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Analysis of the Machining Characteristics of EDM as Functions of the Mobilities of Electrons and Ions

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Electrical discharge machining (EDM) is a process that can be used effectively to machine conductive metals regardless of their hardness. In the EDM process, material removal occurs because of the thermal energy of the plasma channel between the electrode and the workpiece. During EDM, the electrode as well as the workpiece is abraded by the thermal energy. Tool wear adversely affects the machining accuracy and increases tooling costs. Many previous studies have focused on mitigating the problems of tool wear by investigating various EDM parameters. In this study, the tool wear problem was investigated on the basis of the mobilities of electrons and ions in the plasma channel. The material removal volumes of both the electrode and the workpiece were compared as functions of the gap voltage. The material removal difference according to the capacitance was also investigated. The tool wear ratio was calculated under different EDM condition and an EDM conditions for reducing the tool wear ratio was suggested.

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1. Introduction

Electrical machining processes have wide applications in three-dimensional microstructuring.[1,2] Electrical discharge machining (EDM) is one of the electrical machining processes that is based on a thermal process. Electrical breakdown of the electrode and the workpiece occurs when the electric field strength exceeds the dielectric strength. The thermal energy resulting from the electrical breakdown flows into the electrode, workpiece, and dielectric fluid. Not only the workpiece but also the electrode is abraded because of the thermal energy. Electrode deterioration is an inevitable problem that is encountered in the EDM process. It is difficult to predict the occurrence of electrode wear during EDM, and such wear adversely affects the accuracy of EDM. Many studies have been conducted for investigating the influence of EDM parameters on tool wear and for reducing the tool wear that occurs during EDM. Chen et al.[3] studied the EDM parameters related to erosion wear in the EDM process. They investigated the influence of discharge current, pulse duration, and interval time on parameters such as the material removal rate, surface quality, and dimensional accuracies of the tool and workpiece. In this study, we used a copper electrode and a steel workpiece. It was difficult to determine the wear characteristics of the tool and the workpiece with respect to their polarities. DiBitonto et al.[4,5] suggested a theoretical model for the EDM process. An erosion model of the cathode and anode was designed. A point heat source model was applied to the cathode and an expanding circle heat source model was applied to the anode. These heat source models were selected on the basis of the thermal conduction of the materials of the electrode and workpiece. They verified these models through experiments, which were used to investigate the processes of tool wear and the material removal. The electrode and the workpiece were abraded by the collisions of the ions and the electrons in the plasma channel. For obtaining a better understanding of the tool wear and material removal of the workpiece, it was necessary to investigate the kinetic characteristics of the ions and the electrons in the electric field.

In this study, the tool wear and material removal of the workpiece during EDM were explained using the kinetic characteristics of the ions and electrons. The wear characteristics of the cathode and anode during EDM were investigated. The results were discussed using the behavioral characteristics of the ions and electrons in the plasma channel. Variations in the EDM parameters such as gap voltage and capacitance were suggested as possible means to reduce the tool wear and material removal of the workpiece.

2. Experimental

An RC type circuit was used in the experiment. For investigating the influence of the gap voltage on material removal, the same material, copper, was utilized for fabricating both the electrode and the workpiece. A 400 Ω resistor was used, as shown in fig. 1. The experimental conditions are presented in the Table 1. The collisions of the ions and electrons on the electrode and the workpiece were influenced by the kinetic energy and the number of ions and electrons. For changing the kinetic energy, various gap voltages of 60–150 V were applied in the experiments. The velocities of the ions and electrons in the plasma channel increased as the gap voltage were increased. For varying the amount of electric charge, ceramic capacitors having capacitances of 9 pF, 20 pF, 47 pF, and 100 pF were utilized. Kerosene was used as the dielectric fluid. The diameter of the electrode was 300 μm. By using the EDM drilling process, the difference between the material removal volume of the anode and that of the cathode were compared. In these experiments, the electrode was used as the cathode and the workpiece was used as the anode. The electrode was moved by 100 μm downward. The federate of the electrode was set to 0.02 μm/s in order to prevent contact between the electrode and the workpiece during EDM drilling. The rotational speed of the electrode was fixed at 200 rpm.

