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High-speed near dry electrical discharge machining

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ABSTRACT

High-speed near dry electrical discharge machining (EDM) is a novel and promising machining method, which obtains higher material removal rate, lower surface roughness and thinner width of overcut compared with that of high-speed dry EDM. Moreover, debris deposition on the machined surface and electrodes are significantly reduced and an obviously thin heat affected zone is obtained using the near dry dielectric (mist). In this study, a low-flux pump is utilized to supply deionized water at a controlled rate to the high-speed air pipe, which affords a mist dielectric to the machining process. Compared with dry EDM, the high-speed near dry EDM improves the cooling capacity and increases the dielectric strength of the dielectric. Furthermore, electrode injection flushing assisted by side flushing of high-speed mist was used to reduce debris deposition and improve cooling capacity. Comparative milling experiments of Ti6Al4V were conducted under the dry and near dry conditions using the different flushing ways. The effects of current, pressure, droplet size, electrode rotation speed, and droplet density on the material removal rate, surface roughness, width of overcut in continuous machining and material removal weight, trace length, trace width in single pulse machining were studied. In addition, scanning electron microscope, X-ray diffractometer, energy dispersive spectrometer, and micro-hardness tester were also used to study the micro-characters of the machined materials.

1. Introduction

Electrical discharge machining (EDM) is an effective method to machine the so-called 'difficult-to-machine' materials, such as titanium alloy, nickel base alloy and hard alloy, which have wide application range but are difficult to process using the conventional machining methods. Shokrani et al. (2012) showed that dry EDM is considered as the most effective EDM method to eliminate the use of fluid dielectric in manufacturing enterprises, which reduces the machining costs and ecological hazards. The low material removal rate of dry EDM always limits the application of this method. Xu et al. (2008) used ultrasonic-assisted, Joshi et al. (2011) used magnetic-assisted, and Kunieda et al. (2004) used piezoelectric actuator-assisted to promote the ejection of molten materials and reduce the occurrence of short circuits in dry EDM. Puthumana and Joshi (2011) used electrodes with peripheral slots to provide more space for the flow of dielectric for effective debris disposal. A certain increase of material removal rate has been obtained, though the improvement of material removal rate is non-significant. To solve the low material removal rate problem, a high-speed dry EDM method was presented in our previous study (Shen et al., 2015a). The material removal rate of AISI 304 stainless steel in this promising dry machining method could be as high as 5162 mm^3/min, which improved the material removal rate by 2nd order of magnitude compared with that of 36.04 mm^3/min of conventional dry EDM by Tao et al. (2008). The high-speed dry EDM method could quickly melt the work piece materials by extremely high discharge energy and flush them out from the discharge gap by high-pressure and high-speed air flow. In another accepted article of us (Shen et al., 2015b), milling experiments on Ti6Al4V using high-speed compound machining with high-speed air dielectric were conducted. The new and efficient compound machining combined arc machining and electrical discharge machining (EDM) together, both of them were working in parallel. The maximum material removal rate of 5862 mm^3/min was obtained.

However, some obvious shortages appeared in the high-speed machining methods using air as dielectric, such as the thick heat-affected zone and the bad machined surface. The appearance of thick heat-affected zone is due to the weak cooling capacity of air dielectric, which will significantly increase the cost of the subse-

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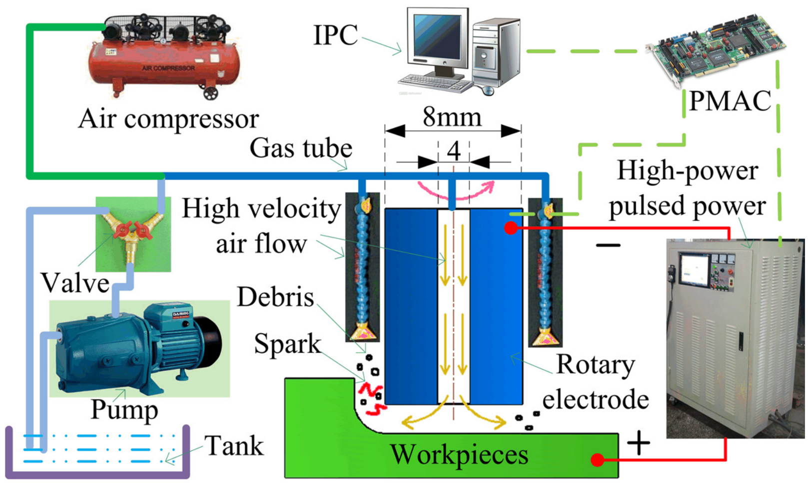

Fig. 1. Schematic diagram of high-speed near dry EDM.

quent finishing stages. The occurrence of the bad machined surface is because the work pieces materials are adhered to the surface of the work pieces and electrodes. The surface roughness and width of overcut are increased due to the adhesion on the work pieces and electrodes surface, which are the major quality standards of an EDM method.

