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Debris and bubble movements during electrical discharge machining

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ABSTRACT

Debris accumulation in the discharge gap causes a poor machining stability and low production efficiency. Thus, an understanding on the mechanism of debris exclusion in electrical discharge machining is important. However, to date, this mechanism has not been fully understood because of the difficulty in observing debris movements in discharge gaps. The current study established a series of experimental devices using transparent materials to observe debris and bubble movements. Based on the observations, the mechanism of debris and bubble exclusion during consecutive pulse discharges is analyzed, and the effects of the electrode jump height and speed on the debris and bubble movements are investigated. In addition, the effectiveness of the debris and bubble movements on machining efficiency is discussed.

1. Introduction

Electrical discharge machining (EDM) is an important process because it allows noncontact machining via the thermomechanical effect regardless of the hardness of the workpiece material. EDM has been widely used for manufacturing dies and molds, as well as in aerospace, automotive, and surgical components. However, the debris accumulation in discharge gaps usually causes a poor discharge status, which not only causes a low material removal rate but also severely damages the machined surface. Therefore, the debris exclusion mechanism during EDM has to be studied to formulate effective methods that will improve machining stability and efficiency. In addition, the bubble movement has to be analyzed as bubbles have a significant influence on debris exclusion.

Debris and bubble movements are strongly related to the discharge and electrode jump conditions. Yoshida and Kunieda [1] reported that debris particles are scattered near the boundary of discharged bubbles because of the viscosity of the dielectric oil. Takezawa et al. [2,3] observed bubble behaviors and investigated the relationship between bubble motion and material removal volume using an alloy with a low-melting temperature. Hayakawa [4] observed flying debris particles, as well as bubble expansion and contraction, using a PMMA plate, in which a metal wire electrode was inserted. However, these studies are limited to a single discharge. Thus, Takeuchi and Kunieda [5] investigated the volume fraction of bubbles in the EDM gap during consecutive pulse discharges to understand the influence of the bubbles on machining stability and material removal rate. However, they only visualized the generation and drift of bubbles based on theoretical analysis. Only a few researchers conducted studies that directly observed the process of debris exclusion during consecutive pulse discharges.

On the other hand, to understand the influence of electrode jump motion on the debris and bubble movements, Cetin et al. [6] analyzed the debris distribution in the discharge gap caused by the electrode jump using a computational fluid dynamics simulation program. However, their study neglected the influences of bubbles, which is important to the debris movement, and lacked experimental observation on debris movement during EDM. Cetin et al. [7] suggested that the electrode jump height has a dominant influence on the improvement of machining stability and that the electrode jump speed affects only the time consumed by the electrode jump. But according to EDM results, the electrode jump speed also has significant influence on the EDM stability.

In the current study, a series of devices with transparent materials were developed to fully understand the mechanisms of debris and bubble exclusions, as well as the influence of electrode jump on debris and bubbles. Moreover, the debris and bubble movements in the discharge gap were clearly observed during consecutive pulse discharges. In addition, the influences of electrode jump height and speed on the debris and bubble movements were also analyzed based on experimental observations.

2. Experimental devices

The gap between the electrode and workpiece was only several tens of micrometers and emerged in oil. Moreover, the view of the gap was obstructed by the electrode and workpiece, making the

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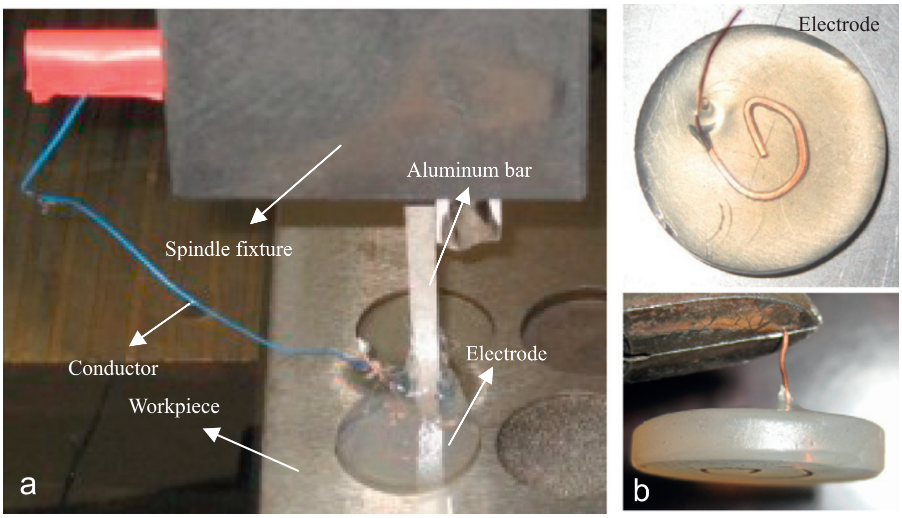