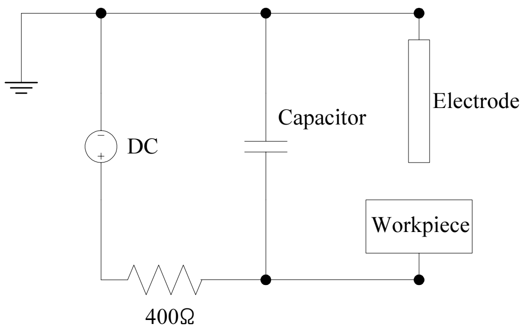

Fig. 1 RC type circuit in EDM

Table 1 Capacitor and voltage conditions

Experiment set	Capacitance (pF)	Voltage (V)
1	9	60–150
2	20	60–150
3	47	60–150
4	100	60–150

3. Electrode wear and removal volume of workpiece

After the experiment, the geometry of the EDM-drilled holes was evaluated using a three-dimensional interferometer (Zygo, NV6300). The removed volume of the workpiece was calculated by integrating the cross-sectional shapes of the drilled holes. The removed volume of the electrode was calculated from the decrease in the length of the electrode. Fig. 2 shows the relationship between the removed volume of the electrode and the gap voltage. As the gap voltage increased from 60 V to 150 V, the removed volume increased and the ionization of the dielectric fluid between the electrode and the workpiece accelerated. The increased number of ions in the plasma channel caused an increase in the removal volume of the electrode. When the gap voltage was 150 V, the removed volume of the electrode increased drastically. In particular, when the 9 pF capacitor was used, the tool wear volume at 150 V was about 2.3 times larger than that at 120 V.

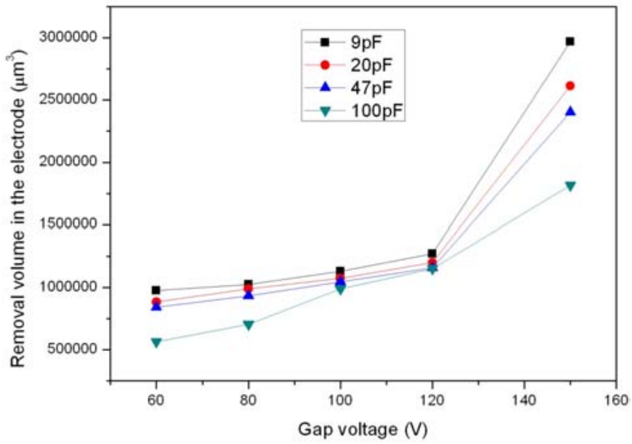

Fig. 2 Relationship between material-removal volume and gap voltage

In the EDM process, the plasma channel was composed of a cathode layer, positive column and anode layer. The cathode layer possessed a high positive ion charge density. The positive column was a quasi-neutral plasma with a low electric field strength.[6] The anode layer possessed a high electron charge density. The cathode layer was divided into a collisionless layer and a quasi-neutral layer. In the collisionless layer, the electron and ion velocities v_e and v_+, respectively, were estimated as a function of voltage V, as shown in equation (1).[6] It was assumed that $V = 0$ at the cathode surface and $V = V_c$ at the edge of the collisionless layer.

$$v_e = \sqrt{2eV/m},\ v_+ = \sqrt{2e(V_c - V)/M} \tag{1}$$

m is the mass of the electron and M is the mass of the ion. V_c is the voltage applied between the collisionless layer and the quasi-neutral plasma. The mass of an ion is thousands of times greater than that of an electron. The velocity of the ion was maximum at $V = 0$, which is the case at the cathode surface. In the plasma channel, the accelerated ions collided with the cathode surface and material removal resulted. When the voltage between the cathode and the anode increases, the velocities of the electrons and ions increase. With an increase in the electric-field strength between the cathode and the anode, the velocities of the ions and electrons increase. The kinetic energy of an ion increases proportionally to the square of its velocity. Since the mass of an ion is thousands of times greater than that of an electron, the kinetic energy generated by ions is far greater than that by electrons. Therefore, the abrasion caused by the accelerated ions on the electrode surface was more rapid than that caused by the accelerated electrons.

Fig. 3 shows the relationship between the removed volume of the workpiece and the gap voltage. When the gap voltage was increased, the number of electrons in the plasma channel also increased because of the release of electrons both from the cathode and from the ionization of the dielectric fluid.

