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Effects of the Cathode Dimension on the Pit Formation by Scanning Micro Electrochemical Flow Cell (SMEFC)

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Abstract
Electrochemical machining (ECM) is a key technique for fabrication of structures on difficult-to-cut materials with high surface integrity. In this work, the prototype of the scanning micro electrochemical flow cell (SMEFC) is introduced and the working principle is explained. This process confines the electrolyte beneath the hollow electrode with the help of a vacuum insert. Unlike conventional ECM methods, SMEFC concentrates the electrolyte in a relatively small region, thus avoiding spreading phenomena. This present study focuses on the influence of cathode dimension on SMEFC machining performance. Three aspects are compared, including cross-sectional profiles of the machined pits and surface microstructures of the pits, as well as electrolyte droplet expansion during electrochemical dissolution. This comparison concludes that the smaller electrode contributes to higher localization. Furthermore, the instability in the case of the thinner electrode is described.

Electrochemical machining (ECM), Scanning micro electrochemical flow cell (SMEFC), Pit formation

1. Introduction

Scanning Micro Electrochemical Flow Cell (SMEFC) is originally utilized for electrochemistry analysis and electrochemical deposition. While, it can be also applied as an ECM method. Some research work involving SMEFC in ECM domain has been conducted by authors [1, 2], such as post-processing of the micro-EDMed surface by SMEFC. While, only the electrode with the outer diameter of 500 μm was utilized as the cathode in the past work. In order to get smaller features, utilization of thinner electrodes may be feasible. In this paper, the effects of the electrode dimension on the pit formation by SMEFC have been investigated.

2. Working principle of SMEFC

The working principle schematic of the SMEFC is shown in Figure 1, in which the electrode is placed at the centre of a block connected with a Venturi tube. The electrolyte can be restricted in a small region beneath the electrolyte tip, as the vacuum condition raises the used electrolyte along the electrode surface. This results in simultaneous electrochemical dissolution only in the limited area, resulting in a small pit. This small pit has potential applications in friction and lubrication [3, 4]. Unlike traditional ECM, an electrolyte tank is not required for the machining region thus electrolyte splashing is prevented, facilitating integration of ECM into other manufacture chains.

The electrode can be vertically positioned by a motion axis, and the vacuum insert is movable in three directions due to the fine tuning stage, which makes it easier to obtain a suitable position relative to the electrode and workpiece. The key dimensional parameters and corresponding abbreviations are found in Figure 1.

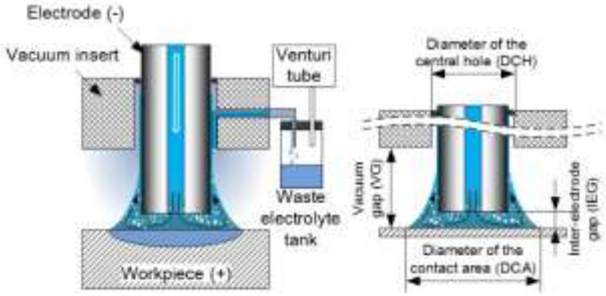

Figure 1. Working principle of SMEFC

3. Experiments

The geometrical parameters of the hollow electrodes used in the experiment have been shown in Table 1. The electrode material is WC/Co, because WC/Co has better stiffness compared with copper, and it guarantees stability when vacuum is applied.

Table 1 Tubular electrode geometry parameters

	Electrode 1	Electrode 2
Outer diameter (μm)	300	500
Inner diameter (μm)	120	180
Cross-sectional area (mm^2)	0.0593	0.1708

The electrowetting phenomena in SMEFC has been mentioned in past research work [1, 2]. Nevertheless, the electrolyte droplets show different morphologies (Figure 2) using electrodes with different dimensions, even though the same current is applied. The difference in the droplet shape affects the distribution of the electric field and further influences the pit shape.

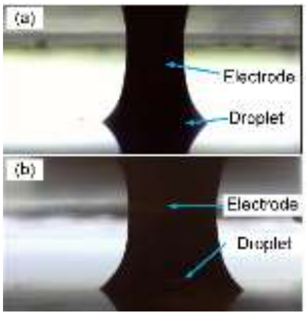

Figure 2. Electrolyte droplet morphologies with different electrodes (a) Electrode 1 (b) Electrode 2

The experiments were conducted under the constant-current mode according to the machining parameters of Table 2. The pits' cross-sectional profiles were measured by the Mitutoyo CS3200 profiler. Figure 3 compares the cross-sectional profiles under three levels of current values. Notably, there are obvious protrusions in the centre of the pits obtained from Electrode 1, which indicates a larger material removal rate. Moreover, the DCA in the case of Electrode 2 is larger than that in the case of Electrode 1 under the same current. Therefore, a thinner electrode induces higher machining localization. However, obtaining a relatively symmetrical shape with a thinner electrode is problematic. In summary, the electrode dimension highly influences pit shape. The cross-sectional profiles in Figure 4 indicate that a smaller VG and a smaller IEG contribute to higher machining localization.

