The initial work reported by Suzuki et al demonstrated the ability of EC-CVD diamond being used as an electrode in EDM. This work deals with further investigation for the application of EC-CVD diamond as an electrode in EDM.

2. Experimental setup and conditions

An EC-CVD diamond thick film segment of 5mm×6mm×0.5mm was mounted on the head of a die-sinking EDM machine using a jig as shown in Fig.1. An area of 3mm×0.5mm of the electrode is used for EDM. Copper, graphite and Cu-W electrodes of similar dimensions were used for comparison. The work material was SKD11 (HRC 61) and kerosene (Vitol 2, Sodick) was used as the dielectric working fluid. Table 1 lists the physical properties of the EC-CVD diamond and other electrode materials, and the experimental conditions are listed in Table 2.

3. Results and discussion

3.1 Comparison of electrode wear and EDM efficiency

A comparison of the electrode wear and efficiency of the EC-CVD diamond electrode with the other commonly used electrodes like copper, graphite and Cu-W is made here for EDM conditions of ui=90V, Ie=6A, te=3,7,15,30µs, EDM depth=0.5mm at reversed polarity.

Figure 2(a) shows a comparison of wear depth of the electrode end among the EC-CVD diamond, copper, graphite and Cu-W. It is well known that the anode electrode wear is reduced at sufficiently long pulse durations when EDM is performed in oil, and it is reported that this phenomenon is mainly due to an increased rate of adhesion of carbon onto the electrode resulting from the dielectric breakdown.

In the case of the EC-CVD diamond electrode, however, the electrode shows no wear even at very short pulse duration of 3µs. In comparison, copper, graphite and Cu-W electrodes show very high wear at the pulse duration of 3µs.

A comparison of the EDM efficiencies or material removal rate (MRR), of the EC-CVD diamond electrode with copper, graphite and Cu-W electrodes at various pulse durations is shown in Fig. 2(b). Beyond pulse duration of 15µs, the EDM efficiency of the copper increases rapidly with the pulse duration, whereas the efficiencies for the EC-CVD diamond and graphite remain constant.

3.2 Effect of polarity

The effect of polarity on the EC-CVD diamond electrode was investigated and compared with a copper electrode under similar EDM conditions. Experiments were performed under EDM conditions of ui=90V, L=3A and t=3/10, 50/50µs. The results of EDM using electrically conductive diamond electrode - 1st report: EDM property

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Further work on the application of commercially available electrically conductive CVD diamond (EC-CVD diamond) as an EDM electrode is carried out in order to obtain detailed characteristics of this material as an electrode. The result confirms that the electrode made of EC-CVD diamond does not show significant wear even at short pulse duration of 3µs, when used as an anode (reversed polarity). The reason for no wear of the EC-CVD diamond electrode even at short pulse durations appears to be due to an acceleration of carbon adhesion from the dielectric fluid on its surface and also its higher thermal diffusivity leading to faster dissipation of the heat from the discharge zone.

1. Introduction

With the achievement of commercial production of electrically conductive CVD diamond (hereafter EC-CVD diamond) thick films, the application of such CVD diamond is now a topic for discussion. The initial work reported by Suzuki et al demonstrated the ability of EC-CVD diamond being used as an electrode in EDM. This work deals with further investigation for the application of EC-CVD diamond as an electrode in EDM.

2. Experimental setup and conditions

An EC-CVD diamond thick film segment of 5mm×6mm×0.5mm was mounted on the head of a die-sinking EDM machine using a jig as shown in Fig.1. An area of 3mm×0.5mm of the electrode is used for EDM. Copper, graphite and Cu-W electrodes of similar dimensions were used for comparison. The work material was SKD11 (HRC 61) and kerosene (Vitol 2, Sodick) was used as the dielectric working fluid. Table 1 lists the physical properties of the EC-CVD diamond and other electrode materials, and the experimental conditions are listed in Table 2.

3. Results and discussion

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Figure 2(a) shows a comparison of wear depth of the electrode end among the EC-CVD diamond, copper, graphite and Cu-W. It is well known that the anode electrode wear is reduced at sufficiently long pulse durations when EDM is performed in oil, and it is reported that this phenomenon is mainly due to an increased rate of adhesion of carbon onto the electrode resulting from the dielectric breakdown.

