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Fast Polishing of Single Crystal Diamond

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Abstract. This paper investigates the polishing of single crystal diamond using the dynamic friction method. It was found that by selecting a proper polishing pressure and sliding speed, a very high polishing rate at 10,300 µm/h (or 2.8×10^{-2} mg/s) with a high quality surface finish can be reached, which is hundreds times faster than the other polishing process reported in the literature. This method can be used to manufacture diamond products and to repair worn diamond components such as diamond cutting tools and diamond dressers for grinding wheels.

Introduction

Diamond is the hardest known substance and is chemically inert to most corrosive environment. As a result, the surface polishing/grinding processes of diamond elements has been inefficient, using the method of diamond to cut diamond. The material removal rate of such processes is extremely low, on the order of tens nm/h [1].

With the increasing applications of synthesized diamond materials, various physical and chemical techniques have been proposed and tried to polish diamond surfaces, based on the mechanical, chemical or thermal material removal. Mechanical, chemo-mechanical, thermo-chemical, high energy beam, electrical discharge machining and dynamic friction polishing are the major techniques developed.

It has been reported that dynamic friction polishing, or commonly referred to as DFP, is a cost-effective, abrasive-free technique for polishing polycrystalline diamond (PCD) and its composites [2-7]. This technique makes use of the thermo-chemical reaction induced by the frictional heating at the sliding interface between a PCD composite specimen and a rotating catalytic metal disk under certain pressure. A series of investigations have been conducted on PCD composites to characterize the upper and lower bounds of temperature rise at the polishing interface [8-9], to explore the material removal mechanisms [6-7], to model the polishing rate [4], to establish the polishing map for production process design [5], and to apply the technique to the polishing of cutting tools and optical elements [10-11].

This paper will investigate the polishing of single crystalline diamond using the DFP technique, aiming to understand the surface quality and polishing efficiency achievable.

Experiment

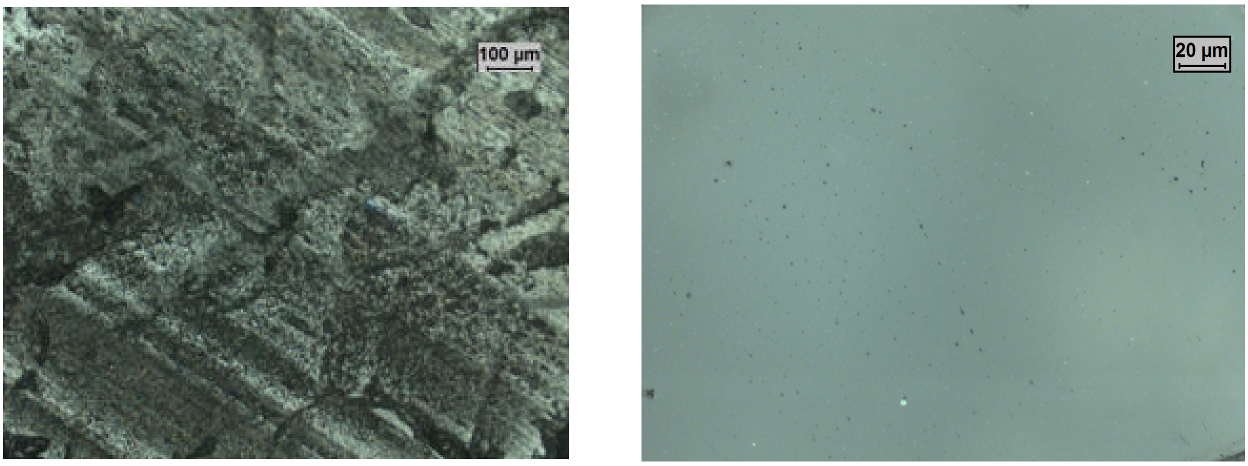
The single crystal diamond specimen used for testing was from a diamond single point dresser (Part Number 00648608 supplied by Blackwood), of which a corn shaped diamond tip of 1 carat (0.259g) was brazed to a cylinder shank of 12.7 mm in diameter. The dresser had been used for dressing grinding wheels and its diamond conical tip had worn out to a blunt flat surface before its use as the polishing specimen in this study. The initial surface roughness of the specimen was approximately 3µm (Ra) and its flat tip diameter was 1.9 mm.

