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Influence of open-circuit voltage on micro electrical discharge machining of Ni-Al_2O_3 functionally graded materials

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Abstract

Ni-Al_2O_3 functionally graded materials (FGMs) have become important for high temperature applications due to a continuous change in composition. However, the manufacturing of Ni-Al_2O_3 FGMs with conventional machining methods is a difficult process because of the high hardness and various graded compositions. In this paper, three-layerd Ni-Al_2O_3 FGMs, pure Ni layer (100 % Ni), 70 % Ni/30%Al_2O_3 layer, 30 % Ni/70%Al_2O_3 layer, have been machined by micro electrical discharge machining (EDM). The machining characteristics of Ni-Al_2O_3 FGMs have been investigated, which include the effect of open-circuit voltage on material removal rate (MRR), electrical discharge status, surface microtopography, and element distribution. The experimental results indicate that with the increasing open-circuit voltage, the MRR of the pure Ni layer and 70 % Ni/30%Al_2O_3 layer increases slowly and the surface quality becomes worse slowly. In contrast, when open-circuit voltage is changed from 110 to 170 V, the MRR of 30 % Ni/70%Al_2O_3 layer increases rapdily. The surface quality of 30 % Ni/70%Al_2O_3 layer becomes better before getting worse with the increase of open-circuit voltage. In addition, the quantity of normal discharges in the pure Ni layer and 70 % Ni/30%Al_2O_3 layer has a little change, and the quantity of normal discharges in the 30 % Ni/70%Al_2O_3 layer increases rapidly with the increase of open-circuit voltage. Finally, a small hole with fast MRR and good surface quality has been machined suceesfually based on the experimental analysis.

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Keywords: Micro electrical discharge machining; Ni-Al_2O_3 functionally graded materials; Open-circuit voltage; Machining characteristics

1. Introduction

Metal–ceramic FGMs ingeniously combine the high temperature resistance of ceramics with the toughness of metals due to a continuous change in composition from one side of metal to the other side of ceramic. Therefore, metal-ceramic FGMs have been widely applied in the field of aerospace, cutting tools and other engineering applications [1-3]. However, the complex graded composition and graded hardness make it difficult to machine with conventional mechanical machining techniques, which has impeded the development of metal–ceramic FGMs.

In comparison with other machining techniques, EDM demonstrates advantages on machining materials with high strength and high hardness because it is a noncontact process without physical cutting forces.The process is carried out in a dielectric fluid where the tool is one electrode in the shape of the cavity to be produced and the workpiece to be machined is the other electrode. The high temperature sparks continuously melt a small portion of the surface of the workpiece, and the material removal process consists of a significant number of melting steps. The electrode and the workpiece do not make direct contact during the EDM process. Therefore, the application of EDM is not constrained by the hardness or the strength of the material to be machined, and it has been proven to be especially valuable in the machining of super-tough, electrically conductive materials [4–6].

To improve the EDM performance of difficult-to-machine

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materials such as metal matrix composites（MMCs) or metal-ceramic FGMs, many studies have been done. One part of the research has been focused on the MMCs. J. W. Liu et al. explored the effect of process parameters on machining performance of Al_2O_3 particle reinforced aluminum alloy 6061 by wire electrochemical discharge machining. The experimental results demonstrated that to achieve the highest MRR, the applied current is the most influential factor[7]. N.V. Rengasamy et al. have investigated the optimization EDM process parameters of Al 4032 alloy reinforced with composites by the Taguchi L25 orthogonal array[8]. In additon, the material removal mechanism, the machined surface morphologies, and the recast Layer have also been explored[9-11]. Moreover, some studies have focused on MMCs with a different volume fraction[12-14].Satishkumar et al. have conducted a comparative study on the machining performance of the Al6063 aluminum alloy, 5% SiCp/ Al6063 composite, 10% SiCp /Al6063 composite and 15% SiCp/ Al6063 composite by WEDM [12]. Biing Hwa Yan et al. used 6061Al matrix material,10 and 20 vol.% Al_2O_3 particles reinforced 6061Al alloys-based composite to investigate WEDM machinability and wire breakage [14].

