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Effect of tube-electrode inner diameter on electrochemical discharge machining of nickel-based superalloy

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Abstract Nickel-based superalloys are widely employed in modern aircraft engines because of their excellent material characteristics, particularly in the fabrication of film cooling holes. However, the high machining requirement of a large number of film cooling holes can be extremely challenging. The hybrid machining technique of tube electrode high-speed electrochemical discharge drilling (TEHECDD) has been considered as a promising method for the production of film cooling holes. Compared with any single machining process, this hybrid technique requires the removal of more complex machining by-products, including debris produced in the electrical discharge machining process and hydroxide and bubbles generated in the electrochemical machining process. These by-products significantly affect the machining efficiency and surface quality of the machined products. In this study, tube electrodes in different inner diameters are designed and fabricated, and the effects of inner diameter on the machining efficiency and surface quality of TEHECDD are investigated. The results show that larger inner diameters could effectively improve the flushing condition and facilitate the removal of machining by-products. Therefore, higher material removal efficiency, surface quality, and electrode wear rate could be achieved by increasing the inner diameter of the tube electrode.

1. Introduction

Nickel-based superalloys have found several applications in modern aircraft engines, because of their superior strength and excellent temperature resistance.[1] Employed as the materials for the turbine blades and vanes, these superalloys have remarkably improved the operability and efficiency of turbines at extreme temperatures.[2] However, nickel-based superalloys are also difficult to machine, and the fabrication of some complex structures from these materials using the traditional

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machining processes can be quite problematic.[3,4] For example, film cooling holes are typical structures in turbine blades and are commonly tiny, numerous, and irregularly divergent. Because they need to be machined with high machining efficiency and surface quality,[5,6] the fabrication of film cooling holes in nickel-based superalloys has been a significant challenge in the aerospace manufacturing industry.[7] Hence, a reliable and efficient process is urgently required for producing these holes without surface defects like recast layers, heat-affected layers, and cracks.

Tube electrode high-speed electrical discharge drilling (TEHECDD) has been proposed as a suitable process for the machining of film cooling holes.[8] In this process, using a tube electrode and low-conductivity salt solution, electrical discharge machining (EDM) and electrochemical machining (ECM) are combined. Therefore, TEHECDD can obtain better machining performances in both machining efficiency and surface quality. In this hybrid process, because tube electrode high-speed electrical discharge erosion occurs in the frontal gap, a hole can be drilled with high speed, while the electrochemical reaction, occurring in the lateral gap, removes the surface defects generated in the EDM process, such as recast layers, cracks, and residual stress.[9] Because of these advantages, TEHECDD is considered as the perfect machining process for the fabrication of film cooling holes.

The greatest obstacle in the TEHECDD method is the removal of machining by-products. As it is a hybrid process, these include not only the melted and vaporized particles generated by EDM but also the hydroxide precipitates and bubbles produced by ECM. The volume of the hydroxide precipitates is several hundred times larger than that of the EDM particles.[10,11] Thus, the narrow machining gap can be more easily blocked by by-products in TEHECDD than in either EDM or ECM. Such blockage makes it difficult to remove the mixed machining by-products and the Joule heat from the machining gap.[12] Moreover, under high-temperature and sharp cooling conditions, the hydroxides and melting metal particles resolidify to form a thick recast layer on the surface of the hole.[13] The blockage of the machining gap also leads to an increase in the concentration of contaminants in the working fluid.[14] The poor decontamination of the working fluid may result in extra arc and secondary discharges, and these abnormal discharges cause instable machining, reducing the machining accuracy, surface quality, and machining efficiency.[15–17] Moreover, because of the poor decontamination of the narrow gap and the high residual Joule heat, the electrochemical dissolution reactions fatally deteriorate, decreasing the quality of the machined surface.[18] Hence, the removal of machining by-products is essential for achieving high machining accuracy and surface quality in TEHECDD.

This study focuses on the improvement of the machining accuracy and surface quality of TEHECDD by the enhanced removal of by-products. To achieve these objectives, tube electrodes of different inner diameters are fabricated for use in TEHECDD, and the effects of the inner diameter on the material removal efficiency, machining accuracy, and surface quality are analyzed. Finally, the inner diameter of the tube electrode is optimized to ensure better machining accuracy and surface quality.

2. Experimental details

2.1. Machine tool

The experimental system specially developed for TEHECDD with different electrode structures is schematically illustrated in Fig. 1. All the experiments in this study were conducted in this system, which consists of tube electrode clamp and flushing units, power supply cell, current/voltage detection unit, and machining region. In this study, a series of electrodes, including five tube electrodes, was investigated. The electrode was fixed on the machine head and could be moved in the feeding directions along a linear guide using motors. By operating the pump, the working fluid could be supplied continuously and steadily to the machining zone through the interior of the tube electrode. The pulse generator placed on the machining channel supplies energy for the entire machining process. The voltage detection unit enables the machining voltage and current to be determined simultaneously, so the process could be controlled in real time.

2.2. Materials

Currently, DZ125L is one of the most commonly used nickel-based superalloys, and it is employed as the material for

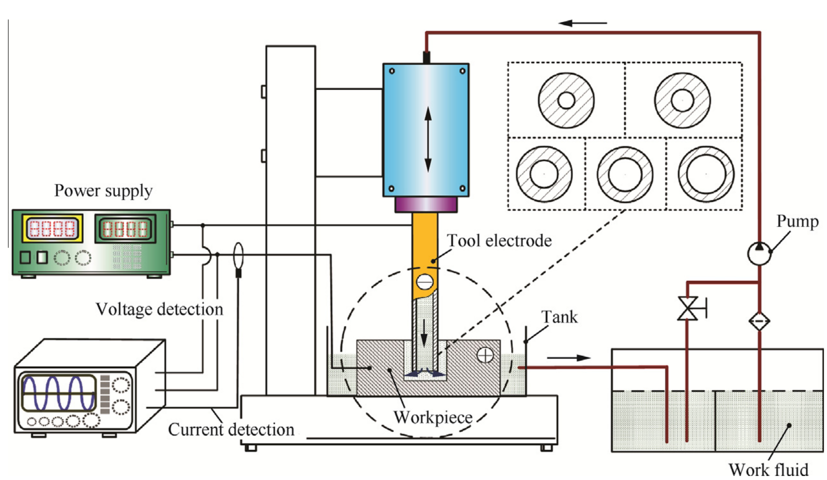

Fig. 1 Schematic diagram of experimental system developed for TEHECDD with different tube electrodes.