In the case of the EC-CVD diamond electrode, however, the electrode shows no wear even at very short pulse duration of 3µs. In comparison, copper, graphite and Cu-W electrodes show very high wear at the pulse duration of 3µs.

A comparison of the EDM efficiencies or material removal rate (MRR), of the EC-CVD diamond electrode with copper, graphite and Cu-W electrodes at various pulse durations is shown in Fig. 2(b). Beyond pulse duration of 15µs, the EDM efficiency of the copper increases rapidly with the pulse duration, whereas the efficiencies for the EC-CVD diamond and graphite remain constant.

3.2 Effect of polarity

The effect of polarity on the EC-CVD diamond electrode was investigated and compared with a copper electrode under similar EDM conditions. Experiments were performed under EDM conditions of ui=90V, L=3A and t=3/10, 50/50µs. The results of
this experiment are shown in Fig.3. There is no wear on the diamond electrode when it is used at reversed polarity even for the short pulse duration of 3\(\mu\)s, whereas, when used at straight polarity, a large amount of wear is observed and the wear depth increases with an increase in the pulse duration. On the other hand, for the copper electrode, the wear depth decreases at negative polarity and increases at straight polarity with increasing pulse duration.

3.3 Discharge voltage and surface characteristics

The voltage and current waveforms during the discharge process shown in Fig.4 (a) indicate an increase in the discharge voltage by about 9V in the case of the EC-CVD diamond electrode compared to the copper electrode. This is attributed to the high resistivity \((\rho=0.4-1\times10^7\Omega\cdot\text{m})\) of the EC-CVD diamond.

It has been reported that in the EDM of electrically conductive Si\(_3\)N\(_4\) ceramic \((\rho=3\times10^7\Omega\cdot\text{m})\), there is an occurrence of joule heating due to the voltage drop in the material, resulting in an increase in the temperature of the material \(4)\). This causes arcing which results in a deteriorated EDMed surface quality. However, the high thermal diffusivity of the EC-CVD diamond seems to cause quick dissipation of the heat generated by joule heating. From Fig.4 (b), the craters on the workpiece surface are larger in diameter in the case of the EC-CVD diamond electrode as compared to the copper electrode. This may be due to an increase in the rate of spread of the plasma at the electrode surface because of the high thermal diffusivity of the EC-CVD diamond electrode.

4. Mechanisms of low wear of diamond electrode

4.1 Thermal diffusivity

The thermal diffusivity of the EC-CVD diamond electrode as seen from Table 1 is almost 3 times that of copper and graphite. Due to this high thermal diffusivity, the heat dissipation from the discharge region increases, and this is therefore considered as one important reason for the low wear of the diamond electrode.

4.2 Adhesion of carbon

Raman spectroscopy was used to investigate the adhesion of carbon on the electrode surface. The experiment for the EC-CVD diamond electrode was performed in dielectric oil at the short pulse duration of 3\(\mu\)s. The results were compared with the Raman spectra of carbon adhered onto a copper electrode surface during EDM for a long pulse duration of 60\(\mu\)s. Figure 5(a) shows the Raman spectrum for the copper electrode surface. Two peaks i.e. the D-peak at about 1340\(\text{cm}^{-1}\) and G-peak at about 1590\(\text{cm}^{-1}\) are observed. The position of the peaks and the ratio of the intensities at these peaks indicate the presence of graphitic carbon. The Raman spectrum of the surface of the diamond electrode after EDM is shown in Fig.5 (b) and for all practical purposes can be considered to be similar to the spectrum in Fig.5 (a). The presence of adhered carbon on the diamond electrode surface even for the short pulse duration of 3\(\mu\)s may point to the possibility of acceleration in the rate of carbon adhesion onto the diamond electrode surface, thus the electrode wear is greatly reduced.

5. Conclusion

In conclusion, the following observations may be pointed out.
1. The EDMing ability of EC-CVD diamond electrode without any wear even at very short pulses gives it a great advantage to become an important electrode material for the machining of micro-parts.
2. There is a significant rise in the discharge voltage of about 9V in the case of EC-CVD diamond, however, due to the high thermal diffusivity, it is believed that joule heating does not occur.
3. The extremely low wear of the EC-CVD diamond electrode even for short pulse durations is thought to be due to an acceleration in the rate of carbon adhesion onto the EC-CVD diamond electrode surface.

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[References]