The DFP experiments were performed on a polishing machine manufactured in-house, as has been illustrated elsewhere [5]. The polishing was conducted by pressing a diamond specimen at a specific load onto a rotating catalytic metal disk in ambient temperature and atmosphere. The sliding speed between the specimen and the metal disk was varied from 20 to 35 m/s. The polishing load used was 39.2, 49 and 58.8 N, respectively.

The surface roughness was measured using the Surftest 402 and Surftest Analyzer (Mitutoyo). The surface structure and topography were analysed by an optical microscope (Leica DM RXE) and a scanning electron microscope. The amount of material removed was determined by measuring the weight changes of a diamond specimen before and after polishing. The specimen weights were measured on an electronic balance (Sartorius Basicplus BP210D of resolution 0.01 mg). The material removal rates were converted to the volume reduced according to the density of diamond (3,500 kg/m^3). The diameters of the flat tip of the diamond were measured before and after each polishing test.

Results and discussion

Because the specimen was a used wheel dresser after a long service time, it contained numerous surface cracks before polishing, as shown in Fig. 1(a). During polishing, there were significant sparkles from the contact interface, indicating that the temperature at the interface had reached a high value to activate the expected chemical reaction between the metal disk and the diamond to transform the diamond to a softer phase of non-diamond carbon [6]. This softer carbon phase was removed consequently by the mechanical abrasion between the diamond and the metal disk. In the process, according to [7], both the diamond and the transformed non-diamond carbon exposed to the air could also react with oxygen and escape as CO and/or CO_2. Meanwhile, the oxidation could accelerate the transformation process of diamond to non-diamond carbon and speed up the material removal in the DFP.



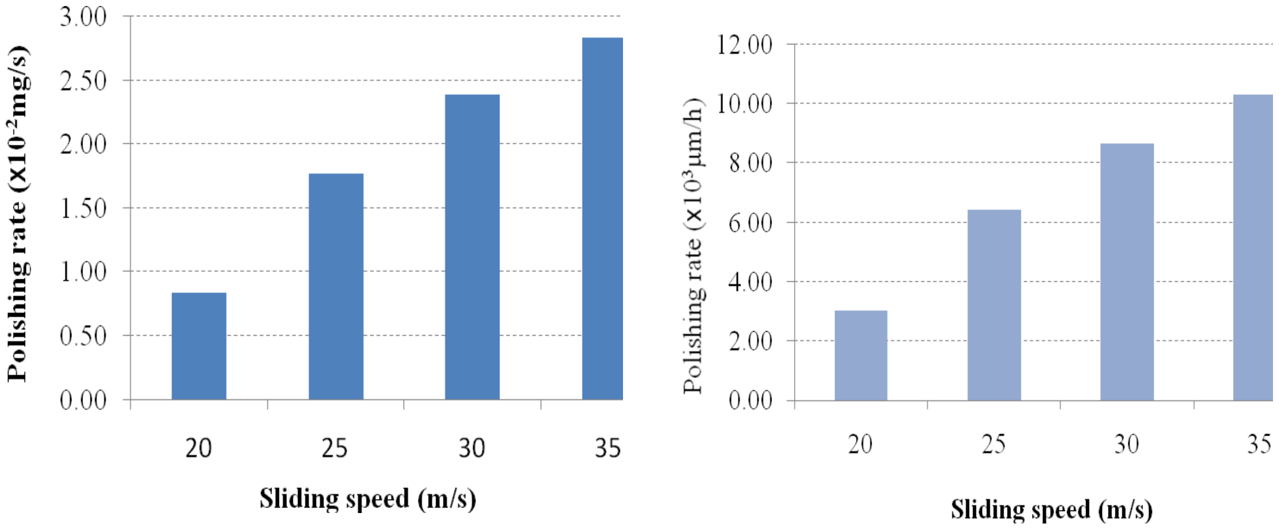
(a) before polishing (b) after polishing

Fig.1 Diamond surfaces before and after polishing.

