Electrical Discharge Machining of Polycrystalline Diamond Using Copper Electrode – Finishing Condition

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Abstract. Research on machining process of Polycrystalline Diamond (PCD) is becoming important as the material was believed suitable to be used for cutting tools of advanced aeronautical structure. Electrical Discharge Machining (EDM) was regarded as the suitable method to machine PCD due its noncontact process nature. The objective of this research is to determine the influence of several EDM parameter such as sparking current, pulse duration, and pulse interval to the material removal rate and surface roughness of the machined PCD. Instead of significantly influenced the material removal rate, the sparking current was also highly influenced the surface roughness. Highest material removal rate of approximately 0.005mm³/s was recorded by the EDM process with the highest current used of 5A, and lowest pulse interval of 1µs. The influence of pulse duration is not clearly seen at the lowest pulse interval used. On the other hand, 0.4µm was the lowest surface roughness value obtained in this research indicated by the highest sparking current, highest sparking duration and lowest sparking interval of 5A, 1µs and 1µs respectively.

1. Introduction

The interesting discovery of new composite material of CFRP-Titanium stakes brings attention to huge aerospace industries to replace the use conventional CFRP. Though, the main challenge was to machine and fabricate the material due to the extreme hardness of titanium layer. Regarded as among the hardest material in the world, Polycrystalline diamond believed as suitable cutting tools to machine this material. In fact, the application of PCD tools not limited to only for aerospace structure machining process, but also for underwater drilling in oil and gas industries as well as for rock drilling in new outer-space discovery. The investigation on the machinability of PCD would greatly important as it plays important role in several aforementioned extreme applications.
Since 2010 extensive research has been initiated to increase PCD machining efficiency and tool quality [1, 2]. But no significant breakthrough was achieved due to the lack of innovative approaches and new theories to solve the two fundamental problems in machining PCD: the ultra-hardness of diamond particles and the low electrical conductivity of PCD material. Despite improvements of various levels were achieved, the increase in machining efficiency was limited. This includes the investigations on using short-pulsed lasers, ultra-short-pulsed lasers and other novel laser-related machining techniques for PCD processing [3, 4]. Precision and near damage-free machining could be achieved by using lasers of ultra-short pulses. The nanosecond-pulsed lasers are likely more desirable for high efficient micromachining where the surface damages can be properly controlled. However, extremely slow process limits its application.

Due to high hardness of PCD, only diamond grinding wheels can be applied in PCD grinding [2]. However, it suffers with high wheel wear (G ratio of 0.01 to 0.05) and extremely low material remove rate [1, 5]. This leads to the high manufacturing cost caused by the long machining time that becomes a major impediment to the implementation of PCD tools: a brazed PCD tool is about 10 times expensive than a tungsten carbide tool, and the price of a vined PCD tool is about 20 times higher than the carbide ones.

Electrical Discharge Machining (EDM) is a noncontact thermal erosion process in which the metal is removed by a series of recurring electrical discharges between the electrode and the electrically conductive workpiece, in the presence of a dielectric fluid. The electric conductivity of PCD caused by the conductive binding material (Cobalt) makes it possible to machine PCD tools with EDM. However, the low electrical conductivity makes the EDM process is almost 3 times slower than EDM of conductive metals. The fundamental problem that causes low machining efficiency in EDG of PCD is the low electricity conductivity of PCD [6].

This study discusses on the erosion performance of Electrical Discharge Machining (EDM) in PCD machining, specifically in finishing stage. Finishing EDM of PCD considered as a slow process due its high melting temperature of diamond grains (approximately 3400°C) and low electrical conductivity. Therefore, there is a pressing need and powerful incentive to develop a new EDM strategy to significantly increase PCD machining efficiency. As an attempted to discover new machining theories, this experiment was carried out as the benchmark for the hereinafter investigation.

