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Machining a small hole to polycrystalline diamond by ultrasonic vibration EDM

Shinichi NINOMIYA[1)], Fumio KOGA[1)], Manabu IWAI [2)], Kiyoshi SUZUKI [3)]

[1]*Nippon Institute of Technology* [2]*Toyama Prefectural University* [3]*K. Suzuki New R& D Office*

ninomiya@nit.ac.jp fumio_koga@eg-koga.co.jp iwai@pu-toyama.ac.jp s-kiyoshi@ipr.ne.jp

Abstract

Electrical discharge machining (EDM) is adopted in the processing of polycrystalline diamond (PCD). However, their machinability is very poor. The authors have demonstrated that the EDM efficiency for the PCD is dramatically increased by the ultrasonic vibration electrodes. In this study, in order to achieve the efficient hole machining to the PCD materials, an ultrasonic vibration EDM using the thin pipe electrode is applied. The effects of electrical discharge machining conditions are investigated in detail. In addition, the ultrasonic vibration EDM by rotating electrode using the ultrasonic spindle is also tried.

PCD (Polycrystalline diamond), Small hole EDM, Ultrasonic vibration electrode, Ultrasonic spindle, EDM efficiency

1. Introduction

For processing PCD (polycrystalline composite diamond), electric discharge machining (EDM) is widely used, but its extremely low machining efficiency is regarded as an issue. Specifically in the EDM processing of a coarse grade PCD (grain size of source diamond particle ≧ φ25μm), machining efficiency becomes significantly low with a rapid wear of the electrode. The authors have shown in the past that the EDM efficiency dramatically improves by use of an electrode added with ultrasonic vibrations [1]. Furthermore, it was also made clear that EDM machinability of the EC-PCD composed of electrically conductive diamond particles was higher than that of the standard PCD (S-PCD hereinafter) [2].

Aiming to establish an efficient processing of a small hole to PCD, effects of EDM conditions were studied in details over the various types of PCD using a copper pipe electrode with ultrasonic vibrations [3]. Moreover, ultrasonic EDM tests using a rotating electrode were also conducted on the PCD.

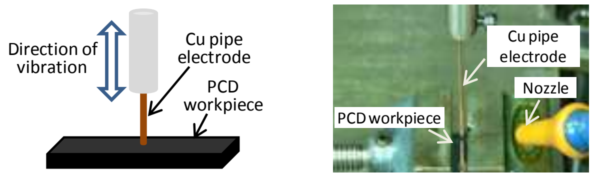
2. Experiments of hole machining to PCD by ultrasonic EDM using a non-rotating electrode

2.1 Experimental method and conditions using a copper pipe electrode of φ1mm

Most commonly, commercially available PCD is sintered onto a carbide substrate. In the first experiment, the PCD layer was separated from the carbide backing beforehand by wire EDM and only the PCD part was used. As an electrode, a copper pipe of φ1.0mm fixed to a head of the ultrasonic hand lapping device with no rotating function was used. Workpiece materials used were S-PCD and EC-PCD composed of ϕ25μm source diamond. Applying an ultrasonic frequency of 28±4kHz, vertical vibration was given to the machining direction (Fig.1). The set depth of cut was 10mm and the set machining time was 10 minutes (Table 1). Subsequently, through hole penetration into the PCD with substrate was examined.

2.2 Experimental results of machining a small hole to the PCD alone by EDM

Experiments of machining a small hole to the PCD layer were conducted, and the results were compared between with and without ultrasonic vibrations. At the same time, effect of the electrode polarity and the pulse condition were also examined (Fig.2). Generally, in processing PCD by EDM, removal efficiency

