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Mechanism analysis of hybrid machining process comprising EDM and end milling

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ABSTRACT

STD 11 alloy steel is an extremely hard and difficult-to-cut material that is used extensively in cutter and die manufacturing for its superior wear resistance. This paper introduces a hybrid machining process (HMP) based on EDM and end milling (EDM-end milling) as an effective method for machining difficult materials. The HMP combines cutting action and an electrical thermal process. The machining mechanism was investigated, and a mathematical model of EDM-end milling is presented. Simulated and experimental cutting results were compared to validate the model. A tungsten carbide end mill was used as a tool electrode to machine STD 11 alloy steel (H_RC 60) with different electric energy pulses. The results show that the method greatly improves tool wear and machining efficiency.

1. Introduction

In recent years, many researchers have focused on the development of hybrid machining processes (HMPs) to combine or enhance the advantages of conventional machining methods and to avoid or reduce some of their adverse effects. HMPs are mainly divided into assisted and combined techniques (Lauwers et al., 2014). Electrical discharge machining (EDM) is a well-known non-traditional process that can be used to machine STD 11 alloy steel, which is extremely hard and difficult to machine but is used extensively in cutter and die manufacturing. This process is based on ablation of the materials through melting and evaporation at very high temperatures between the tool electrode and workpiece.

EDM plays an important role in manufacturing micro-scale parts because of its ability to machine almost all electrically conductive or semi-conductive hard materials, as well as conducting materials and electrically non-conductive ceramic (Praneetpongrung et al., 2010). Tong et al. (2008) successfully machined complex three-dimensional shapes on steel plate using EDM. The method is also suitable for fabricating deep micro-holes with high aspect ratio (Lim et al., 2003). The generators of the EDM system are classified into three major categories: resistance capacitance (RC) generators, transistor generators, and multi-mode pulse generators (Li et al., 2013). Jahan et al. (2009) investigated micro-hole machining of tungsten carbide with both transistor and RC generators and experimentally showed that RC generators are more suitable for precision machining.

However, compared to a traditional machining process, EDM has disadvantages of poor surface quality and low efficiency. In addition, EDM is greatly affected by the machining environment, cooling, and flushing conditions. Numerous methods have been developed to improve the efficiency of the EDM process, such as magnetic force-assisted EDM (Lin and Lee, 2008), rotating electrode EDM (Yan and Wang, 1999), and vibration-assisted EDM (Hoang and Yang, 2013). Vibration-assisted EDM is considered as the most effective method among these for improving the flushing conditions and machining efficiency since the ultrasonic vibration can help to accelerate the dielectric circulation and debris removal. Vibration can be applied to the tool (Zhang et al., 2002), the workpiece (Gao and Liu, 2003), or the dielectric.

Although machining efficiency has been improved to a certain extent using the vibration-assisted method, the production efficiency is much lower than in traditional machining. EDM also faces challenges regarding product quality and machining cost. Byiringiro et al. (2012) presented a novel HMP that combines micro EDM and end milling (EDM-end milling). The effect of using a tungsten carbide tool as a tool electrode has been investigated in detail for side milling steel alloy (AISI 1045). Reasonable machining time and surface quality were achieved using the Taguchi method, and a unique, powerful, and flexible empirical model was developed. However, the machining mechanism of the HMP method was not described in detail. Also, the effect of electric discharge energy on the surface roughness and tool wear is still not as clear as in the EDM-end milling process.

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Nomenclature

θ_1	Cutting angle
i_r	Immersion ratio
θ_2	Contact-only angle
α	EDM angle
β	Non-contact angle
δ	Flank angle
h	Radial depth
k	Non-contact ratio per revolution
t	EDM ratio per revolution
R	Radius of the end mill tool
f	Feed rate
n	Spindle speed
n_t	Number of flutes
μs	Microsecond
ms	Millisecond

This paper proposes a mechanism for the EDM-end milling process. The percentage of discharge in this process can be predicted and verified through experiments. The change in discharge voltage was observed using an oscilloscope to verify the theory. Based on exact understanding of the process, the aim is to explore the application and feasibility of the HMP in machining difficult-to-cut materials. STD 11 (HRC 60) hardened alloy steel was machined via EDM-end milling and conventional milling. The performance of the EDM-end milling method was evaluated in terms of the surface roughness, tool wear, and machining efficiency. The results show that the process reduces tool wear and greatly improves machining efficiency.

