Experiment Analysis Research on Electrical Discharge Machining Polycrystalline Diamond Tool

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Abstract. As the hardest material in the field of synthetic materials, polycrystalline diamond has been paid more and more attention in the field of tools, which embody the basic characteristics of "high efficiency, precision and flexibility" of modern advanced cutting technology and cleaner production. Electrical discharge machining is typically used in processing polycrystalline diamond tools, especially in the machining of special shape, thin and fine cutting tools. In this paper, 2 micrometer and 10 micrometer polycrystalline diamonds are taken as the research object, and the surface quality of the disc electrode and wire electrode is simply compared by means of process and material test. The effects of diamond particle size, electrode polarity and electrode speed on the surface quality and the material removal rate of precision electrical discharge machining polycrystalline diamond are studied. The results show that there is no porous structure and no selectivity in discharge etching when the negative polarity electrode machine is used. With the increase of electrode rotation speed, the removal amount of polycrystalline diamond increases gradually, while the surface roughness of polycrystalline diamond decreases first and then increases. When the electrode linear velocity reaches 80 m/min, the surface roughness of polycrystalline diamond sample reaches the minimum value, and the removal amount of polycrystalline diamond material tends to be stable.

1. Introduction

Polycrystalline diamond (PCD) is a synthetic product of diamond powder grown by catalyst under high temperature and high pressure. Its structure is very similar to that of natural diamond. It is formed by C-C covalent bond and has good toughness. The ultra-hard materials tool is represented by polycrystalline diamond (PCD) tool has higher hardness, better wear resistance, stronger thermal stability, chemical stability and excellent thermal conductivity than high-speed steel tool and cemented carbide tool. It embodies the basic characteristics of "high efficiency, precision and flexibility" and cleaner production of modern advanced cutting technology. The development direction of modern efficient, high-speed and green cutting tools [1-2]. In developed countries, PCD tools are widely used to replace cemented carbide tools in precision machining fields such as aerospace, automobile manufacturing and machining, especially for processing non-ferrous metals and their alloys. Machining efficiency is increased by more
than two times [1]. The tool life can be increased to ten times of traditional cemented carbide tools, and the tool wear and failure rate are reduced [3-4].

As the hardness and wear resistance of polycrystalline diamond are very high, it is a common method to use EDM grinding to achieve the removal of materials with softness instead of rigidity. EDM is a self-excited discharge process based on the principle of pulse discharge erosion. The physical process of discharge erosion is a comprehensive process of electro-magnetic, thermodynamics, hydrodynamics, etc. [5-7]. Different from mechanical machining, EDM belongs to non-contact machining, which has no mechanical cutting force. It has the advantages of simple tool electrode forming, small relative loss and so on. It can be effectively applied to PCD Tool Machining with sharp and fine cutting edges and complex cutting edges. However, there are also differences between the disc electrode and the wire electrode, the suitable cutting tools are also different, and the cutting edge of the cutting tools also shows different shapes.

Experts have made many explorations in the fields of EDM, EDG and WEDM of PCD materials, and obtained much valuable research results. These studies can be basically classified into three categories. One is based on the processing mechanism of PCD material removal [2, 7-9], which adopts the way of combining processing test and material test analysis. Through SEM observation, XRD analysis, energy spectrum analysis and Raman spectrum analysis before and after PCD material processing, the element comparison, component analysis and grain boundary analysis before and after processing are carried out To judge the removal mechanism of PCD material in EDM. The other is to study the processing technology of PCD material [10, 11], which is also based on experiments. Taking the surface quality (such as surface roughness, straightness, etc.), processing efficiency, material removal rate, etc. of workpiece as evaluation indexes, the relationship model between processing technology parameters (such as open circuit voltage, peak current, pulse width, pulse interval, etc.) and evaluation indexes is established to find out the technology Law. The third is to study the selection of electrode materials for EDM [2,12,13], the influence of copper, copper and graphite electrodes on EDM, and the influence of rotating electrode on machining efficiency. These research all pay attention to the important factors of EDM, and ignore the seemingly unimportant machining parameters, such as electrode polarity, electrode speed and diamond particle size. For EDM precision machining, these "secondary factors" also have an important impact on the surface quality and machining efficiency. In addition, for a polycrystalline diamond, the particle size also affects the quality and efficiency of processing to a certain extent.

In this study, two kinds of polycrystalline diamond materials with different particle sizes are taken as the research objects. By means of processing test and material analysis, the differences of surface quality between disc electrode and wire electrode are analyzed and compared, and the influences of diamond particle size, electrode polarity and electrode rotation speed on surface quality and material removal rate of PCD EDM are explored. This provides the experimental basis for the economical development of the EDM process of PCD.

2. Experiments method and equipment
Polycrystalline diamond samples were selected with diamond PCD composite tablets with particle sizes of 2 and 10 microns respectively (their material properties are shown in table 1).The electrode adopts disc-shaped copper electrode and copper wire, the end surface of which is used for grinding PCD layer, and the line electrode is used for cutting PCD cutter edge. The electrical discharge machine named BDM-903 (as showed in Fig. 1) produced by Beijing Institute of Electro-machining is selected as experimental machining equipment. The machine tool with wire electrode selected the ALN400Q of Sodick co. (as shown in figure 2). HITACHI's s-4800 scanning electron microscope, D/ max-ra X-ray diffraction analyzer and domestic TR240 surface roughness meter were selected as the experimental analysis instruments.
Table 1. Physical properties of PCD tool blanks

| Crystal granularity size (µm) | Diamond content (%) | Cobalt content (%) | Density (g/(cm)³) | Elastic Modulus (GPa) | Thermal Conductivity (W/m.k) |
|-------------------------------|---------------------|-------------------|-------------------|----------------------|-----------------------------|
| 2                             | 84.5                | 15                | 4.2               | 930                  | 520                         |
| 10                            | 90                  | 10                | 4.0               | 1050                 | 580                         |

