Realization of Current Area Restriction in ECM Process by Electrolyte Suction Tool with Auxiliary Electrode

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Abstract. The suction tool had been applied to the electrochemical machining due to the characteristics of its restricted electrolyte flow. In this paper, a new suction tool with built-in auxiliary anode was designed and applied to electrochemical machining. Since the function of the built-in auxiliary anode is to further restrict the electric field and lead to a narrower current area in the inter-electrode gap, in addition to the constricted electrolyte flow, higher machining accuracy and surface quality can be achieved. Based on the proposed tool structure, the numerical simulation of current density distribution was carried out to show the effectiveness of the new tool. The machining characteristics of the new tool were also experimentally investigated.

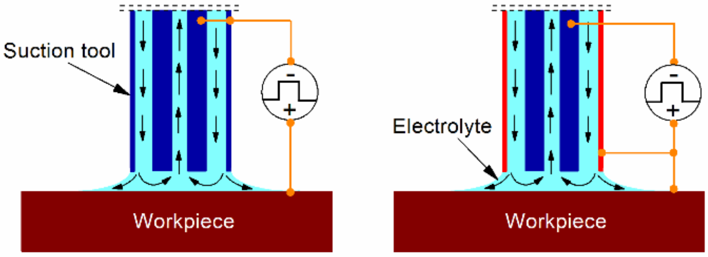
Introduction

Electrochemical machining (ECM) is a non-contact removal machining method based on electrochemistry, with the features of no tool wear, high removal rate, and good surface quality [1]. Therefore, ECM is suitable for machining difficult-to-cut materials. In the conventional ECM process, the electrode shape is transferred to the workpiece by moving the electrode with complicated shape close to the workpiece in the feed direction perpendicular to the workpiece surface [1]. This transferring method is only suitable for mass production, because the preparation of complicated tools requires long time and high cost. On the other hand, scanning ECM with a simple tool to obtain a complicated shape is on demand, especially for small or medium volume production. Electrolyte jet machining [2, 3] is one method to meet this demand. The movement of a simple nozzle enables selective machining without the use of special masks, since the electrolytic current concentrates on the jet area [4]. However, the jetted electrolyte scatters around, which causes stray corrosion and decreases the machining accuracy. To solve this problem, methods to restrict the electrolyte just under the tool electrode have been proposed. Yamamura [5, 6] realized local wet etching by using a concentric cylinder tool and two pumps, one for supplying the electrolyte to the gap area by pressure and one for recycling the supplied electrolyte from the gap area by suction. Endo et al. [7] proposed selective electrochemical machining by using a novel electrolyte suction tool, which has both functions of electrolyte restriction and gap-width detection. The suction tool had been applied in hole drilling [7, 8], shape generation [7] and oil pocket machining on a sliding surface [9]. However, even with the electrolyte suction tool, some electrolyte leaks out from the area under the tool electrode due to the bubble and other by-products generation. In this case, the current density becomes lower in the leakage area, which deteriorates the machining characteristics [10, 11].

In this study, in order to solve the low current density caused by the electrolyte leakage, a new suction tool with built-in auxiliary anode (BIAA) was proposed and applied to further restrict the electric current area in addition to the suction tool. Simulation and experiments were carried out to verify the effectiveness of the new tool. In this study, the conventional suction tool proposed by Endo et al. [7] is called suction tool, while the newly proposed suction tool with built-in auxiliary anode is called BIAA suction tool for simplicity.

Principle and experimental setup

Principle of ECM with BIAA suction tool. The principles of ECM with suction tool and BIAA suction tool are shown in Fig.1. The tool electrode consists of two coaxial tube electrodes, which form the inlet fluid channel and the reflux channel. During machining, the electrolyte enters the machining area from the inlet fluid channel, and then enters the reflux channel under the negative suction pressure. In ECM with BIAA suction tool, the outer tube works as the auxiliary anode which has the same electric potential as the workpiece. Meanwhile, in the case of suction tool, the outer tube is connected to the cathode of the power supply. Because of the electric potential distribution in BIAA suction tool, the current area will be restricted.



