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Mirror-like finishing by electrolyte jet machining

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ABSTRACT

This paper describes a mirror-like finishing technique by electrolyte jet machining. When the jet is still, the workpiece area where it collides into can be selectively finished to a mirror-like surface due to high current density at the center of the jet. When the jet is being translated, the low current density in the radial flow of the impinging jet deteriorates the surface roughness while the jet is passing over the surface. This problem can be resolved by reciprocating the jet at a high translating speed. Pulsed current and bipolar pulse also realizes mirror-like finishing even at low translating speeds.

1. Introduction

Electrolyte jet machining (EJM) [1,2] is an adaptation of electrochemical machining. In EJM, a workpiece is machined only in the area hit by the electrolyte jet which is ejected from a nozzle. By translating the jet over the workpiece, intricate patterns can be fabricated without the use of a special mask [3]. Even three-dimensional shapes can be machined by controlling the current and dwelling time of the jet over the workpiece [4,5]. Use of a focused laser beam directed into the jet stream was found to further enhance the material removal rate [6,7]. EJM can be used not only for removing processes by anodic dissolution, but also for the coloring process by anodic oxidation [8]. Furthermore, by reversing the polarity, selective electroplating [9] and 3D additive manufacturing can be performed [10]. In addition, there are no heat affected zones, residual stress, cracks, or burrs seen with mechanical or thermal machining methods like cutting, grinding, electrical discharge machining, and laser beam machining, because EJM is an electrochemical process. In previous researches [11,12], it was found that high current density in the electrolyte jet brings about mirror-like surface, while lower current density results in rough topography. Hence, the surface becomes smooth at the center of the jet with high current density when the jet is standing still. However, the area around the jet impinging zone becomes rough because the current density is low in this area. As a result, when the jet is being translated, the low current density in the radial flow of the impinging jet deteriorates the surface roughness while the jet is passing over the surface. To solve this problem, this study proposes three methods to mirror-finish the surface of arbitrary shapes by translating the electrolyte jet. The first method uses significantly high jet translation speed. This method needs an expensive XY table which can move at a high feed speed with high accuracy. The second method uses monopolar pulse current with short duration and long interval, thereby the machining rate is low. Hence, a third method using bipolar pulse was proposed to increase the machining rate.

2. Electrolyte jet machining

2.1. Principle of electrolyte jet machining

Electrolyte jet machining is carried out by jetting electrolytic aqueous solution from the nozzle toward the workpiece while applying voltage to the gap as shown in Fig. 1. Fig. 2 shows the electric potential distribution in the electrolyte flow ejected from a cylindrical nozzle and the resultant current density distribution over the workpiece surface, calculated by Yoneda et al. [13]. When the electrolyte jet hits the workpiece at a sufficiently high flow rate, the electrolyte flows rapidly outward in a fast thin layer, and suddenly changes in its thickness in the area far away from the nozzle due to the hydraulic jump phenomenon. Only when this fast thin layer is formed, distribution of the current density can be concentrated under the nozzle as shown in Fig. 2(b). As a result, the material under the jet is selectively removed because of electrolytic dissolution.

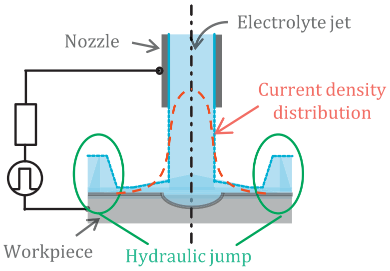

Fig. 1. Principle of electrolyte jet machining.

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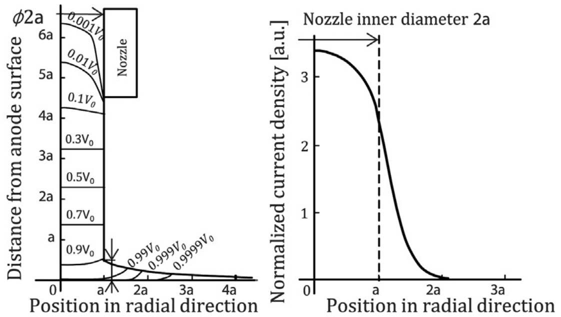


(a) Electric potential distribution. (b) Current density distribution.

Fig. 2. Electric potential and current density distributions in impinging cylindrical jet.

2.2. Experimental equipment

A schematic view of the experimental equipment is shown in Fig. 3. The workpiece is set on a table which is placed in a work sink to drain the electrolyte. The work sink and nozzle are installed on an orthogonal-type robot whose XYZ axes are numerically controlled. Using the first method which applies significantly high translating speed, the work sink is installed on a reciprocating table which is equipped with a linear motor which can realize high reciprocating speed. Machining current is supplied from a high-speed bipolar power supply with DC ~20 kHz frequency band controlled by a function generator. Since the electrolyte is supplied from a gear pump, the flow rate is controlled by varying the pump revolution speed. In this study, a sodium nitrate aqueous solution with 20 weight% was used.