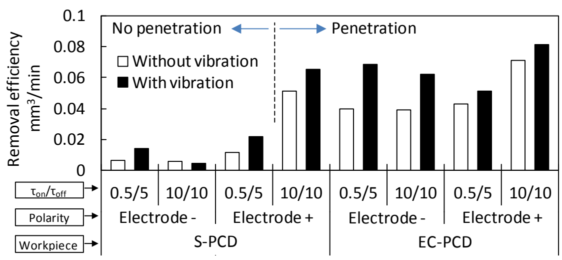


(a) Experimental set up (b)Photo of experiment

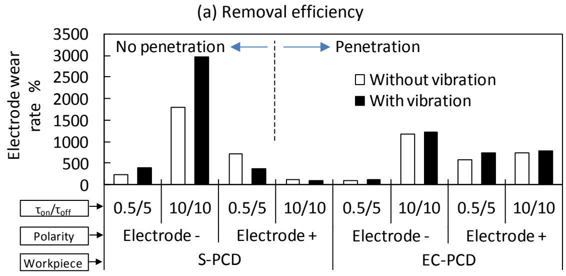
Figure 1. Experimental set up of hole EDM to PCD

Table1. Experimental conditions of hole EDM to PCD

Machine used	Die-sinking EDM machine AQ35L (Sodick)
Electrode	Cu pipe: φ1.0mm(outer), φ0.6mm(inner)
Workpiece	S-PCD025 t=2.0mm(PCD layer t_{PCD}=0.35mm) EC-PCD025 t=2.0mm(PCD layer t_{PCD}=0.4mm)
EDM conditions	Electrode polarity [- or +], Eo=120V, SV=60V, Ip=17.6A, τ_{on}/τ_{off}=0.5/5μs, 20/20μs, In OIL, Without jump, Machining time=10min, Machining depth=10mm
US conditions	Ultrasonic oscillator(ML-35M,Taga), 28±4kHz, 18μm$^{p\text{-}p}$



(a) Removal efficiency



(b) Electrode wear rate

Figure 2. Experimental results of machining a small hole to the PCD alone by EDM

(φ1.0mm Cu pipe electrode(inner 0.6mm): Non rotation, Ip=17.6A, Eo=120V) increases at the "+" polarity of the electrode under the condition of relatively long pulse. In contrast, the electrode wear is accelerated when a polarity is reversed [2]. Through the experiments, roughly similar tendency could be seen.

While through holes could be machined to the EC-PCD workpieces under every condition, in the case of the S-PCD, full penetration was achieved only under the condition of polarity "+" and pulse 10/10μs, and under all other conditions, penetration could not be done within the set machining time (10 minutes). Looking at the effect of the ultrasonic vibrations, removal efficiency was found higher when ultrasonic vibrations were given under most of the conditions. Under the condition of electrode polarity "-" on the S-PCD, machining efficiency was extremely low in whole and wear of the electrode became large in spite of adding ultrasonic vibrations. In the case of EC-PCD, removal efficiency became drastically higher with ultrasonic vibrations, but the electrode wear slightly increased.

2.3 Results of the Experiment to machine a through hole to the PCD material with carbide substrate

The experiments were conducted to penetrate through both PCD and carbide layers. Changing the electrode to a copper pipe of ϕ1.1mm, pulse condition of te/to=20/20μs and a set current of Ip=5, 20A were adopted. In this particular experiment, the S-PCD containing higher volume of sintering agent was used. Results are shown in Fig. 3. All the PCD samples were penetrated even at IP=5A though working time required was more than one hour. Under the condition of I=20A, the penetration was accomplished in 8-25 minutes. Under any conditions, it was confirmed that the application of ultrasonic vibrations improved the removal efficiency. Since the machining conditions are not optimum at this stage, further improvement of the machining efficiency can be expected by some ingenuity such as switching a polarity for PCD layer and carbide layer.

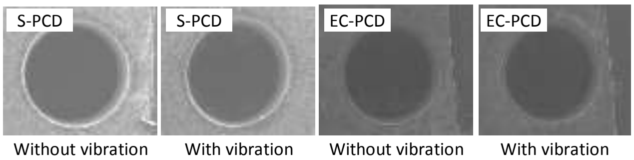
3. Hole machining experiments to PCD by ultrasonic EDM using rotating electrode

Mounting an ultrasonic spindle on a die sinking EDM machine, ultrasonic EDM machining of a hole to the PCD was carried out using the conditions shown in Table 2. A solid round bar of tungsten carbide (φ4mm) was used as a rotating electrode which was fixed to the spindle via a shrink fit chuck (Fig.4(a)). As a trial experiments, adopting slightly weakened discharge conditions and a set machining time of 15 minutes, effects of the ultrasonic vibrations were examined. Grain size of the PCD sample used was 10μm.