(a) Suction tool (b) BIAA suction tool

Fig.1 Structure and principles of suction tools

Experimental design and conditions. The schematic of ECM with BIAA suction tool test equipment is shown in Fig.2. A 1mm thick stainless steel sheet with a circular hole works as the auxiliary anode, and the hole is concentric with the tube electrode. The electrolyte flow from the outer tube into the machining area, then through inner hole of tube and reflow to the electrolyte tank. The experiments were designed to investigate the machining characteristics of ECM with BIAA suction tool. The topography of machined surface was observed by a microscope (VW-9000, Keyence) and measured by a shape measuring instrument (KS-1100, Keyence). Main experimental conditions are showed in Table 1.

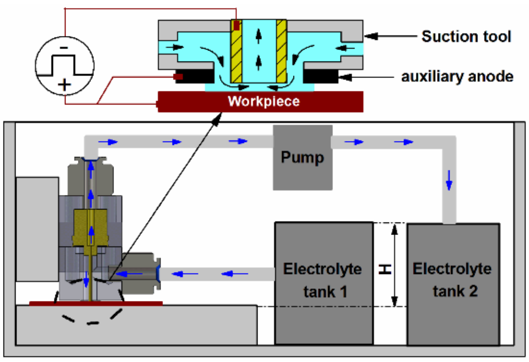


Fig. 2 Schematic of ECM with BIAA suction tool test equipment

Table 1 Machining conditions

Item	**Description**
Workpiece	SUS304
Tool electrode	Tube electrode material: SUS304 Outer diameter: 1000µm Inner diameter: 700µm.
Auxiliary anode	Material: SUS304 Diameter of the hole: 1387µm.
Inter-electrode gap	50µm, 100µm, 150µm
Machining time	2s
Voltage	15V
Electrolytic solution	20 wt.% $NaNO_3$

Numerical simulation of current density in ECM with suction tool and BIAA suction tool

In order to investigate the distribution of current density under different inter-electrode gap (IEG) in ECM with suction tool and BIAA suction tool, a two-dimensional symmetric electric field analysis model was established with COMSOL Multiphysics 5.0 (Fig.3). In this numerical model, the restricted electrolyte area was set to 2mm, the potential of workpiece and auxiliary anode was 15V, and the tool electrode was 0V, the electrical conductivity of electrolyte was 10 S/m, the IEG was 50μm, 100μm and 150μm, respectively. The distribution of current density in ECM with suction too and BIAA suction tool under different IEG is shown in Fig. 4. The result shows that the current area is restrict in narrower area in the case of BIAA suction tool.

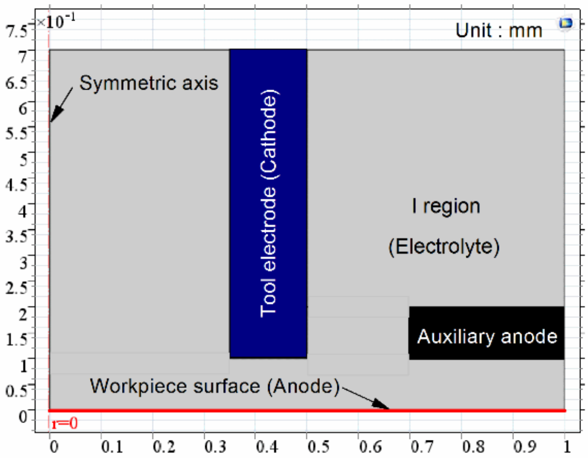


Fig. 3 Two-dimensional symmetric electric field analysis model

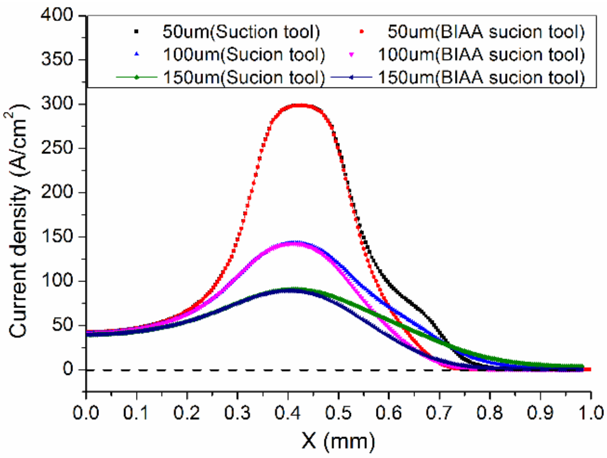
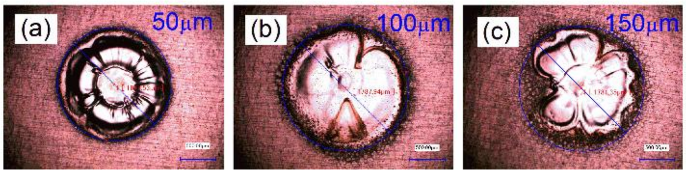


