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Study on machining characteristics of WEDM with ultrasonic vibration and magnetic field assisted techniques

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ABSTRACT

Wire electric discharge machining (WEDM) allows improved machining performance with both high material removal rate (*MRR*) and surface quality. In this study, a hybrid technique of WEDM using assisted ultrasonic vibration (USV) and magnetic field (MF) is firstly proposed to enhance the machine characteristics, and then to investigate the effects of the main process parameters on the *MRR* and surface quality including surface roughness (R_a) and surface crack density (*SCD*) in machining Ti_6Al_4V. Additionally, analysis is conducted on the pulse discharge waveforms and the morphology of machined surface, the effect of removing the debris between the wire tool and workpiece and the ratio of normal machining states. Comparison of the experimental results of USV, MF and conventional WEDM reveals that when process parameters are selected in the appropriate range, the hybrid process of WEDM with assisted USV and MF can significantly improve the ratio of normal pulse discharge states, increase the machining efficiency, and improve surface quality simultaneously, reducing R_a and *SCD*. The proposed hybrid process of WEDM presents enormous advantages and potential for applications in the practical machining and manufacturing field.

1. Introduction

Wire electrical discharge machining (WEDM) is an essential non-conventional machining process, widely utilized in the manufacturing field due to the ability to machine shape more challenging electrically conductive materials such as mold steels, ceramics and composites, regardless of mechanical characteristics (hardness, strength, stiffness, etc.). The WEDM process is a violent thermal process utilizing thermal energy from thousands of electrical discharges to erode a certain volume of metal in a fraction of one second leading to melting, vaporization, and ionization of the electrode materials at the pulse discharge point. The process generates discharge craters, recast layers, and cracks on the surface of the workpiece, between the wire electrode and the workpiece, causing surface quality of the machined surface to deteriorate in accordance with the presence of these craters, recast layers and cracks. Moreover, the machined debris that is not washed away by dielectric fluid in the thermal process would accumulate in the machining gap and narrow the discharge channel, which can induce the abnormal pulse discharge leading to instability of the WEDM process. Thus, as described in Lin and Lee (2008), effective removal of debris in the machining gap will improve the efficiency and surface quality of the WEDM process.

1.1. Literature review of ultrasonic vibration and magnetic field-assisted WEDM

Recent studies have explored utilization of ultrasonic vibration (USV) and magnetic force (MF) separately to reduce the machined debris to enhance the performance of EDM process. In a MF assisted EDM process, Yeo et al. (2004) applied a magnetic field perpendicular to the rotation of electrode to improve debris circulation and obtained the higher aspect ratio micro holes on hardened tool steel in Micro-EDM. Improvement for machine output was achieved as Chattopadhyay et al. (2008) placed the workpiece inside an induced magnetic field, wherein polarity of the magnetic field gets reversed periodically, during rotary EDM of EN-8 steel with a rotary copper electrode. Lin and Lee (2009) proposed a novel EDM process by

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adding magnetic force to a conventional EDM to expel debris from the machining gap rapidly and simply. They also investigated the machining characteristics influencing the materials removal rate (*MRR*), the electrode wear rate (*EWR*), and surface roughness. Heinz et al. (2011) utilized a similar process in magnetic field-assisted Micro-EDM to produce Lorentz force in nonmagnetic materials and improve *MRR*. The Lorentz force was exerted directly into the workpiece, and the volume of material removed was increased by up to nearly 50%, while erosion efficiency was increased by over 54%. As for the application of USV assisted EDM process, Guo et al. (1997b) first combined ultrasonic technique with WEDM and Guo et al. (1997a) proposed the machine mechanism to describe the vibration modes of the wire under ultrasonic action. Experimental results revealed that ultrasonic vibration significantly affects the overall performance of WEDM. Hoang and Yang (2013) proposed a development method of utilizing non-ultrasonic vibration on both the workpiece and wire tool to improve the machining efficiency of Micro-WEDM. Mohammadi et al. (2014a) applied ultrasonic vibration in wire electrical discharge turning (WEDT) to obtain high *MRR* and good surface quality including eroded craters, surface roughness, recast layer thickness and micro-crack based on single discharge analysis and regression analysis (Mohammadi et al., 2014b).

USV and/or MF were applied separately in the above studies in EDM, Micro-EDM or WEDM to improve machine performance. However, only limited studies have combined USV and MF simultaneously in the EDM process. Jafferson et al. (2014) applied these two assisted methods to the Micro-EDM milling of nonmagnetic materials to enhance debris removal and analyzed *MRR* and tool wear rate (*TWR*). But their experimental results revealed that utilizing magnetic field or ultrasonic vibrations separately could achieve high *MRR*, but the combination of both assisted methods resulted in poor performance. In contrast, Lin et al. (2014) proposed a hybrid process of EDM with ultrasonic vibration and an assisted magnetic force to explore effects of the main machining parameters on *MRR*, *EWR* and surface quality in the machining of SKD 61 mold steels. After optimization of the process parameters, the experimental results demonstrated that the proposed hybrid process could significantly improve the machining performance.