3. **Surface quality analysis of EDG disk electrode and wire electrode**

The cutting edge of PCD sample with particle size of 10 micro meter processed by 0.2mm brass wire is shown in Fig.3, and three modes of rough machining, semi-finish machining and finish machining are adopted respectively. From Fig.3, it can be simply found that after PCD processing, the cutting edge appears obvious melting state, and the cutting edge has different degrees of etch craters, with good straightness; the size and quantity of etch craters have a certain relationship with the machining technique.
Figure 3. SEM of wire-EDM (a) rough machining; (b) semi-precision machining; (c) precision machining

Figure 4. SEM of EDG (a) rough machining; (b) semi-precision machining; (c) precision machining

The surface morphology of PCD processed by 200 mm diameter copper disk electrode is shown in Fig.4. It also uses rough machining, semi finish machining and finish machining. From this figure, it can be simply found that the molten materials and different sizes of etch craters also appear on the machining surface, but the straightness of the edge is acceptable, and the arc surface appears at the edge.

Compared with Fig. 3 and Fig. 4, it is obvious that the straightness of the cutting edge processed by the disc electrode is worse than that processed by the line electrode, and the size of the etch pit is basically the same; from the surface roughness point of view, the disc electrode processing is better than the line electrode processing.

4. Influence of electrode polarity

Different from traditional electrical discharge machining, EDG (electrical discharge grinding) uses rotating disc-shaped copper electrode as tool electrode. In addition, EDG generally adopts the flushing type processing, so the working medium is slightly different from the traditional electrical discharge machining, and adopts the N32 mechanical oil with higher ignition point. The process parameters adopted in the processing test are shown in table 2. Generally, the surface roughness W_Ra of processed materials is selected as the evaluation standard of processing quality. The removal amount V_W of processed material is selected as the evaluation index of processing efficiency.

Table 2. Process parameters of disc electrode processing test

| Machining current (A) | Open voltage (v) | Pulse duration (μs) | Pulse interval (μs) | Electrode speed (r/min) | Amount of remove (mm) |
|-----------------------|------------------|---------------------|---------------------|-------------------------|-----------------------|
| 3                     | 120              | 10                  | 15                  | 100–400                 | 0.10                  |

Fig.5 and Fig.6 are scanning electron microscope images of PCD samples with particle size of 10 microns after using negative polarity and positive polarity discharge processing. It is obvious from the figure that no porous structure can be found on the processed surface with negative polarity processing.
However, when the surface is processed with positive polarity, it has obvious porous structure, and the roughness of the surface processed with negative polarity is better than that processed with positive polarity. This indicates that discharge removal is selective under the condition of positive polarity machining, and the removal of polycrystalline diamond is uneven. In particular, under the condition of small current, with the positive polarity processing, very little diamond (several microns) is eroded. Fig.7 and Fig.8 are the XRD patterns of PCD samples with particle size of 10 microns after using positive polarity and negative polarity discharge processing. As can be seen from the figure, for positive polarity processing, the proportion of diamond and graphite will decrease, while the proportion of cobalt, tungsten and oxide will increase. These oxides are mainly compounds formed by high-temperature oxidation reaction in the process of discharge and eventually deposited on the diamond surface, forming a metamorphism layer with graphite.

Figure 5. SEM measurement for negative polarity machining

Figure 6. SEM measurement for positive polarity machining

Figure 7. XRD analysis for negative polarity machining
5. **Influence of electrode rotation speed and diamond particle size**

Fig. 9 and Fig. 10 are the relationship curves of electrode speed, diamond particle size and EDM quality, efficiency under the unified electrical discharge machining parameters test. It can be seen from Fig. 9 that with the increase of the linear speed of electrode rotation, the surface roughness value of PCD samples with the particle size of 2 micrometer decreases first, and then increases, especially when electrode rotation speed is at 60 m/min, the surface roughness value of samples reaches the minimum value. In the same way, the surface roughness of PCD samples with 10 micrometer particle size decreases first and then increases, but the minimum value of the surface roughness of the samples is reached when electrode rotation speed is at 80 m/min. It is also shown that under the same discharge processing, the surface roughness of the workpiece is different with different particle size, and the optimal processing technology should be adjusted according to the change of material particle size.

It can be apparent from Fig. 10 that when the electrode does not rotate, the removal amount of PCD material is the lowest; with the increase of the electrode rotation speed, the removal amount of PCD material increases gradually, and when the electrode speed reaches 80 m/min, the removal amount of PCD material increases slowly. This is because the electrode rotation improves the discharge processing conditions and accelerates the material removal speed. However, when the electrode rotation speed matches the discharge parameters, the effect of electrode rotation speed on the material removal speed is not obvious. It can also be seen from Fig. 10 that with the increase of the electrode rotation linear speed, the removal speed of large-size diamond is faster, but the trend of change is the same.
Figure 10. The relation curve of electrode speed, diamond particle size and workpiece material removal

6. Conclusion
From the above analysis, we can get the following conclusion:

(1) The straightness of the cutting edge processed by disc electrode is worse than that processed by wire electrode, and the size of the erosion craters is basically the same.

(2) When using the negative polarity machining, the processed surface does not have a porous structure, the surface quality is good, and there is no selectivity for discharge erosion.

(3) When the electrode speed is at 60~80 m/min, the workpiece surface roughness reaches the minimum value. With the increase of electrode rotation linear speed, the removal amount of PCD material gradually increases. When the speed reaches 80m/min, the removal amount of PCD material gradually slows down.

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