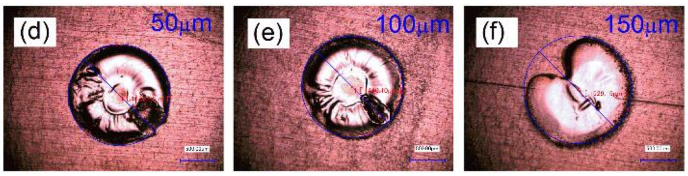
Fig. 4 Current density distribution in ECM with suction tool under different IEG

Experimental results and discussions

Morphology of the machined hole under ECM with suction tool and BIAA suction tool. In order to investigate the machining characteristics of ECM with suction tool and BIAA suction tool, a relevant experiment was carried out. Fig.5 illustrates the machined holes under different IEG in ECM with suction tool and BIAA suction tool. In the case of suction tool, the diameter of machining area at the IEG of 50μm, 100μm and 150μm is 1611μm, 1787μm and 1781μm, respectively (Fig.6). While in the case of BIAA suction tool, the diameter of machining area becomes 1436μm, 1440μm and 1529μm, respectively. The experimental results show that the BIAA suction tool can achieve better machining accuracy compared with the suction tool. The experimental results also coincide with the numerical simulation results. The position of current density zero point at 0.75mm in ECM with BIAA suction tool, while position of current density zero point at 0.9mm in ECM with suction tool.



(a) With suction tool



(b) With BIAA suction tool

Fig. 5 The machined hole by ECM under different IEG

According to the results of numerical simulation, the auxiliary anode only affects the electric field distribution at the edge of the electrode without affecting the high current density area just below the tool electrode. The simulation results were verified by the experimental results. Meanwhile, the maximum machining depth is very close in ECM with suction tool and BIAA suction tool (Fig.7).

