiece was proposed by our group [5]. By using this new tool, the distribution of equipotential lines and current density are changed in the leakage area. It is difficult to flow current under the auxiliary anode, and the area with low current density can be reduced, resulting in the high machining accuracy and the high surface quality around the machining mark.

In addition, the flow direction of the electrolyte flow direction influences the machining characteristics, mainly due to the behaviour of gas bubbles generated around the the auxiliary anode.

In this paper, scanning ECM with the different electrolyte flow modes was conducted by using the suction tool with the auxiliary anode to investigate the machining depth and the machining surface quality. Also, based on the result, scanning ECM with and without auxiliary anode was conducted to investigate the machining accuracy and the surface quality around the machining mark.

2. Experimental setup, method and structure of suction tool

2.1. Experimental setup and method

Experimental setup is shown in Fig. 1. Electrolyte suction tool was connected to the electrolyte supply tank and the waste tank, and mounted on an XYZ stage. The negative pole of the power supply was connected to the electrode, and the positive pole was connected to the workpiece and the auxiliary anode. The suction pressure was adjusted to -6 kPa by the pressure

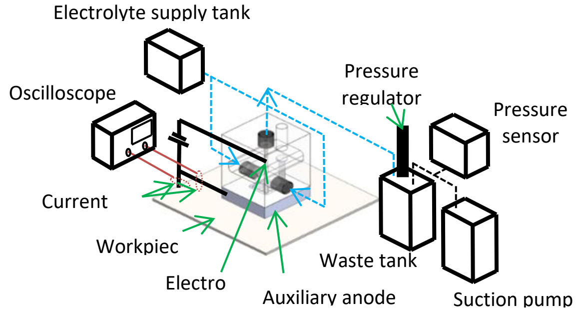


Figure 1. Experimental setup

regulator and the pump. The distance between the auxiliary anode and the workpiece was set to 50 µm before machining.

Experimental conditions are shown in Table 1. In this paper, the auxiliary anode was made of graphite. Voltage pulse of the power supply was used for the experiments to remove by-products and bubbles generated during the pulse-on time since by-products and bubbles can be removed by circulating electrolyte during the pulse-off time when electric current rarely flows.

Table 1 Experimental conditions

Material of auxiliary anode	*t* 1 mm Graphite plate
Material of workpiece	SUS304
Material of electrode	SUS304
Scanning rate	10 mm/min
Machining time	60 s
High voltage	15 V
Low voltage	2 V
Pulse width	10 ms
Pulse interval	10 ms
Electrolytic solution	20 wt% $NaNO_3$aq
Flow mode	Inner Flow Mode (IFM) Outer Flow Mode (OFM)

2.2. Structure of electrolyte suction tool

The structure of electrolyte suction tool is shown in Fig. 2. This tool is composed of the stainless pipe electrode, the graphite auxiliary anode, and acrylic plates for forming the electrolyte path. The outer and inner diameter of the stainless pipe is 1 mm and 0.7 mm, respectively. The both diameter of the holes in the graphite auxiliary anode and in the acrylic plate is 1.4 mm. The two holes in the acrylic plate and in the auxiliary anode were drilled, and the graphite auxiliary anode had a screw hole for electricity feeding. The pipe electrode, the graphite auxiliary anode and the acrylic plates were assembled by keeping all center holes concentric and then connected by adhesive.

