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Observation of material removal from discharge spot in electrical discharge machining

Shinya Hayakawa[a,]*, Yusuke Kusafuka[a], Fumihiro Itoigawa[a], Takashi Nakamura[a]

[a]*Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya 466-8555, Japan*

* Corresponding author. Tel.: +81-52-735-7256; fax: +81-52-735-7256. *E-mail address:* hayakawa.shinya@nitech.ac.jp

Abstract

In this paper, we observed the moment of material removal from a discharge spot using a high-speed video camera to investigate the material removal phenomena and the scattering behavior of debris particles in the electrical discharge machining process. Since material removal occurs not only during the discharge duration but also after the discharge duration, the observation of material removal occurring after the discharge duration was first carried out without inference from the strong light from the arc plasma. Then, material removal occurring during a discharge duration was investigated. In this experiment, a discharge is ignited on the front side of a foil electrode and the back side of the foil electrode was observed with blocking out the strong light from the arc plasma. The observed results show that there are different types of material removal that simultaneously occur in a pulse discharge. One is caused by the explosive evaporation of molten metal and the other is caused by the undulation of the molten metal. It is also found that debris particles removed during the discharge duration are small and their flying speed is high, whereas those removed after the discharge duration are large and their flying speed is low.

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Keywords: Electrical discharge machining; Material removal; Debris particle; Discharge spot; High-speed video camera

1. Introduction

Although electrical discharge machining (EDM) is one of the important machining processes and widely used in the manufacturing industry, the mechanism of material removal in EDM is not fully understood. Many studies investigating the material removal process have been reported. For example, Takezawa et al. [1,2] observed the behavior of generated bubble and investigated the relationship between bubble motion and material removal volume using a low-melting-temperature alloy. They inferred that the material removal of the molten volume is affected by the bubble contraction and collapse process and that material removal occurs immediately before bubble collapse. On the other hand, Tamura and Kobayashi [3] reported that the effect of the impulsive force caused by expansion and shrinkage of a bubble on crater formation is insignificant. Yoshida and Kunieda [4] also reported that debris particles are scattered even when a pulse discharge is generated in air. Yang et al. [5] calculated the hydrostatic pressure inside an electrode using molecular dynamics methods and reported that extremely high pressure is generated inside the melting area, and the fact that the pressure inside the electrode is higher than that on the electrode surface is one of the main reasons for the ablation of melting atoms and the formation of a bulge on the electrode surface. Eubank et al. [6] calculated the plasma temperature and pressure, and argued that superheating is the dominant mechanism of anode and cathode erosion.

The authors [7,8] observed the motion of generated bubble and scattered debris particles using a high-speed video camera and reported that material removal occurs more than once for a pulse discharge, not only during the discharge duration but also immediately after the discharge duration. We also reported that material removal occurs while the generated bubble is expanding, whereas no debris particles are removed while the generated bubble is contracting [8]. However, since material removal occurs even when a pulse discharge is generated in air [4], the effect of the shear force caused by

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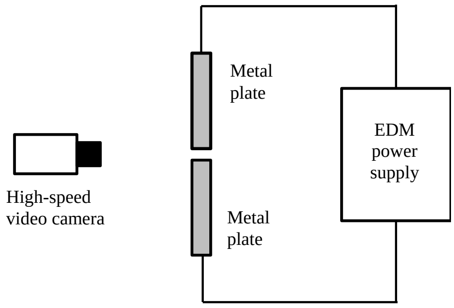

Fig. 1. Experimental setup

Table 1. Experimental conditions

Electrodes	Iron plate (t = 2 mm)
Machining medium	Air
Applied voltage	90 V
Discharge current	30 A
Discharge duration	64 μs
Pulse interval	64 μs
Frame rate	50,000 fps
Exposure time	20 μs

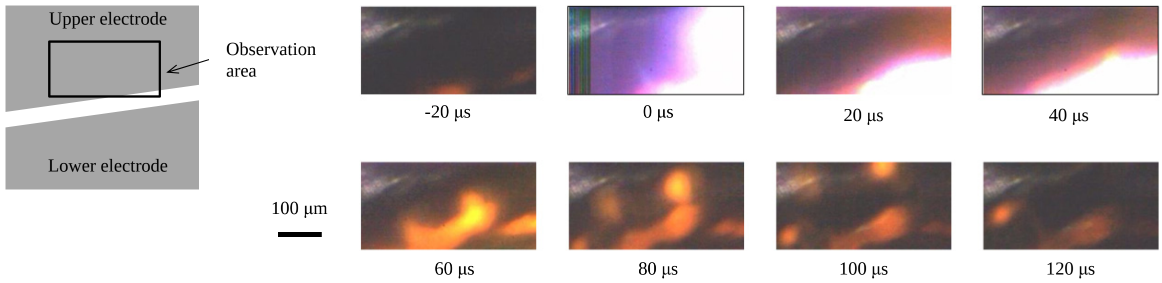

Fig. 2. Material removal occurring immediately after discharge duration

bubble expansion is considered to be not significant. Therefore, we considered the effect of the pressure drop to be the important cause of the material removal associated with bubble expansion [8].

In this paper, we observed the moment of material removal from a discharge spot using a high-speed video camera to investigate the material removal phenomena and the scattering behavior of debris particles in the EDM process.

2. Material removal occurring after discharge duration

2.1. Experimental method

The observation of material removal from a discharge spot is difficult because strong light from the arc plasma interferes with the observation. However, since material removal occurs not only during the discharge duration but also after the discharge duration, as reported by the authors [8], the observation of material removal occurring immediately after the discharge duration was first carried out without inference from the strong light from the arc plasma.

The experimental setup is shown in Figure 1. Two metal plates of 0.2 mm thickness were used for the electrodes and their end faces faced in air. Pulse discharges were ignited between them, and the discharge spot and scattered debris particles were observed using a high-speed video camera from the direction parallel to the discharging surface. When a discharge occurred within the observation area and material removal occurred after the discharge duration, the material removal phenomena at the discharge spot could be observed.

2.2. Observed results

Figure 2 shows an example of the observed results. In this case, debris particles were removed from the discharge spot in such a way that molten metal droplets were ejected from the undulating molten metal pool. The experimental conditions are listed in Table 1. The frame rate and exposure time of the high-speed video camera were set at 50,000 fps and 20 μs, respectively. The times indicated in Figure 2 were determined from the first frame showing the discharge light. Within the observation area, the vicinity of the lower end of the upper electrode can be seen, and the gap space between the electrodes can be seen in the bottom right corner of the observation area. Strong light from the arc plasma is shown in the images with times of 0 μs to 40 μs. At 60 μs, immediately after the discharge ceased, two debris particles were about to be ejected from red-hot spots on the electrode surface, in upward and upper left directions. It can be seen that the particles were removed from the molten metal pool at times of 80 μs to 100 μs. On the other hand, in some other cases, molten metal droplets that were about to be ejected from the high-temperature region could not break away and were pulled back to the molten metal pool.

Figure 3 shows another example of the observed results. In this case, debris particles were explosively blown out of the molten metal pool. The experimental conditions are listed in Table 2. The frame rate and exposure time of the high-speed video camera were set at 100,000 fps and 10 μs, respectively. The times indicated in Figure 3 were determined from the first frame showing the discharge light. Within the observation area, the vicinity of the top right corner of the lower electrode