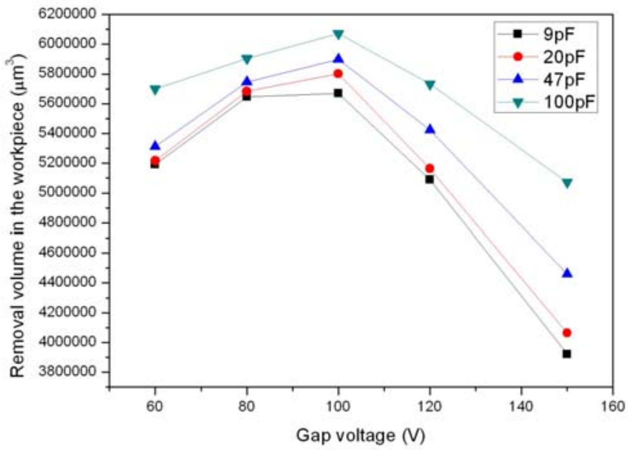

Fig. 3 Relationship between removed volume of workpiece and gap voltage

The removed volume of the workpiece increased gradually as the gap voltage increased from 60 V to 100 V. At gap voltages of 120 V and 150 V, the removed volume decreased because of the drastically increased tool wear. With respect to the gap voltage, the rate of change in the removed volume of the workpiece increased more slowly as compared with that of the electrode on account of the mass difference between an electron and an ion.

4. Tool wear ratio

Fig. 4 shows the relationship between the tool wear ratio and the gap voltage. The tool wear ratio is the ratio of the removed

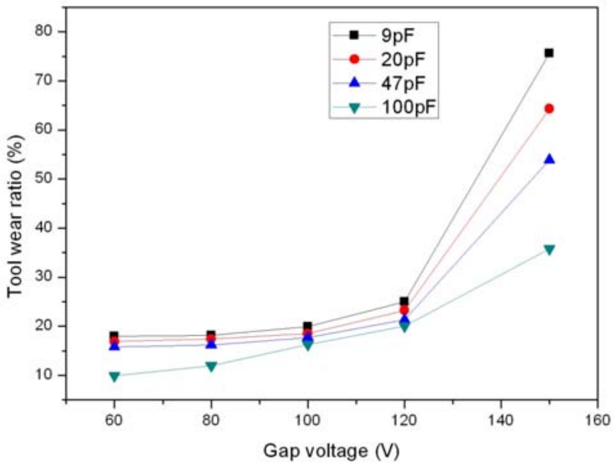

Fig. 4 Relationship between tool wear ratio and gap voltage

volume of the electrode to that of the workpiece. At 150 V, the tool wear ratio increased due to the increased tool wear and the decreased removal volume of the workpiece at that voltage. The tool wear ratio did not exceed 100 % under any of the EDM conditions. The tool wear volume was smaller than the material removal volume of the workpiece in the all experiment conditions. In the gap voltage, the tool wear ratio at a capacitance of 100 pF was lower than those at other capacitances. In the capacitance, the tool wear ratio at a gap voltage of 60 V was lower than those at other gap voltages. When the gap voltage was 60 V and the capacitance was 100 pF, the tool wear ratio was 10 %. It was minimum tool wear ratio in the experiment conditions.

5. Conclusion

The electrode wear rate and the material removal rate were compared on the basis of their relationships with the gap voltage. The electrode wear increased with the gap voltage. At 120 V and 150 V, the tool wear ratio increased rapidly because of the collisions of the accelerated ions on the electrode surface. The material removal volume of the workpiece increased from 60 V to 100 V and then decreased at 120 V and 150 V. When the gap voltage was increased from 60 V to 100 V, the increased kinetic energy of the accelerated electrons influenced the material removal of the workpiece. The material removal volume of the workpiece at 120 V and 150 V decreased due to the rapid increase in tool wear. Due to mass difference between the electron and the ion, the influence of ion on the cathode was more serious than that of electron on the anode. The tool wear ratio increased with the gap voltage. The tool wear ratio was minimum at 60 V and maximum at 150 V for each of the capacitors used; it decreased with an increase in the capacitance.

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