Experiments Research on Electrical Discharge Grinding Polycrystalline Diamond Tool based on Surface Quality Analysis

Yunhai Jia1,*, Jianmei Guo1, Qinjian Zhang2 and Yue Sun1

1Research and development center, Beijing Institute of Electro-Machining, Beijing 100191, China
2School of mechanical and electrical engineering, Beijing Information Science and Technology University, Beijing 100192, China
*jyh308401@sina.com.cn

Abstract. As the hardest material in the field of synthetic materials, polycrystalline diamond has attracted more and more attention in the field of tools, which reflects the basic characteristics of ‘high efficiency, precision and flexibility’ of modern advanced cutting technology and clean production. Electrical discharge grinding (EDG) is often used in polycrystalline diamond tools, especially in special shape, thin and fine edge cutting tools. Taking two kinds of grain size of polycrystalline diamond as the research object, taking the machining test and material test as the analysis means, this paper simply compares the surface quality of disc electrode and wire electrode machining, and studies the influence of diamond particle size, electrode polarity and electrode rotation speed on the surface quality and material removal rate of precision electrical discharge grinding polycrystalline diamond. The results show that there is no porous structure, good surface quality and no selectivity in discharge removal when using the negative polarity machining. With the increase of electrode rotation speed, the removal amount of polycrystalline diamond material increases gradually, and the surface roughness of polycrystalline diamond material decreases first, then increases. When the electrode rotation speed reaches 80 m/min, the surface roughness of the polycrystalline diamond sample reaches the minimum value, and the removal amount of polycrystalline diamond material also tends to be stable.

1. Introduction
Polycrystalline diamond (PCD) is a synthetic diamond powder grown by catalyst under high temperature and high pressure. Its structure is very similar to natural diamond, which is formed by C-C bond and has good toughness. Polycrystalline Diamond tool has a higher hardness than HSS cutting tools, carbide cutting tools and better wear resistance, better thermal stability, chemical stability and thermal conductivity, excellent embodies the modern advanced cutting technology [1, 2].Developed countries in aerospace, automobile manufacturing, machinery processing, such as precision machining industry, especially the processing of non-ferrous metals and their alloys, the widespread adoption of PCD cutting tool instead of carbide cutting tools, processing efficiency more than 2 times [1], the
cutting tool service life can be improved to ten times the traditional carbide cutting tools, reduce the tool wear and failure rate [3-4].

Because the hardness and abrasion resistance of polycrystalline diamond are very high, it is a common method to use electrical discharge machining (EDM) to achieve material removal by using soft and rigid materials. EDM is a self-excited discharge process based on the principle of pulsed discharge erosion. The physical process of discharge erosion is a comprehensive process of electromagnetism, thermodynamics, fluid dynamics, etc. [5, 6]. Different from mechanical machining, EDM belongs to non-contact machining, without mechanical cutting force, with the advantages of simple tool electrode forming, low relative loss, etc., it can be effectively applied to the PCD cutting tool machining with sharp edge and complex shape edge. However, there are also differences between disc electrode and wire electrode processing, suitable for processing tools are also different, the cutting edge of the processing tools also shows different morphology.

Experts have made many explorations in PCD materials such as EDG and EDM wire cutting, and obtained much valuable research result. These studies can be divided into three categories, basic type of research is around the processing mechanism of PCD material removal of [2, 6-9], the processing and analysis of a combination of materials testing, SEM observation before and after by PCD material processing, XRD analysis, energy spectrum analysis and Raman spectrum analysis and carry on the processing element before and after the contrast and the analysis of the components, the analysis of the grain boundary, to judge the PCD material removal mechanism in EDM. Another kind is the study of PCD material processing technology [10-12], also basic use test is given priority to, to the processing surface quality of workpiece, such as surface roughness, straightness, etc.), processing efficiency, material removal rate as the evaluation index, such as establishing process parameters (such as open circuit voltage, peak current, pulse width, pulse interval, etc.) and the relationship between evaluation index model, search process. The third category is the selection of electrode materials for EDM [2, 13, 14], and the influence of white copper, red copper and graphite electrodes on EDM and the effect of rotating electrode on machining efficiency. These studies all focus on important factors affecting discharge machining and ignore seemingly unimportant processing parameters, such as electrode polarity, electrode rotation speed and diamond particle size. For EDM precision machining, these "minor factors" also have important influences on surface quality and machining efficiency. In addition, the particle size of polycrystalline diamond also affects the quality and efficiency of processing to a certain extent.

In this study two kinds of grain size of polycrystalline diamond material as the research object, through processing according to the method of analysis of the material science, simple analysis compares the surface quality of plate electrode and wire electrode processing differences, explore the diamond granularity, electrode and electrode polarity speed of polycrystalline diamond spark discharge grinding surface quality and the influence of material removal rate. This provides an experimental basis for making reasonable electrical discharge grinding process of polycrystalline diamond.

2. Experiments method and equipment

| 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                         |
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 a wire electrode selected the ALN400Q of Sodick co. (as shown in Fig. 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.

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

The cutting edge of PCD sample with particle size of 10 microns processed by 0.2mm brass wire is shown in Fig.3. Three modes of rough processing, semi-finishing processing and finishing processing are respectively adopted. It can be easily seen from Fig.3 that after PCD processing, the cutting edge was in an obvious melting state, and there were different degrees of corrosion pits on the cutting edge, and the cutting edge had a good straightness. The size and number of each crater are related to the processing technology.