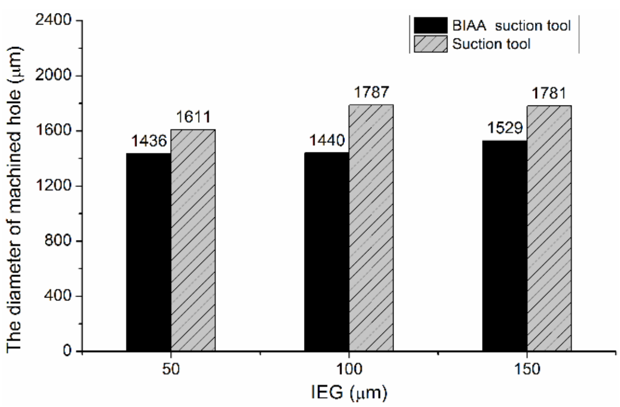


Fig. 6 Diameter of machined hole under different IEG

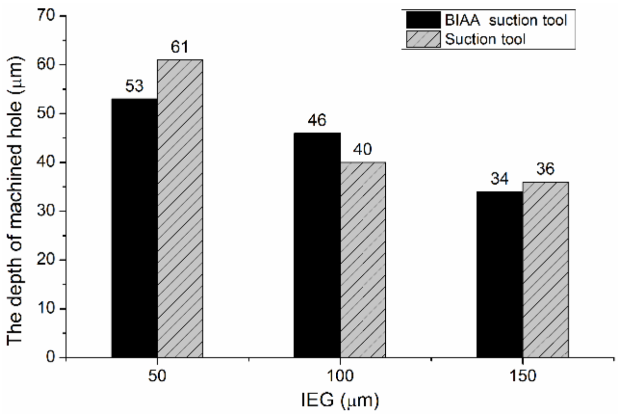
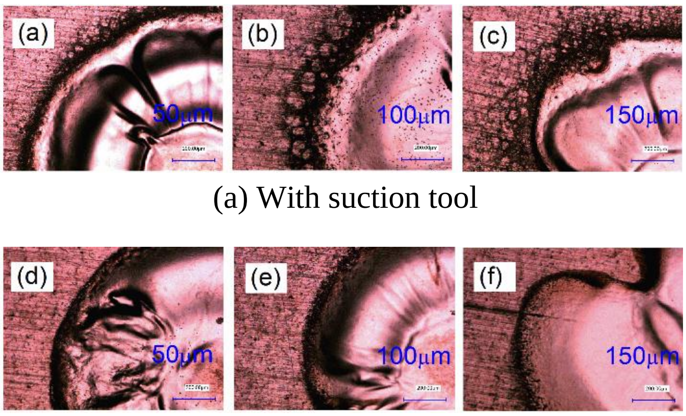


Fig. 7 The depth of machined hole under different IEG

Stray corrosion on the edge of the machined hole under ECM with suction tool and BIAA suction tool. According to the results of numerical simulation, the stray current distribution increases with the increase of IEG. The simulation results were verified by the experiment results as shown in Fig.8, because the stray corrosion in the edge of the hole becomes more serious with suction tool, which seriously affects the machining accuracy of ECM. In ECM with BIAA suction tool, the phenomenon of stray corrosion is not obvious, so the auxiliary anode can further improve machining accuracy of ECM with suction tool.



(a) With suction tool

(b) With BIAA suction tool

Fig. 8 Stray corrosion on the edge of the machined hole

Conclusions

In this paper, the ECM with BIAA suction tool was proposed and the characteristics were investigated. The experiment results illustrate that auxiliary anode can effectively restrict the electric current distribution and reduce the stray corrosion in the edge area of the suction tool. Therefore, improvement of the machining accuracy of ECM with suction tool was realized.

Acknowledgements

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References

[1] J.F. Willson, Practice and Theory of Electrochemical Machining, John wiley & Sons, Inc., 1971.

[2] M. Kunieda, M. Yoshida, H. Yoshida, Y. Akamatsu, Influence of Micro Indents Formed by Electro-chemical Jet Machining on Rolling Bearing Fatigue Life, ASME, PED-Vol64 (1993) 693-699.

[3] J. Kozak, K.P. Rajurkar, R. Balkrishna, Study of Electrochemical Jet Machining Process, Journal of Manufacturing Science & Engineering. 118 (4) (1996) 490-498.

[4] Y. Yoneda, M. Kunieda, Numerical Analysis of Cross Sectional Shape of Micro-Indents Formed by the Electrochemical Jet Machining, Journal of JSEME. 29(62) (1996) 1-8. (In Japanese)

[5] K. Yamamura, Fabrication of Ultra Precision Optics by Numerically Controlled Local Wet Etching, CIRP Annals - Manufacturing Technology. 56 (1) (2007) 541-544.

[6] K. Yamamura, Development of Numerically Controlled Local Wet Etching, Science & Technology of Advanced Materials. 8 (3) (2007) 158-161.

[7] K. Endo, W. Natsu, Proposal and Verification of Electrolyte Suction Tool with Function of Gap-width Detection, International Journal of Electrical Machining. 19 (2014) 34-39.

[8] H. Nagoya, W. Natsu, Study on ECM Characteristics in Hole Machining with Electrolyte Suction Tool, International Journal of Electrical Machining, 22 (2017) 20-25.

[9] Y. Takashima, W. Natsu, Study on Electrochemical Machining of Oil Pocket on Sliding Surface with Electrolyte Suction Tool, Procedia CIRP, 42 (2016) 112-116.

[10] S. Hizume, W. Natsu, Influence of Machining Conditions on ECM Characteristics of Titanium Alloy in Shape Generation by Scanning Tool Electrode, Procedia CIRP, 68 (2018) 746-750.

[11] S.Hizume, W. Natsu, Influence of Low Current Density on Scanning ECM with Suction Tool, Proceedings of JSEME annual meeting 2017, (2017) 25-28. (In Japanese)