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Effect of tube-electrode inner structure on machining performance in tube-electrode high-speed electrochemical discharge drilling

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ABSTRACT

Film cooling holes are required in many crucial and widely used structures. The creation of good film cooling holes requires machining at high speeds with high accuracy and good surface quality. For this purpose, a promising hybrid machining method combining electrical discharge machining and electrochemical machining, called tube-electrode high-speed electrochemical discharge drilling (TEHECDD), has been proposed, which can be used for machining difficult-to-machine superalloys. In TEHECDD, the flushing condition is considered as an important element. To improve the flushing condition and further enhance the machining performance, improved tube-electrode structures, obtained by varying the inner diameter and inner shape, are introduced. In this study, different inner structures are designed for the tube electrodes, whereby the mechanism of the enhanced TEHECDD performance for different tube-electrode inner shapes are analysed and the effects of different tube-electrode inner structures on the machining performance are investigated. The results show that an increase in the tube-electrode inner diameter results in a higher material removal rate, smaller average bore diameter, and smaller taper angle. However, for the single-hole tube electrode, a larger inner hole results in the formation of a residual cylinder. Thus, the double-hole and multi-hole tube electrodes are proposed and found to be effective in removing the residual cylinder. Finally, it is verified that the tube electrodes with improved inner shapes can be used to further enhance the machining performance. The double-hole tube electrode is confirmed to have the optimal structure.

1. Introduction

The important components of turbine engines, including blades and vanes, were required to be operated at excessively high turbine inlet temperatures, which usually exceed the allowable metal temperature, reported by Krewinkel (2013). Therefore, Yao et al. (2014) stated effective cooling techniques were required to maintain the temperature of the turbine blades and vanes within acceptable limits. Currently, film cooling techniques are commonly accepted and widely used; in these techniques, film cooling holes are employed to decrease the incident convective heat flux on the surface and protect the surface from hot gas exposure, reported by Bilgi et al. (2004). Bamberg and Heamawatanachai (2009) proposed because such film cooling holes were to be placed all over the body of the blades and vanes at various injection angles, small and micro-sized holes with high aspect ratios needed to be created. In addition, Fang et al. (2014) reported that the film cooling holes were to be created in nickel-based superalloys, titanium alloys, single-crystal alloys, and other difficult-to-machine materials. It was extremely difficult and even impossible to machine such materials by conventional processes. Hence, an efficient machining process for massive film cooling holes was important for the fabrication of aero-engine components. Besides, as turbines engines become more advanced, more rigorous demands were placed on the surface quality of the holes. Especially, recast layers and micro-cracks, which were usually generated after thermal machining, were not allowed to exist on machined surfaces, reported by Wang et al. (2009).

For the fabrication of film cooling holes, tube-electrode high-speed electrochemical discharge drilling (TEHECDD) was accepted by many researchers as a novel hybrid process with high machining efficiency and good surface quality, proposed by Zhang et al. (2015). In this process, tube-electrode high-speed electrical discharge drilling and electrochemical surface finishing were simultaneously combined into the same process, whereby the advantages of these two processes, including high efficiency and good surface quality, were well exploited. For achieving the above-mentioned performance in the TEHECDD process, a crucial factor is the appropriate

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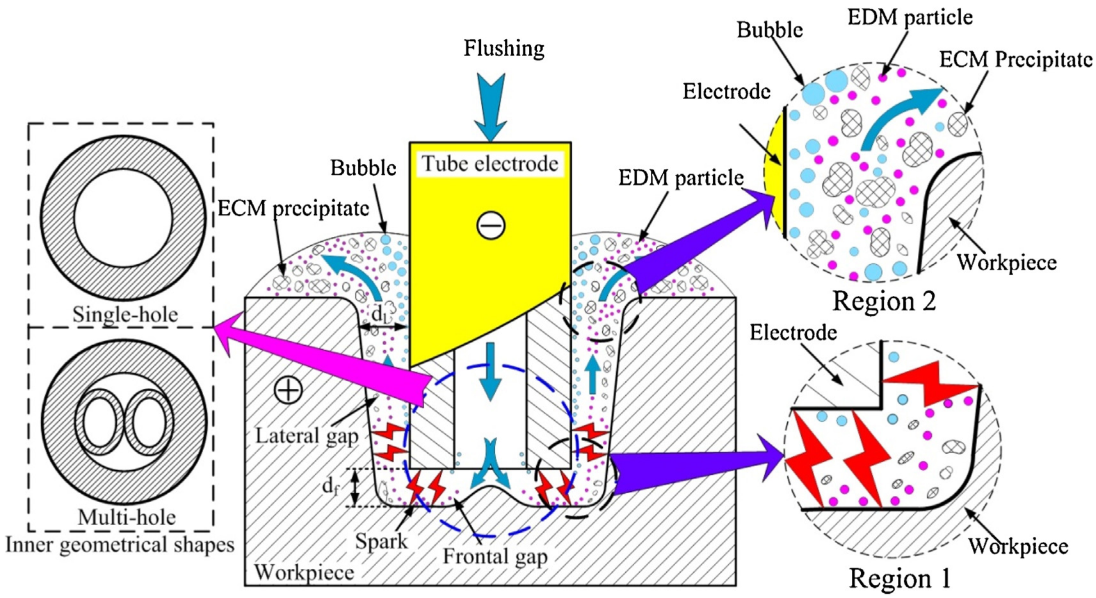

Fig. 1. Mechanism of TEHECDD for different inner geometrical shapes.