2. Methodology

PCD known as synthetic diamond which is among the hardest materials in the world. It is produced by a sintering process that composed diamond particle and metallic binder of cobalt substance under high pressure and high temperature condition. CTX002 PCD grade was used for this erosion experiment with the dimension of 7mm x 0.5mm for the width and thickness respectively. Copper rod with diameter of 10mm was used as the electrode. Figure 1 shows the PCD and Copper electrode used in this investigation.
The research was conducted by 4-axis SODICK EDM die sinking machine. Three variable parameter were used in this research: pulse ON, pulse OFF, and current. The process was categorized as high voltage machining as high peak voltage was fixed at 120V for the entire experiment. Negative polarity was used in this investigation as found more suitable for finishing process [8]. The detail machining parameter is shown in Table 2.

| Parameter                   | Description     |
|-----------------------------|-----------------|
| Supply voltage              | 120V            |
| Current                     | 1A and 5A       |
| Pulse duration (Pulse-on)   | 1µs and 5µs     |
| Pulse interval (Pulse-off)  | 1µs and 5µs     |
| Depth of cut                | 0.1 mm          |

The erosion performance was indicated by the material removal rate (MRR) and surface roughness (Ra) produced by cooper electrode. Cleaning process using Acetone was done prior to ultrasonic cleaning as it is crucial to remove deposited debris on the machined surface. The roughness measurement was done according to EN ISO 4288 using Surface Roughness Tester Mitutoyo SJ-400. The Material removal rate (MRR) of the work piece was calculated by using the following formula. Where $V$ is volume of material removed and $t$ is the machining time.

$$MRR = \frac{V}{t}$$
3. Result and Discussion

Figure 2 shows the MRR obtained by the process where the error bars indicate 95% of confident interval. It can be seen that the higher the sparking current is, the faster is the erosion process. As shown in Figure 2a, the MRR obtained by 5A was recorded approximately 800% higher than the MRR obtained by the sparking current of 1A. Similar to as found by the EDM of ordinary material, it was due to the production of higher sparking energy. At lower interval, the influence of pulse duration is not significant. Although the mean value of MRR is higher for small pulse duration, 95% confident interval indicates there is a possibility to obtained similar MRR compared to 5 µs pulse interval.

At high sparking current of 5A, the influence of pulse interval can be clearly seen. This can be due to several reasons: (1) Due to high thermal conductivity of PCD, fast heat dissipation can be expected. Hence, increasing pulse interval (pulse-off) from 1 µs to 5 µs would significantly increase the probability of heat losses before the next sparking event, (2) The interval time between spark isn’t enough for dielectric strength recovery. Hence, immature sparking frequently happened which resulted to inefficient sparking process. Due to the static electrode implemented, slow dielectric flow under the gaps can be expected which made slower strength discovery. As reported by reference [9], faster the electrode rotation is, the faster is the dielectric strength recovery and removal process.

![Graph showing MRR with pulse interval](image)

Figure 2: Result on Material Removal Rate (MRR); a. Using 1 µs Pulse Interval (Pulse-Off) b. Using 5 µs Pulse Interval (Pulse-Off)

In general, the process produced the surface roughness of lower than 1 µm. The value was higher than some published data of PCD EDM with rotating electrode in reference [10]. The higher in surface
roughness value was due to inefficient debris removal in EDM of static electrode. The debris accumulation caused to the spark concentration, consequently resulted in worse surface roughness [9-11].

Interestingly, this investigation revealed that the lower current is not necessarily able to produce lower surface roughness. As shown in Figure 3, lower surface roughness was produced by the EDM with 5A sparking current that is normally not the case for ordinary material. In EDM of ordinary material, higher peak current of the same pulse duration reported as produced higher sparking energy. This resulted in production of deeper crater and rougher surface [12].

![Figure 3: Result on Surface Roughness (Ra); a. Using 1µs Pulse Interval (Pulse-Off) b. Using 5µs Pulse Interval (Pulse-Off)](image)

As discussed in reference [13], PCD EDM undergo a unique removal mechanism. Breaking mechanism of diamond grains reported as the erosion mechanism for roughing while graphitisation erosion for finishing process [13]. If this is the case, better surface roughness obtained by 5A could be due to the sufficient graphitisation activation energy provided by the process.

The researchers believed that clear description on the efficient erosion in production of smooth PCD surface can be explained by carefully analyse the sparking profile produced by the process. As mentioned by The outcome would then elucidate the erosion mechanism of PCD that believed distinctive from the ordinary material.

4. Conclusion

It was theorized that the material removal rate and surface roughness is closely related to the sparking energy produced by the process. In the case of material removal rate, the high current used of 5A was produced bigger sparking energy, thus made faster to the erosion process. In this study, 0.0047 mm/s recorded as the highest MRR. 5A current was also influence to the production of lowest surface roughness. Yet, the reduction of surface roughness with the higher sparking energy remained undiscovered. To reveal the exact
reason, the observation of the spark profile is essentially required that would be the future extension of this research.

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