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Improvement of hole exit accuracy in electrochemical drilling by applying a potential difference between an auxiliary electrode and the anode

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ABSTRACT

Electrochemical drilling (ECD) is a promising and low-cost process for yielding multiple holes simultaneously in difficult-to-machine materials. In this process, the hole exit accuracy is very sensitive to the electrode feeding depth. In practice, excessive electrode feeding is necessary to ensure that all holes are drilled through simultaneously when there is an error in thickness of the workpiece plate. This results in stray removal at the hole exit and an etched and pitted surface. In the modification of ECD described here, a potential difference is introduced via an insoluble platinum auxiliary electrode that is attached beneath a dielectric perforated plate and arranged opposite to the hole exits to diminish the damage from the stray current and thereby improve the tolerance of the exit accuracy to excessive electrode feeding. Simulation results indicate that an appropriate value of the potential difference concentrates the current at the tool tip and may reverse the current direction on the workpiece surface. Experiments verify that this approach is effective in obtaining holes with good exit accuracy in the case of excessive electrode feeding. Furthermore, it is confirmed that this method is capable of drilling multiple holes with remarkably enhanced exit accuracy and uniformity.

1. Introduction

The art and science of film cooling, which allows aircraft engines to achieve extremely high turbine firing temperatures, have created a demand for methods of producing cooling holes in turbine blades and vanes. These holes are 1–4 mm in diameter and have aspect ratios in the range of 40–150 (Bilgi et al., 2004). Electrochemical drilling (ECD) is a promising and low-cost process for making holes in difficult-to-machine materials, such as nickel-based super alloys, titanium and inter-metallic compounds (Sen and Shan, 2005). Compared with traditional methods, ECD has advantages in the absence of residual stress, tool wear and metallurgical defects (Ali et al., 2009). Therefore, it has been widely applied in the aerospace, aeronautics, defence and medical industries (Pattavanitch and Hinduja, 2012).

In ECD, the material removal inevitably continues on the machined surface, resulting in undesirable dissolution and inferior accuracy control (Zhu and Xu, 2002). This is known as stray removal, and is typically minimized by side insulation of the tube electrode. Together with electrode insulation, the passivating electrolyte has been used to enhance the dimensional control near the threshold value of the current density (Bilgi et al., 2007). Pulse current has also been successfully used in ECM to obtain higher precision (Rajurkar et al., 1999). When the pulse is off, the absence of dissolution promotes the renewal of the electrolyte and the removal of products. Therefore, better gap conditions and a smaller machining gap confines the current to the region under the tool (Rajurkar et al., 1993). The discovery that ultrashort pulses result in the incomplete loading of the double layer in regions far from the tool (Schuster et al., 2000) has greatly enhanced the localization of electrochemical dissolution.

Furthermore, various attempts have also been made to modify the electrolyte flow pattern and electrolytic refreshment to improve the machining accuracy. Orbital electrode movement distributes the electrolyte flow more uniformly, reduces the disruption phenomena (Rajurkar and Zhu, 1999) and diminishes the spikes in the frontal zone (Hewidy et al., 2001). A pulsating power supply in synchronization with a vibrating tool provides a positive and beneficial effect by changing the physical conditions in the machining gap (Hewidy et al., 2007) and enables relatively high stock removal processing with a minimum interelectrode gap of just a few micrometers (Zaitsev et al., 1998). A coaxial gushing and sucking method (Hu, 2007) was proposed to improve the hole entrance accuracy by gushing fresh electrolyte and removing the

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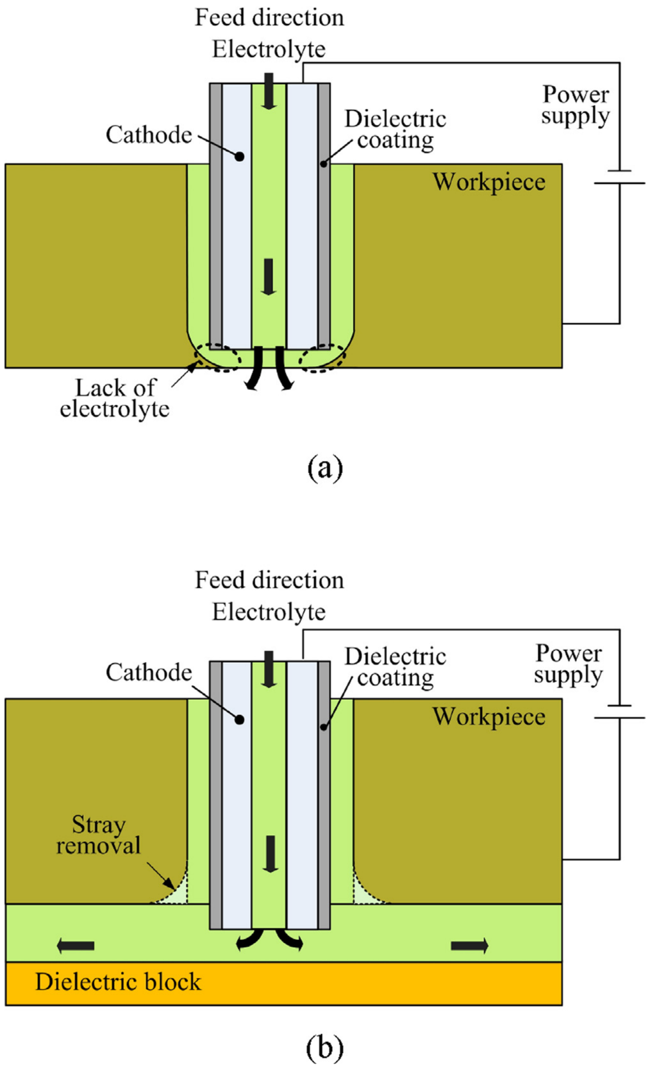

Fig. 1. Schematic diagram of the conventional ECD processes: (a) without back pressure; (b) with a back pressure.

reaction product and bubbles at the hole entrance. The range of electrolyte flow is reduced, and the stray removal at the entrance is diminished.