Fig. 1. Device for observing the debris and bubble movements in the bottom gap.

observation of the debris and bubble movements difficult. The current study establishes a series of experimental devices using transparent materials to observe the debris and bubble movements in the gap during EDM. Fig. 1(a) shows the setup for observing the debris and bubble movements in the bottom gap, and Fig. 1(b) shows the magnified pictures of the electrode taken from different perspectives. The electrode was made of an EVA hot-melt adhesive with a copper wire inside. The copper wire was the real discharge part of the electrode. Considering that the EVA hot-melt adhesive is a transparent material, the phenomena in the bottom gap were clearly observed. It was difficult to fasten the electrode and fixture together. Thus, an aluminum bar was clamped onto the fixture and the electrode was stuck onto the bar. The workpiece was a tool steel with a cylindrical blind hole. The blind hole was 3 mm deep, with diameter of 20.38 mm, which was 0.4 mm larger than that of the electrode. Thus, when the electrode moved into the blind hole, the bottom and side gaps were generated between the electrode and blind hole. A conductor was used to connect the fixture and copper wire and to supply power to the copper wire inside the electrode.

Fig. 2 shows the setup for observing the debris and bubble movements in the side gap. A transparent PMMA tube was stuck onto the flat surface of the workpiece as the side wall so that the phenomena in the side gap can be clearly observed. The inner diameter of the PMMA tube was 0.2 mm larger than that of the cylindrical copper electrode. The experimental device was set up as follows to achieve a uniform side gap:

(1) The electrode was clamped onto the spindle fixture.
(2) Several layers of scotch tape were stuck onto the side surface of the electrode to fasten the electrode tightly to the tube.
(3) The electrode was inserted into the tube and the spindle was fed down until the tube touched the surface of the workpiece.
(4) The tube was stuck onto the surface of the workpiece using an EVA hot-melt adhesive.
(5) The electrode was pulled out of the tube and the scotch tape was removed. Thus, when the cylindrical electrode moved into the tube, a uniform side gap was generated.

3. Observation of debris and bubble movements during consecutive pulse discharges

The debris and bubble movements in the bottom and side gaps were observed separately. The debris and bubble movements in the bottom gap were observed first. Table 1 shows the experimental conditions, and Fig. 3 shows the observation results. Fig. 3(a) and (b) shows that numerous bubbles were generated and that most of them were interconnected during discharge. The bubbles rapidly expanded and pushed most of the debris to the edge of the bottom gap. The bubbles mostly occupied the bottom gap, and almost all of the debris were distributed on the oil between bubbles. The bubbles came out of the side gap as the discharge continued, and thereafter, the volume and distribution of the bubbles in the bottom gap stabilized [Fig. 3(c) and (d)].

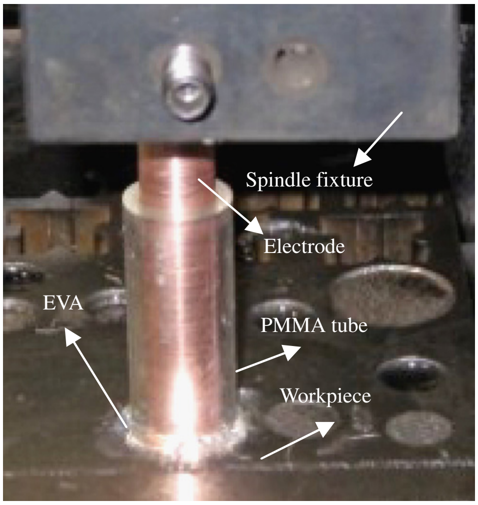

Fig. 2. Device for observing the debris and bubble movements in the side gap.

Table 1
Experimental conditions.

Parameters	Values
Discharge voltage (V)	75
Discharge current (A)	9.8
Discharge duration (μs)	114
Pulse interval time (μs)	80
Discharge machining time (s)	0.12
Electrode diameter (mm)	19.98
Hole diameter (mm)	20.38
Dielectric fluid	Kerosene