2. Machining mechanism of EDM-end milling

Fig. 1 presents a schematic diagram of the developed EDM-end milling system. The system consists of a RC power supply for the EDM, a miniature desktop machine tool, and an electric flushing pump. EDM oil is used as the dielectric fluid. A tungsten carbide end-mill tool is used as an electrode and fixed to a high-speed spindle, which has a maximum speed of 24,000 rpm.

2.1. EDM-end milling model

In the EDM process, the discharge is divided into open circuit, normal discharge, arc discharge, and short circuit states. The main cause of the different discharge states is the distance between the workpiece and the end mill tool. The core of this study is the location of the EDM zone and the proportion of normal discharge in the machining process. EDM occurs when there is no contact between the workpiece and the electrode tool. The machining mechanism of the EDM-end milling with 2 flutes is shown in Fig. 2. The analysis

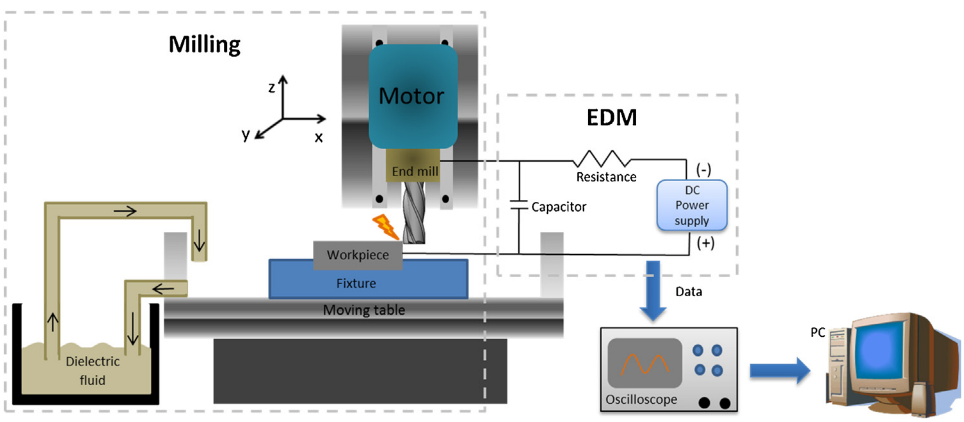

Fig. 1. Hybrid machining setup.

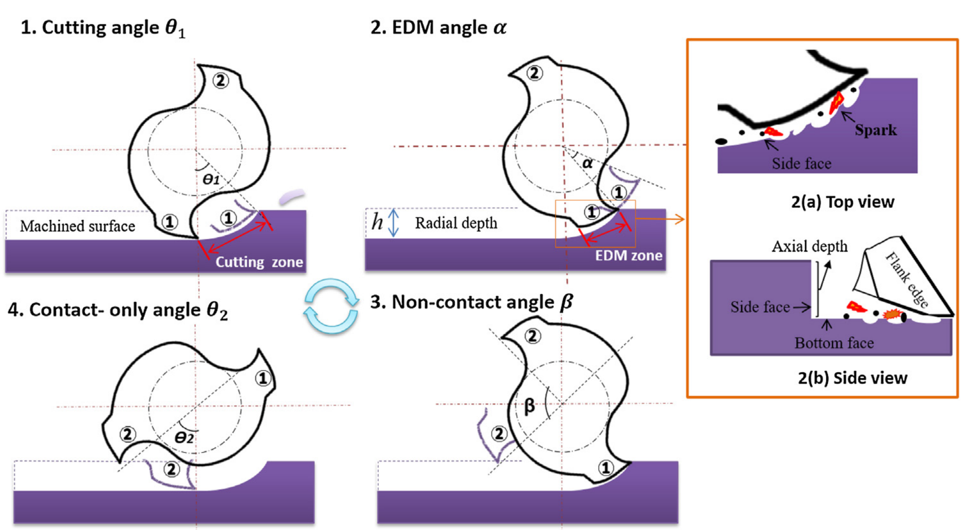

Fig. 2. EDM-end milling machining mechanism (feedrate ≈ 0).