1.2. Outline of our work

Most studies have focused on the application of USV and/or MF to Micro-EDM/EDM to improve the machining performance, but fewer studies have been performed to examine the effects of USV and MF assisted simultaneously/separately on WEDM. The machining mechanism of the WEDM process still is distinct from that of EDM process, and results from EDM studies are not directly applicable to WEDM. Therefore, in this study, a hybrid process of WEDM with USV and MF is firstly proposed to enhance the machine characteristics, and then to investigate the effects of the main process parameters on the *MRR* and surface quality including surface roughness (R_a) and surface crack density (*SCD*) during the machining of tungsten steel. The effect of removing the debris between the wire tool and workpiece and the ratio of normal machining states are presented and determined by analysis of the pulse discharge waveforms and the morphology of machined surface.

2. Principle of ultrasonic vibration-assisted WEDM

There are two ultrasonic vibration excitation strategies including wire-excited and workpiece-excited methods according to Hoang and Yang (2013). The wire-excited method was first applied to improve the machining performance of WEDM by Guo et al. (1997a). As shown in Fig. 1, an auxiliary device to produce

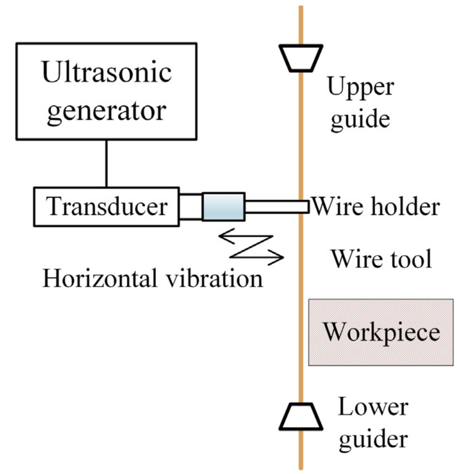

Fig. 1. Schematic diagram of ultrasonic vibration applied to the wire tool.

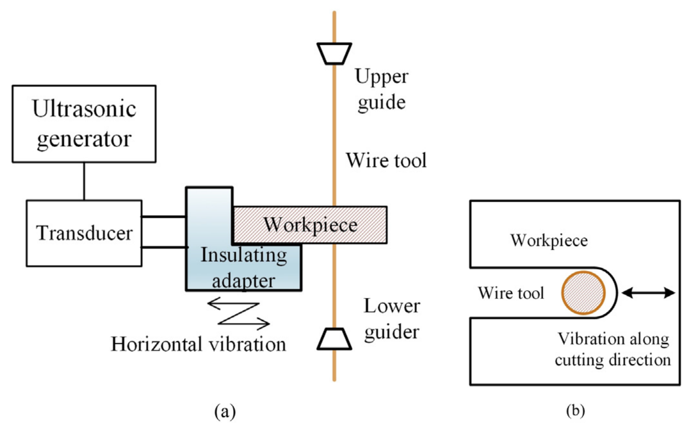

Fig. 2. Schematic diagrams of ultrasonic vibration systems: (a) Vibration applied to the workpiece. (b) Cross-section of wire tool and workpiece.

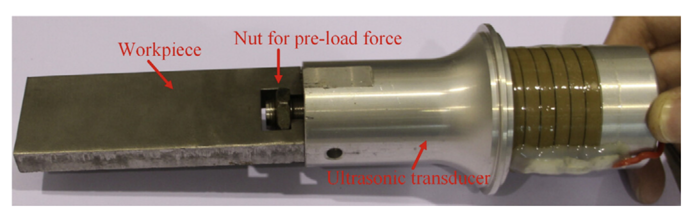

Fig. 3. The configuration of workpiece and ultrasonic vibration device.

ultrasonic vibration is installed between the upper and lower guides and is set above the workpiece. Its transducer can set the wire to vibrate along the cutting direction and transverse to the plane of cutting. The vibration amplitude of the wire is amplified by the wire holder which is connected to the transducer, so the transducer together with the wire holder is set up to produce vibration under the resonance condition and the vibration amplitude can be adjusted by the output power of the generator. The wire vibration can generate more nodes and antinodes as vibration frequency increases. These antinodes will increase the liquid pressure variation and circulation of dielectric flow, allowing to increase the flush efficiency of debris. Fig. 2(a) presents a schematic diagram of the workpiece-excited method and Fig. 3 demonstrates the method to clamp the workpiece in the ultrasonic vibration system. The self-designed ultrasonic vibration apparatus was attached to the column of WEDM. The workpiece is connected and excited by the insulating adapter and ultrasonic generator so that the