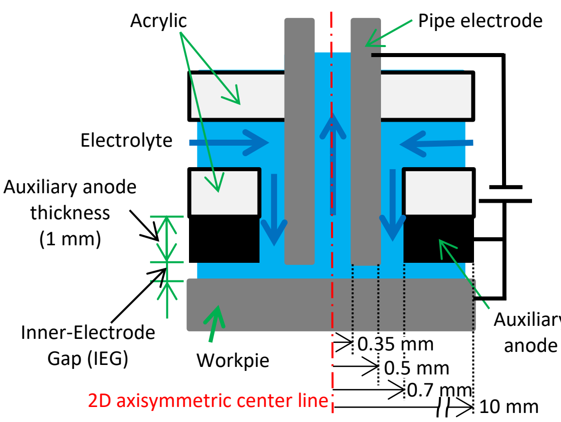
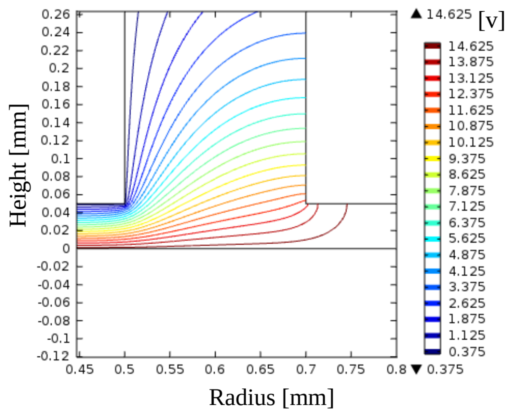


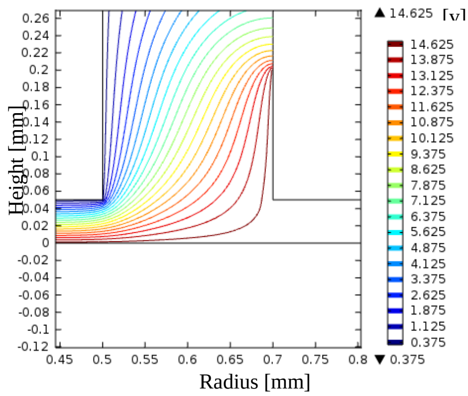
Figure 2. 2D structure of electrolyte suction tool

Figure 2 shown the electrolyte flow in the inner flow mode. Electrolyte flows through the space between the outer side of the pipe electrode and the holes in the graphite auxiliary anode and acrylic plate, and then enters the space between the pipe electrode and the workpiece, and finally flows through the centre hole of the pipe electrode under the suction pressure. In this way, electrolyte is circulated.

In order to prove the effectiveness of the auxiliary anode, simulation with COMSOL Multiphysics was carried out. The equipotential lines in the leakage area during ECM with and without auxiliary anode are shown in Fig. 3. Fig. 3(a) shows that equipotential lines exist under the insulating part in the case of ECM without auxiliary anode. However, as shown in Fig. 3(b), there are no equipotential lines under auxiliary anode in the case of ECM with auxiliary anode, which means that the auxiliary anode changes the distribution of equipotential lines and prevents the current flow under auxiliary anode. The calculated result of the current density distribution on the workpiece surface is shown in Fig. 4. From Fig. 4 it can be seen that the distribution of current density in the case of ECM with auxiliary anode is nearly same as that in the case of ECM without auxiliary anode at the radius from 0 to 0.55 mm. However, there is a clear difference between the current density at the radius from 0.55 mm to 0.8 mm. Therefore, it is recognised that low current area is restrained by adopting the auxiliary anode.



(a) w/o auxiliary anode



(b) w/ auxiliary anode

Figure 3. Distribution of equipotential lines

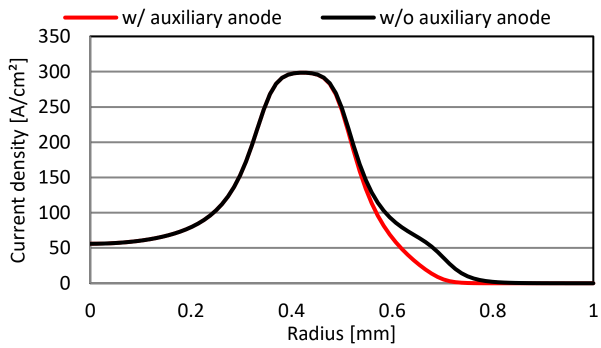
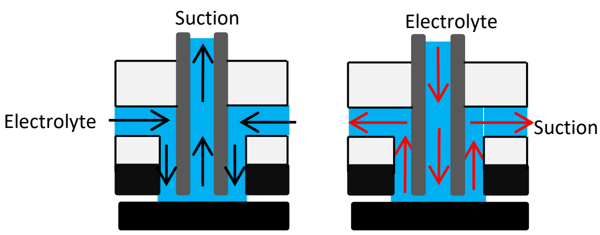