The polishing produced a dramatically improved surface finish, as shown in Fig. 1(b). The surface roughness (Ra) was reduced to about 50 nm. All the surface cracks as shown in Fig. 1(a) had been successfully removed.

Chen and Zhang [5] have investigated the polishing of PCD composites of SiC bond using the same dynamic friction method. They reported that on these composites cracks along the PCD-SiC boundaries could be easily formed during polishing at certain combinations of speed and pressure. They considered that such polishing-induced cracking was attributed to the non-uniform thermal stresses in the composites because the coefficient of thermal expansion of diamond is much lower than that of the binder phase, SiC. In the present study, the specimen was of a single diamond phase; and hence there was not a thermal mismatch issue of the material during polishing. As a result, the polishing of the single phase diamond is much easier to control.

The effect of polishing speed on the material removal was studied at a given polishing load of 49 N which gives a mean contact pressure of 17.3 MPa (the contact area diameter was 1.9 mm). The polishing duration was 2 minutes. The sliding speed was varied from 20 to 35 m/s. As shown in Fig. 2, the polishing rate increases with the rise in sliding speed. At the speed of 35 m/s, the material removal rate was 10,300 µm/h (or 2.8×10^{-2} mg/s). Within the 2 minutes of the polishing, approximately 340 µm of the diamond specimen was removed.



(a) Polishing rate in weight (mg/s)

(b) Polishing rate in thickness (µm/h)

Fig. 2 Effect of sliding speed on polishing rate

It will be interesting to compare the material removal rate of the current single diamond phase with that of the PCD composites. In the case of the latter, Chen and Zhang [5] found that the highest polishing rate achievable without cracking was 630 µm/h (7.76×10^{-2} mg/s) at the polishing condition of sliding speed = 31 m/s and pressure = 2.2 MPa. In the 2 minutes of their polishing on PCD composites, the depth removed was 21 µm. Table 1 gives a more detailed material removal rate comparison of polishing PCD composites with that of the single crystalline diamond. It can be seen that when the polishing pressure increased about 8 times from 2.2 to 17.3 MPa, the removed material in thickness increased more than 16 times from 630 to 10,300 µm/h. With the PCD composites, such a high polishing pressure cannot be used, because otherwise, as outlined above, significant cracking will take place.

Table 1. Comparison of polishing rate

	Specimen diameter (mm)	Pressure (MPa)	Sliding speed (m/s)	Polishing rate in thickness (µm/h)
Single crystalline diamond	1.9	17.3	35	10,300
PCD composites	12.7	2.2	31	630

Table 2 compares the material removal rates by various polishing techniques published in the literature [1], which shows that the polishing rate attainable by the DFP is about hundreds times that of the others.

Table 2. Polishing rate and surface roughness produced by various polishing techniques

	Mechanical polishing	Thermo-chemical	Chemo-mechanical	Ion beam	Laser	EDM	DFP
Polishing rate in thickness	Few µm/h	Few µm/h	Tens µm/h	Tens µm/h	Hundreds µm/h	Hundreds µm/h	Ten thousands µm/h
Surface roughness (Ra)	20 nm	5 nm	20 nm	1 – 50 nm	5 – 70 nm	1,330 nm	50nm

The above results show that single crystal diamond could be polished very effectively by the dynamic friction technique, indicating that the technique has a great potential to industry applications, such as in shaping diamond cutting tools and jewelry pieces, or in repairing worn diamond tips (e.g., cutting tools and grinding wheel dressers) at a substantially lower production cost.

Conclusions

This paper has investigated the polishing of single crystalline diamond by the dynamic friction technique. The study concludes that by selecting a proper polishing pressure and sliding speed, a very high polishing rate with a quality surface finish can be obtained in a few minutes. This is hundreds times faster than the other polishing techniques reported in the literature.

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