Another part of researchers pay attention to EDM characteristic of metal-ceramic FGMs. Seo et al. have utilized EDM to drill holes on functionally graded 15–35% SiCp/Al composites and demonstrated machining characteristics [15]. Considering the unique structure of the Ni-Al_2O_3 FGMs, Liu et al. have proposed self-induced EDM to machine the pure Al_2O_3 layer, and machined the Ni-Al_2O_3 FGMs successfully using self-induced EDM [16]. In addition, the effect of technological parameters on the process performance of pure Al_2O_3 layer of Ni-Al_2O_3 FGMs by self-induced EDM has also been dicussed[17].

These studies have mainly focused on the effects of technological parameters on MMCs machining performance including material removal rate, surface quality and electrode wear. Moreover, some researchers consider the influence of the structure and the graded composition of metal-ceramic FGMs on EDM machinability. However, studies on the effect of machining parameters on micro electrical discharge machining of metal-ceramic FGMs including pure metal conposition and metal matrix composites with large ceramic volume fraction are still scarce. In this study, the influence of open-circuit voltage of RC-type pulse generator on the process performance of Ni-Al_2O_3 FGMs, including MRR, discharge properties and surface quality, have been investigated.

2. Experiments

Fig. 1 shows the schematic illustration of the machining system used for conducting the EDM experiments. This machine is equipped with a resistor-capacitor (RC) discharge pulse generator as shown in Fig. 2. The value of open-circuit voltage, resistance and capacitance can be adjusted according to the specific machining requirements. In the experiment, the tool electrode and the workpiece are connected, respectively, to the negative and the positive poles of the pulse power. Tool electrode is a graphite electrode with a diameter of 1mm. Kerosene is used as the machining fluid. Workpiece material is a three-layered Ni-Al_2O_3 FGMs, which includes pure Ni layer (100 % Ni), 70 % Ni/30%Al_2O_3 layer, 30 % Ni/70%Al_2O_3 layer. The mean particle size of Al_2O_3 power was 8μm. Table1 summerizes the properties of powers in Ni–Al_2O_3 FGMs. Table 2 shows machining conditions.

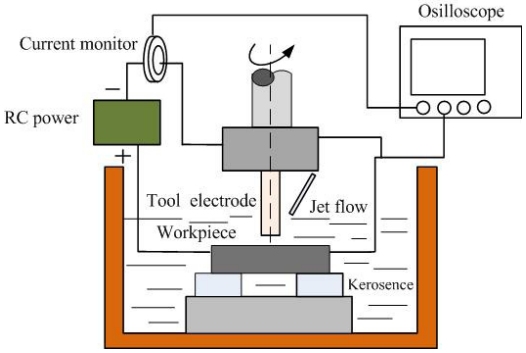

Fig. 1. Schematic diagram of the set-up

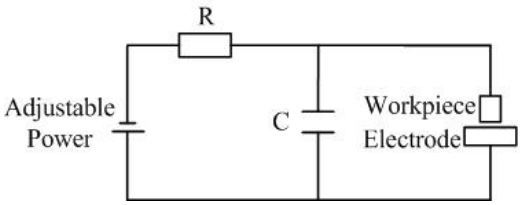

Fig. 2. Schematic of RC circuit for EDM

Table 1 Physical properties of powders used in Ni–Al_2O_3 FGMs

	Melting point (K)	Thermal conductivity (W/mK)	Specific resistance(Ωcm)	Hardness (HV)
Al_2O_3	2323	17	>1014	1760
Ni	1723	90	6.84×10-6	60

Table 2 Machining conditions

	EDM conditions
Tool electrode	Graphite（Φ1mm）
Electrode polarity	(-)
Resistance R (Ω)	500
Open-circuit voltage U (V)	110,140,170,200,230
Capacitance C (pF)	1×105
Rotating (rpm)	1000
Machining fluid	Kerosene

In this paper, the graded layers, pure Ni layer (100 % Ni), 70% Ni/30%Al_2O_3 layer, 30% Ni/70%Al_2O_3 layer, were machined separately. The EDM machining performance of each layer, including MRR(mm3/min), discharge properties, surface quality and element distribution, was campared. The MRR was evaluated under each machining condition by measuring the removal volume and the required time. Discharge waveforms are observed with a current monitor (TektronixTCPA300) and recorded on a digital oscilloscope