Figure 4. Current distribution under electrolyte suction tool

2.3. Electrolyte flow mode

Since the electrolyte can be sucked through the center hole or through the outer cylinder, the electrlyte flow direction is different. The 2D structure of electrolyte suction tool with the different flow modes is shown in Fig. 5. Fig. 5(a) show the way that the electrolyte flows from the outer cylinder toward the center, and is sucked into the center hole of the electrode. This flow mode is defined as inner flow mode [hereinafter referred to as IFM]. In the IFM, bubbles generated around the auxiliary anode flow to the tool tip, and prevent the material dissolution

[6]. Therefore, the amount of machining is reduced, resulting in the deterioration of machining depth and machining surface quality. On the other hand, in outer flow mode [hereinafter referred to as OFM] shown in Fig. 5(b), electrolyte flows from the centre and is sucked from the outer cylinder. In the OFM, since ECM is performed without the influence of the generated bubbles around the auxiliary anode, improving the machining depth and the machining surface quality can be realized.



(a) Inner flow mode (IFM) (b) Outer flow mode (OFM)

Figure 5. Comparison of structures with different flow modes

3. Results of scanning ECM with different electrolyte flow modes

In order to investigate the machining accuracy and the machining surface quality with the different flow modes, scanning ECM was conducted with the different flow modes as shown in Fig. 5. Also, the auxiliary anode was connected to the positive pole of the power supply to observe the influence of the bubbles generated around the auxiliary anode.

The shapes of the machining marks were measured with a contour measuring instrument (Mitsutoyo, CONTRACER CV-3100) as shown in Fig. 6, and the shapes of the machining mark are shown in Fig. 7.

From Fig. 7, the depth of the machining mark with the OFM is deeper than that with the IFM. In Fig. 7(a), the machined surface in OFM is flat. On the other hand, the machining surface with the IFM was rough.

In order to observe the machining surface roughness, the machining surface was measured by a surface roughness measuring instrument (Mitsutoyo, SJ-210) as shown in Fig .6①. The result of the roughness measurement is shown in Fig. 8. In Fig. 8, the machining surface with the IFM is rougher than that with the OFM since the bubbles generated around the auxiliary anode flow under the tool tip and prevent material dissolution.

In order to investigate the machining efficiency with the different flow modes, the currents flowed through the workpiece was measured by an oscilloscope (Tektronix, TBS 2000series) while machining. Figure 9 shows the comparison of current with the different flow modes. In Fig. 9(a), the machining current steady flows as 0.9 A with the OFM except for the initial 5 s. On the other hand, in Fig. 9(b), current value as 1A is high when the machining starts, however, current value reduces by about 0.2 A when the machining finished. The reason

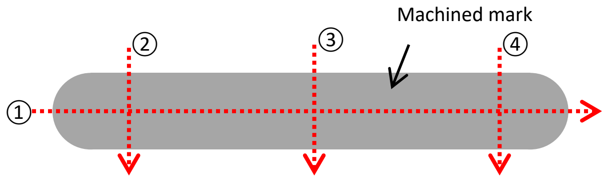
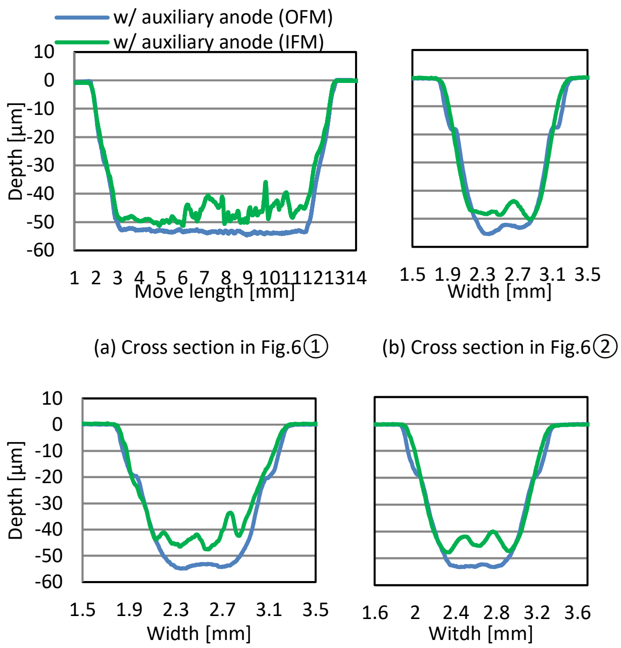