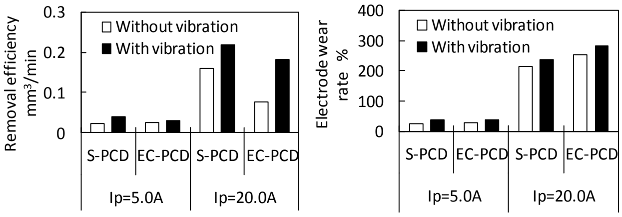
In any case of experiment, the machining time of 15 minutes was spent down while machining the PCD layer. From the experimental results (Fig.4(b)-(d)), it was found that the machining efficiency improved to 2-7 times or more by adding ultrasonic vibrations in the case of using the rotating electrode. It is necessary to select right conditions to think about the large wear of the electrode. However, it was obvious that the electrode wear was suppressed in any case by giving ultrasonic vibrations. Another advantage is a largely improved roundness of the hole by using the rotating electrode comparing to the case of using non rotating electrode. In addition, from the SEM observation of the machined surfaces, it seems that the flow of the discharge waste during machining varies between with and without US vibrations and the machining with US vibrations helps distributed exhaustion.

4. Conclusion

It was found that EDM efficiency can be largely improved by adopting the ultrasonic EDM using a non rotating copper pipe electrode or a rotating copper tungsten electrode attached to the ultrasonic spindle in the small hole machining to various types of PCD materials. The authors would like to express our deep appreciation to Sodick and Industria for their great contribution and cooperation.



(a) Appearance of through hole on the PCD (Ip=20A)



(b) Removal efficiency and electrode wear rate

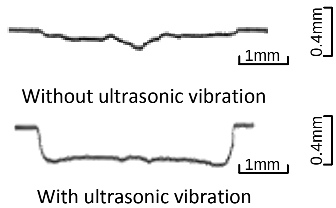
Figure 3. Results of the Experiment to machine a through hole to the PCD material with carbide substrate

(φ1.1mm Cu pipe electrode(inner 0.2mm): Non rotation, 20/20μs, Eo=120V)

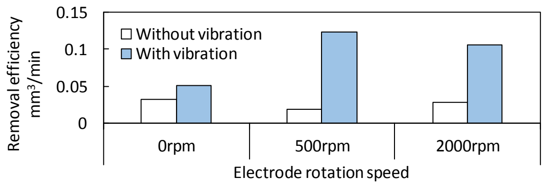
Table1. Experimental conditions of a hole machining to PCD by ultrasonic EDM using rotating electrode

Electrode	Solid round bar of tungsten carbide : φ4.0mm
Workpiece	S-PCD010 t=2.0mm(PCD layer t_{PCD}=0.5mm)
EDM conditions	Electrode polarity [+], Eo=90V, SV=60V, Ip=9A, τ_{on}/τ_{off}=50/20μs, In OIL, Without jump, Machining time=15min
US conditions	Ultrasonic spindle (iR2-2: Industria), 40±1kHz, 4μm$^{p\text{-}p}$

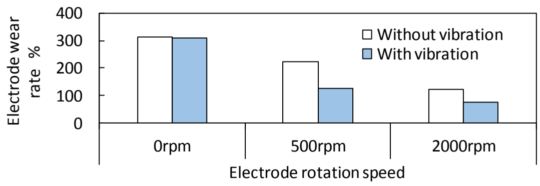
(a) State of experiment



(b) Example of sectional shape of S-PCD hole (500 rpm)



(c) Removal efficiency



(d) Electrode wear rate

Figure 4. Hole machining experiments to S-PCD010 by ultrasonic EDM using rotating electrode

(Tungsten carbide electrode(φ4mm), Eo=90V, Ip=3A, te/to=50/20μs)

References

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