Figure 4 shows the surface morphology of PCD processed with 200mm diameter copper disc electrode, as well as rough machining, semi-finishing and finishing. From the figure, it can be easily found that the processed surface also has molten materials and craters of different sizes, but the straightness of the cutting edge is general, and a curved surface appears at the cutting edge.
Compared with Fig.3 and Fig.4, it is obvious that the straightness of the cutting edge processed by disc electrode is worse than that processed by wire electrode, and the size of the etching craters is basically the same. From the surface roughness, disc electrode processing is better than line electrode processing.

4. Influence of electrode rotation speed and diamond particle size

Fig.5 and Fig.6 are the curves of the relationship between the electrode speed, diamond and the quality and efficiency of the discharge grinding process under the unified discharge machining process parameters test. As can be seen from Fig.5, with the increase of electrode rotation speed, the surface roughness of PCD samples first decreases, and then increases. In particular, when electrode speed is at 60 m/min, the surface roughness of samples reaches the minimum value. Similarly, about 10 microns granularity PCD material samples of the surface roughness value is reduced, first after the increase, but the sample surface roughness value reaches the minimum value is in electrode speed 80 m/min, it also suggests that, in the same discharge processing, particle size is different, the surface roughness of the workpiece are different, the optimization of processing technology changed correspondingly adjusted according to the material particle size.
As can be seen from Fig. 6, when the electrode is not rotated, the removal amount of PCD material is the lowest. With the increase of the rotation speed of the electrode, the removal amount of PCD material gradually increased. When the electrode speed reached 80m/min, the removal amount of PCD material gradually slowed down. This is because the rotation of the electrode improves the discharge machining conditions and accelerates the material removal speed. However, when the linear velocity of the electrode rotation matches the discharge parameters, the effect of electrode rotation speed on material removal speed is not obvious. It can also be seen from Fig. 6 that, with the increase of the rotation speed of the electrode, the removal speed of large-size diamond is faster, but the change trend is the same.

5. Conclusions

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 etching craters is basically the same.

2. With the increase of the speed of electrode rotation, the surface roughness of PCD material first decreases and then increases. When electrode speed is at 60~80 m/min, the surface roughness of the sample reaches the minimum value. With the increase of particle size, the speed of the electrode which obtained the best surface quality also increased under the same discharge machining process.

3. With the increase of the electrode rotation speed, the removal amount of PCD material gradually increases. When electrode speed reaches 80m/min, the removal amount of PCD material gradually slows down.

Acknowledgments

This research is supported by Beijing Natural Science Foundation the Grant No. 3162013 and Young Scholar Program of Beijing Academy of Science and Technology the Grant No. YS201905. The authors would also like to thank the anonymous reviewers whose comments greatly helped in making this paper better organized and more readability.

References

[1] M.W. Cook, P.K. Bossom. Trends and recent developments in the material manufacture and cutting tool application of polycrystalline diamond and polycrystalline cubic boron nitride. International Journal of Refractory Metals & Hard Materials. 18 (2000) 147-156.

[2] Yunhai JIA, Jiangang LI. Impact Analysis of Electrode Material on Electrical Discharge Grinding Polycrystalline Diamond Cutting Tools. Procedia CIRP. 68 (2018), p. 643.
[3] Michiko Ota, Juny Okida, et al. High Speed Cutting of Titanium Alloy with PCD Tools. Key Engineering Materials. 389 (2009), p. 157.

[4] Ezugwu E, Bonney J and Yamane Y. An overview of the machinability of aero engine alloys. Journal of Materials Processing Technology. 134 (2003) 233-253.

[5] Yu Jiashan. Theory of electrical discharge machining. Beijing: National Defence Industry Press; 2011. p. 55-71.

[6] M. Kunieda. Fundamentals of electrical discharge machining and future prospects [J]. Journal of the Japan Society for Precision Engineering. 71(2005):189-194.

[7] Liu, J, Deng, F, Lu, X, Zhang, P. A study on structural evolution of metamorphic layer on the surface of PCD in electrical discharge machining. Diamond and Related Materials. 91(2019) 46-53.

[8] Yan, M, Cheng, Y, Luo, S. Improvement of Wire Electrical Discharge Machining Characteristics in Machining Boron-doped Polycrystalline Diamond Using a Novel Iso-pulse Generator. International Journal of Precision Engineering and Manufacturing. 20(2019) 159-166

[9] Jia, Y.H, Guo, J.M, Guo, Y, Yu, F. Research on micro-size electrical discharge machining polycrystalline diamond. Materials Science Forum. 943(2018) 14-19.

[10] Tang, J, Zhang, H, Ye, P. Research on electronic discharge grinding of polycrystalline diamond based on response surface method. Key Engineering Materials, 764(2018) 123-132.

[11] Yunhai Jia, Jiangan Li and Lin Chen. Research on Electrical Discharge Grinding Technics of Polycrystalline Diamond Compact Cutting Tool. Advanced Materials Research. 1004-1005 (2014) 1182-1185.

[12] M.Boujelbene, E.Bayraktar, W.Tebni. Influence of machining parameters on the surface integrity in electrical discharge machining. Archives of Materials Science and Engineering. 39 (2009) 110-116.

[13] Jiwang Yan, Kazunori Watanabe, Tojiro Aoyama. Micro-electrical discharge machining of polycrystalline diamond using rotary cupronickel electrode. CIRP Annals – Manufacturing Technology 63 (2014) 209-212.

[14] M. Zulaffif Rahim, Songlin Ding and John Mo, Electrical Discharge Grinding of Polycrystalline Diamond—Effect of Machining Parameters and Finishing In Feed. Journal of Manufacturing Science and Engineering. 137(2015) 1-11.