Kao et al. (2007) obtained a higher material removal rate and less debris deposition in EDM using a liquid-gas mixture dielectric compared with that of using air. Tao et al. (2008) obtained a fine surface quality using deionized water mixed in the nitrogen compared with the conventional dry EDM. Wang et al. (2014a) compared the effects of different flushing methods of electrode injection flushing and side flushing on the processing effectiveness in the combined machining of EDM and arc machining. A thinner re-solidified layer and less debris deposition were obtained with electrode injection flushing assisted by side flushing. However, only the electrode injection flushing method was used in the high-speed dry EDM of AISI 304 stainless steel (Shen et al., 2015a) and high-speed compound machining of Ti6Al4V (Shen et al., 2015b).

In this study, a series of measures are proposed to improve this promising and environmental method. The measures are as following: a certain amount of non-polluting deionized water is mixed in the high-speed air (forming mist) to increase the cooling and debris flushing capacity of dielectric. A side flushing device is added to the machining process to reduce the adhesion of work pieces materials on the work pieces and electrodes. To verify the effect of the improving measures, a number of comparative milling experiments were conducted under the dry and near dry conditions using different flushing ways. The effects of current, air pressure, droplet size, electrode rotation speed, and droplet density on the material removal rate, surface roughness, width of overcut in continuous machining and material removal weight, trace length, trace width in single pulse machining were studied. Moreover, scanning electron microscope (SEM), X-ray diffractometer (XRD), energy dispersive spectrometer (EDS), and micro-hardness tester were also used to research the different micro-characters of the machined materials in the high-speed dry and near dry EDM.

2. Experiment details

2.1. Experimental Setup

Comparative milling experiments were conducted in a self-developed CNC EDM machine tool. The machining principle can be seen in Fig. 1. A high power pulsed supply (maximum current of 700 A) is connected with the electrode and work piece, which provides enough energy for the discharge gap. Waveforms of voltage and current in high-speed near dry EDM can be seen in Fig. 2. High-speed air mixed with a certain flux of deionized water as dielectric flows into the machining gap through inner and outer of the electrode. The flux of deionized water is controlled by a control valve connected with the high-speed air pipe and the rest deionized water will flow back to the sink through an overflow valve. A small-flux flowmeter is used to measure the flow rate of the deionized water into the high-speed air pipe. The high-speed dielectric expels the debris efficiently. A motion control card (Turbo PMAC, Delta Tau Data System) is used as a slave computer to control the servo feed and rotation of the spindle, which is similar with that used in the study of Wang et al. (2012). An industrial personal computer (IPC) is used as a principal computer to command the motion control card and display machining status, which also controls the parameter setup of the pulsed supply.

2.2. Experimental conditions

An air compressor (LB75250, maximum pressure of 0.7 MPa) was used to provide high-speed air and a self-absorption-ejector pump (JEY1500AL, 2.2 kW) was used to provide the deionized water. A small-flux flowmeter (Omega FPR-300) was used to measure the flow rate of the deionized water. A precision balance (Sartorus BS224S) with a weighing accuracy of 0.1 mg was used

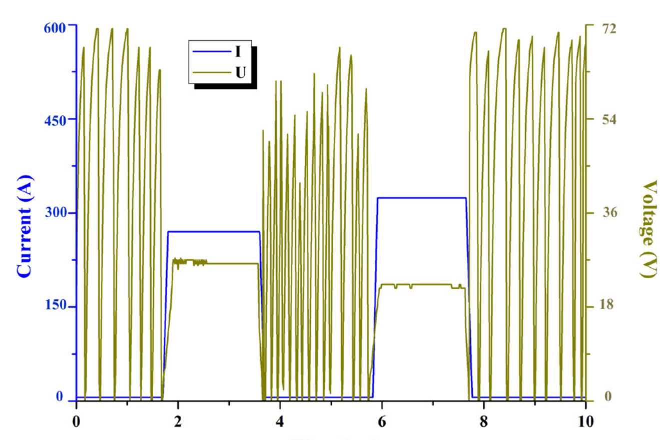

Fig. 2. Waveforms of voltage and current in high-speed near dry EDM.