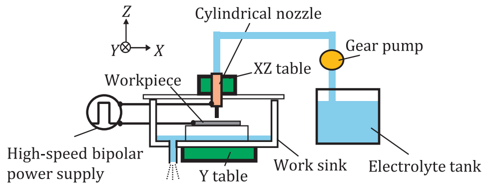
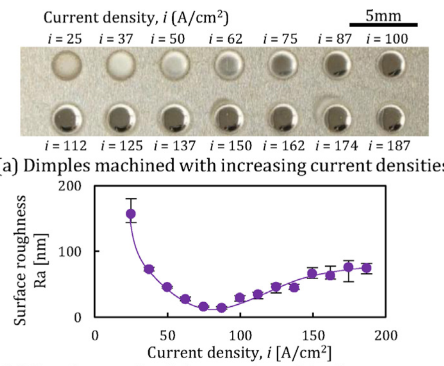


Fig. 3. Experimental equipment.

2.3. Influence of current density on surface roughness

The surface roughness can be controlled by the current density in the electrolyte jet. Fig. 4(a) shows photographs of the dimples machined using a cylindrical jet 1.43 mm in diameter while increasing the current density on stainless steel (SUS304) [12]. For simplicity, current density is defined as the machining current divided by the nozzle inner area, because current density is not uniform over the workpiece. By decreasing the machining time inversely proportional to the current density, the total electric charge can be maintained the same. For this reason, approximately 50 μm deep dimples can be obtained for every condition. The machined surfaces were not glossy when the current density was lower than 50 A/cm^2, while mirror like surfaces were obtained with higher current densities. Fig. 4(b) shows the relationship between surface roughness Ra and current density. With increasing current density, the surface roughness rapidly decreased, after which it gradually increased again. When the current density is low, the dissolution rate is uniform over the surface due to the thin diffusion layer. Hence, the asperity on the surface cannot be smoothened. On the contrary, it is augmented due to uneven distribution of micro structures, defects, and impurities having different electrochemical potentials as shown in Fig. 5(a) [14]. When the current density is sufficiently high, the thickness of the diffusion layer increases. In this situation (Fig. 5(b)), the gradients of the electric potential and concentration of molecules and ions governing the electrochemical reactions at convex points are steeper than those at concave points because the interface between the bulk flow and diffusion layer becomes flat. Thus, convex points are dissolved at a higher rate than concave points, smoothing the surface roughness. Further increase in the current density results in thicker diffusion layer, equalizing the dissolution rate over the workpiece as shown in Fig. 5(c). Hence, the surface roughness cannot be improved efficiently.



(a) Dimples machined with increasing current densities.

(b) Roughness of stainless steel machined.

Fig. 4. Influence of current density on surface roughness.

3. Finishing with direct current

3.1. Principle of finishing with direct current

To mirror-finish arbitrary areas by translating the jet, a direct current method with high translation speed was proposed. To investigate the influence of the translating speed on the surface roughness of grooves, the number of reciprocations of the nozzle was increased in proportion to the translating speed to obtain the same groove depth. Fig. 6 schematically demonstrates the change in the surface roughness at a point in the groove, when the nozzle is passing over the point repeatedly. It was assumed that current density lower than the threshold value, indicated by the broken line, increases the surface roughness at a slow speed, while current density higher than the threshold decreases the roughness more quickly until the minimum roughness is reached. The simulation result shows that, when the jet is approaching the point, the surface roughness increases gradually because of the low current

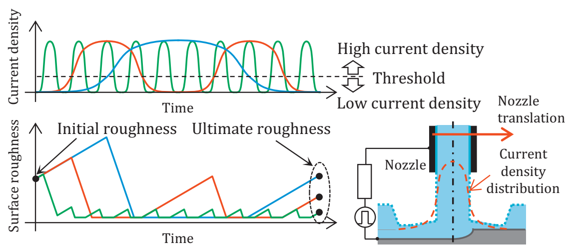
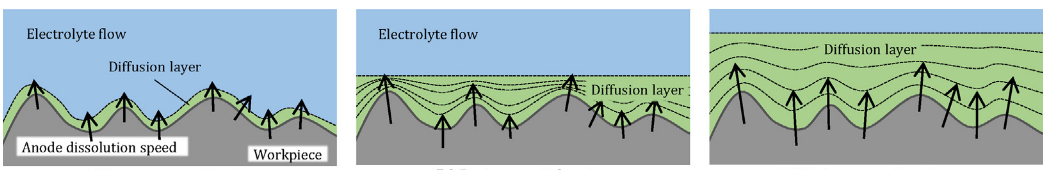


Fig. 6. Principle of surface finishing with translation.



(a) Low current density. (b) Best current density. (c) High current density.

Fig. 5. Principle of surface finishing by EJM.