In particular, some interesting research has focused on changing the distribution of the current line between the electrodes to eliminate the stray current attack. A dual pole tool (Zhu and Xu, 2002), which is wrapped with a metallic bush outside the insulated cathode tool, has been invented to improve the machining accuracy. The bush, connected with the anode, substantially weakens the electric field at the side gap and reduces the stray removal of material there. A magnetic field (Fan et al., 2004) has been applied perpendicularly to the electric fluxes to reduce the dispersion corrosion in the non-machining area. The polarity of the magnetic field on the tool electrode aligns the magnetic moments of the ions toward the machining area. Therefore, the electric quantity flowing toward the machined surface was reduced. Thief-anodes (Jain et al., 2005) and segmented tools (Jain et al., 1987) have also been employed to control the magnitude of the stray current by modifying the electrode structure.

A review of the literature reveals that most research in this area focuses on avoiding the stray removal and improving the machining accuracy in the hole interior. However, the literature shows few studies on the accuracy of the exit machining. In a conventional ECD process, as illustrated in Fig. 1(a), a major part of the electrolyte flows out from the hole exit. When the electrode continues to feed, short circuits or sparks will be encountered in the zone that lacks electrolyte. To hold the electrolyte, a sacrificial layer or a dielectric block is usually placed under the workpiece by forming a back pressure. A sacrificial layer is not recommended in industrial applications because it is destroyed as the hole is drilled through, and a single sacrificial layer can be employed only once, which adds to process cost and time. A dielectric block could be employed for some workpieces.

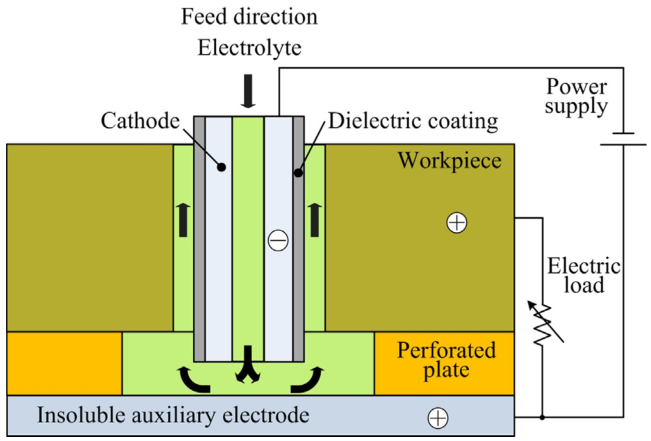

Fig. 2. Schematic diagram of ECD with an insoluble auxiliary electrode.

In simultaneous drilling of multiple holes, the tube electrodes are fixed in arrays. When there is an error in thickness of the workpiece plate, it is impossible to precisely adjust the feeding depth for each hole, and excessive electrode feeding is necessary to ensure that all holes are drilled through. As the accuracy of the hole exit is very sensitive to the electrode feeding depth, excessive electrode feeding will result in stray removal at the hole exit as well as an etched and pitted bottom surface, as shown in Fig. 1(b). It will then not be possible to control the machining accuracy or uniformity of the hole exits are uncontrollable.

This study presents a new method in which a potential difference is applied between an auxiliary electrode and the workpiece

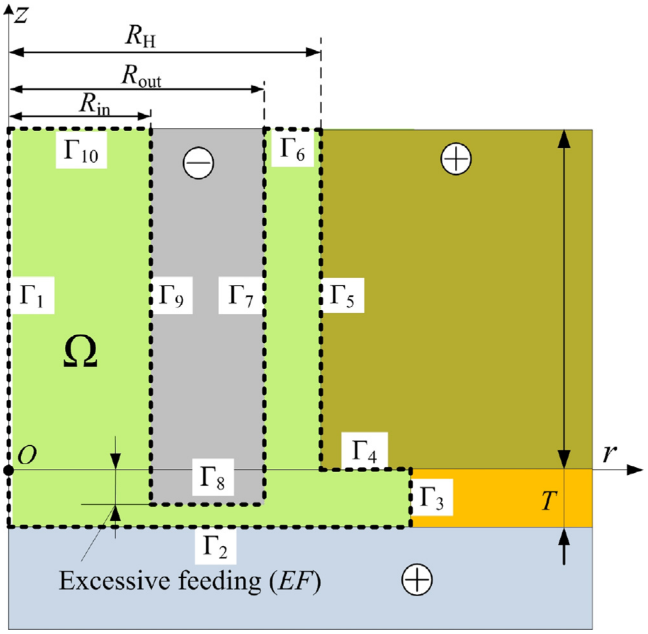

Fig. 3. Electric potential domain in the inter-electrode gap.