Figure 6. Measured lines of the machined mark



(a) Cross section in Fig.6① (b) Cross section in Fig.6②

(c) Cross section in Fig.6③ (d) Cross section in Fig.6④

Figure 7. Shapes of machining marks with different flow modes

is that bubbles generated around the auxiliary anode inserted to the space between the tool tip and the workpiece and stayed in that space, increasing the resistance of ECM while machining. Therefore, with the IFM, the depth of the machining mark was shallower and the machining surface was rougher than those with the OFM.

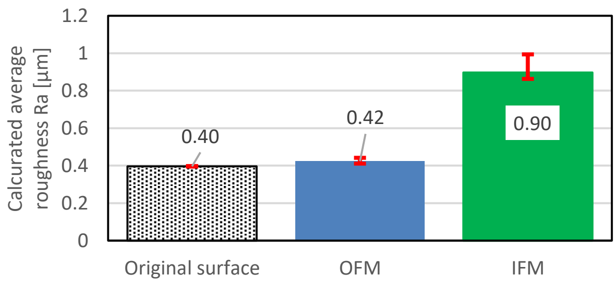
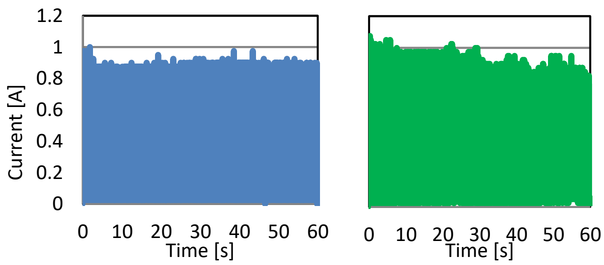


Figure 8. Roughness of machining surfaces



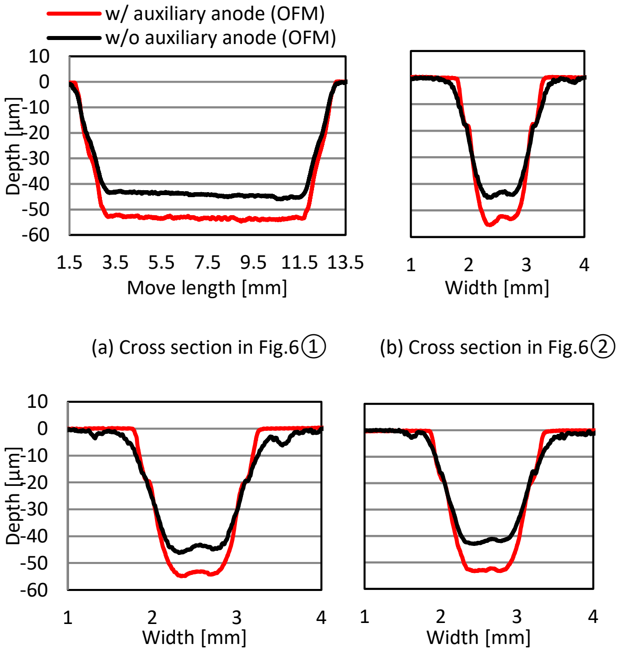
(a) Outer flow mode (OFM) (b) Inner flow mode (IFM)

Figure 9. Comparison of current with different flow modes

4. Effectiveness confirmation of auxiliary anode in scanning ECM

In previous section, the electrolyte flow mode was changed, resulting in the high machining accuracy and the machining surface quality. Based on the result, the effectiveness of the auxiliary anode in scanning ECM was investigated with the OFM. The scanning ECM experiments, with and without the auxiliary anode, were carried out by connecting the auxiliary anode to the positive pole of the power supply (hereinafter referred to as w/ auxiliary anode) and by disconnecting the wiring between the auxiliary anode and the power supply (hereinafter referred to as w/o auxiliary anode). The machining conditions are shown in Table 1.