Table 2 Machining parameters

VG (µm)	380, 280
IEG (µm)	50, 20
DCH (µm)	1000
Current (mA)	50,100,200
Flow rate of the electrolyte(mL/s)	0.03 for Electrode 1 0.06 for Electrode 2
Electrolyte	Sodium nitrate aqueous 250g/L
Workpiece	STAVAX mold steel
Machining time (s)	6

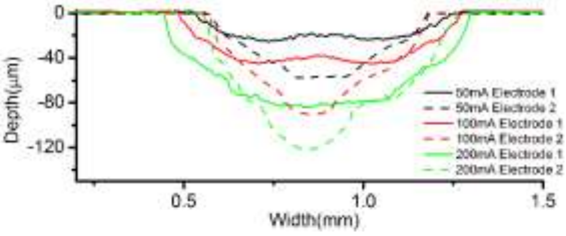

Figure 3. Cross-sectional profiles of the machined pits

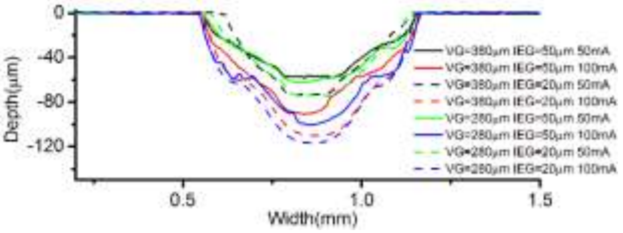

Figure 4. Cross-sectional profiles when using Electrode 1 with different VG and IEG

The expansion process of the DCA was also examined. The DCA value was recorded with time by a homemade on-line monitoring system, the details of which has been introduced in ref [2]. Figure 5 shows the changing process of the DCA with Electrode 1 and 2 when the target current is set to 100mA. A typical increase trend during the whole process can be observed for both electrodes. While, more fluctuations in DCA appear in the case of Electrode 1 during the transition process. This instability implies that the droplet cannot be controlled as stably as that when using a thicker electrode.

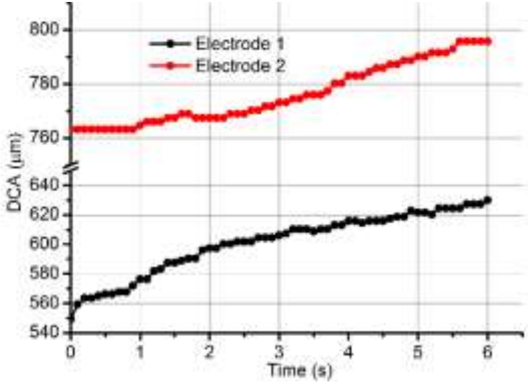

Figure 5. DCA changing with time

The SEM pictures (Figure 6) show the differences in the surface microstructures caused by the electrode dimension. The pits machined with Electrode 1 show worse surface quality compared with its counterpart. In addition, there are more residues left in Figure 6 (c) than those in Figure 6 (f). The surface microstructures derived by Electrode 2 maintain better uniformity than the situation of Electrode 1, which is determined the hydraulic condition.

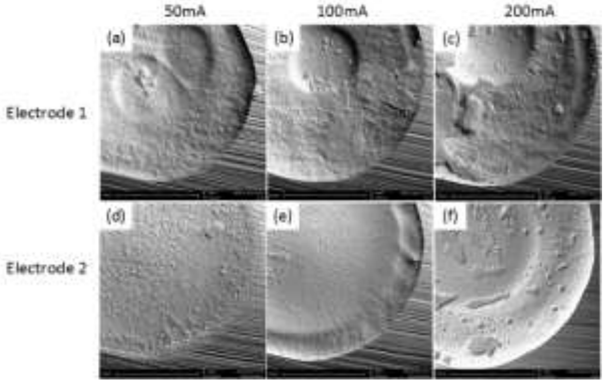

Figure 6. SEM pictures of the small pits (IEG = 50 µm, VG = 380 µm)

4. Conclusion

Based on the experimental comparison of the two different electrodes discussed above, we conclude that the electrode dimensions highly influence pit shape, the diameter of the contact area (DCA) changing process and surface microstructures when other machining conditions are fixed. Thinner electrodes enhance the machining localization of SMEFC. A smaller inter-electrode gap (IEG) and vacuum gap (VG) can conduce to better machining localization. Future research will focus on improving the surface quality and making the cavity more symmetrical when using thinner electrodes.

References

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