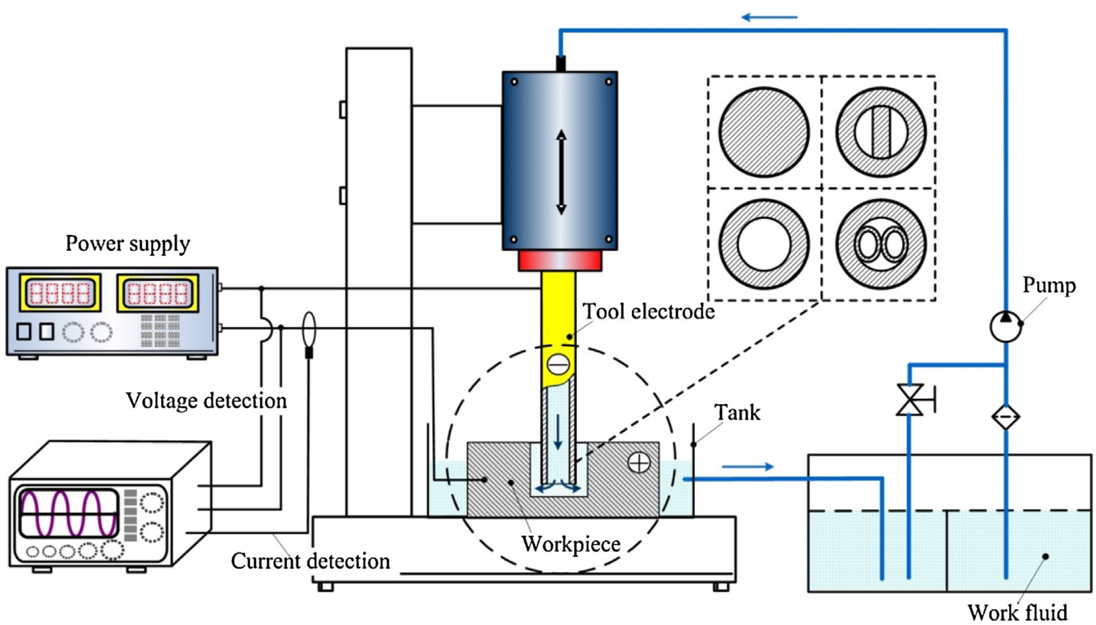

Fig. 2. Experimental system developed for TEHECDD with different tool electrodes.

use of the tube electrode. The working fluid is supplied to the machining gaps from the interior of the tube electrode to cool down the machining region and push the machining by-products, including metal pieces, hydroxide precipitates, gas bubbles and Joule heat, out of the gap between the workpiece and tube electrode.

However, Goodlet and Koshy (2015) found that in the electrical discharge machining of the film cooling hole, because of the narrow machining gap, the flow rate of the working fluid was limited to a low level; thus, the machining by-products and heat could not be rapidly carried away from the machining zone, reported by Kumagai et al. (2006). Especially in TEHECDD, the complex machining by-products include not only debris and Joule heat produced in the electrical discharge erosion process but also hydroxides and gas bubbles generated in the electrochemical dissolution process. Hence, the risk of blockage in TEHECDD is greater than that in any single process of electrical discharge machining (EDM) or electrochemical machining (ECM). Thus, the flushing condition is extremely important for the machining performance in TEHECDD. Lonardo and Bruzzone (1999) described that under poor flushing conditions, the increasing debris, hydroxides, and bubbles in the working fluid might sometimes cause extra arc pulses, whereas the abnormal discharge currents reduce the machining accuracy, surface quality, and machining speed of the film cooling holes in EDM process. In addition, Chen et al. (2014) found that the poor removal of Joule heat might result in high electrode wear and cause a thick recast layer to be formed on the EDMed surface. Furthermore, the blockage caused by the machining by-products leads to an increase in the contaminant concentration in the working fluid. Wong et al. (1995) noted that because of the poor decontamination of the narrow gap and the mass residual Joule heat, the electrochemical dissolution reactions fatally deteriorate, and consequently, a good machined surface cannot be obtained. Hence, to