The shapes of machining marks were measured with a contour measuring instrument as shown in Fig. 6, and these shapes of the machining marks are shown in Fig. 10. In Fig.10, the depth of the machining mark with the auxiliary anode is deeper than that without the auxiliary anode. However, in Fig. 10(b)-(d), the diameter of the machining mark without the auxiliary anode is larger than that with the auxiliary anode, and the machining area spreads without the auxiliary anode. Therefore, the machining area of ECM can be reduced by using the auxiliary anode.



(a) Cross section in Fig.6①   (b) Cross section in Fig.6②

(c) Cross section in Fig.6③   (d) Cross section in Fig.6④

Figure 10. The shapes of the machining marks with and without the auxiliary anode

The image of the area around the machining mark with and without the auxiliary anode is shown in Fig. 11. In Fig. 11, the surface around the machining mark with the auxiliary anode is not changed. However, the leakage area without the auxiliary anode was machined and discolored.

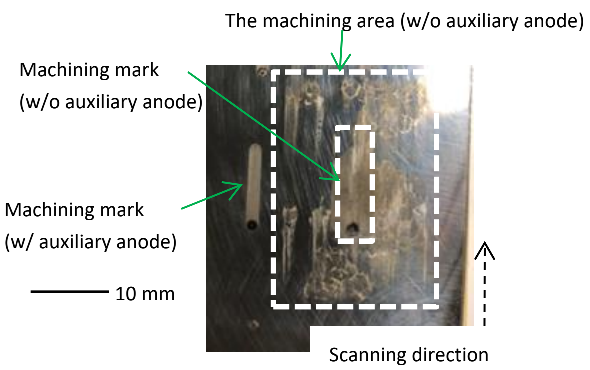


Figure 11. Image of area around machining mark

The surface roughness around the machining marks was measured by a surface roughness measuring instrument. The measurement result is shown in Fig. 12. In Fig. 12, the surface around the machining mark with the auxiliary anode is the same roughness as the original surface. Therefore, the area around the machining mark was not machined by reducing the low current density. On the other hand, the surface around the machining mark without the auxiliary anode is rougher than the original surface since current flows to the leakage area which is machined, resulting in the deterioration of the surface quality.

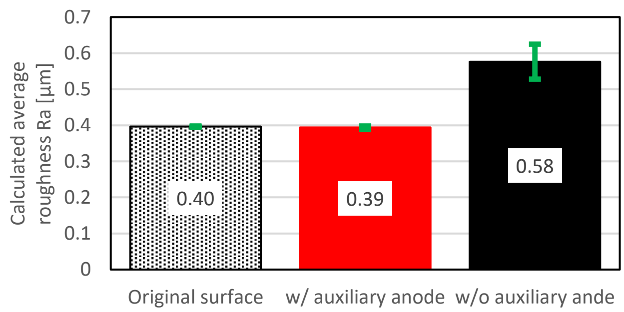


Figure 12. Surface roughness around machining mark

5. Conclusions

The scanning ECM with two flow modes was conducted. The machining mark with the OFM was deeper than that with the IFM and the machining surface quality was improved with the OFM.

The effectiveness of the proposed suction tool was investigated in scanning ECM. The current area of ECM with the auxiliary anode was narrower than that without the auxiliary anode, resulting in the high machining accuracy. Moreover, ECM with the auxiliary anode improved the surface quality around the machining mark, that the surface around the machining mark with the auxiliary anode was the same roughness as the original surface.

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