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Wear performances and mechanisms of ultrahard polycrystalline diamond composite material grinded against granite

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ABSTRACT

The wear characteristics of a novel ultrahard polycrystalline diamond (UHPCD) were verified comparing with polycrystalline diamond (PCD) through a lathe used here by grinding against granite. The wear ratios of UHPCD and PCD against granite in grinding were calculated according to the sample weight loss. The hardness and the wear morphologies of UHPCD and PCD were characterized by a micro hardness tester, a confocal laser scanning microscope (CLSM) and a scanning electron microscope (SEM). Additionally, both UHPCD and PCD were used in the manufacture of the core drilling bits. The field application tests of the bits were carried out. The results showed that the wear resistances of UHPCD under different rotate speeds are about two times than that of PCD. A cambered face which was fitted to the granite column surface formed at the end face of PCD after the wear process. Differently, a convex structure with the cutting edge of CVD diamond formed at the end face of UHPCD. The hardness of the core of UHPCD (105–115 GPa) which is higher than that of PCD (53–57 GPa) led to the different wear topographies. Higher hardness with a strong support contributes to a superior wear resistance performance. The results of field application tests reveal that the lifespan of UHPCD bits (up to 132.33 m) is superior to that of PCD bits (up to 83.76 m). These findings provide a basis for further geological application of UHPCD.

1. Introduction

Superhard materials with excellent wearing resistance and high efficiency [1,2], are urgently required for the deep or ultra-deep hole drilling. The polycrystalline diamond (PCD) has been used in rock drilling bits for nearly 40 years due to its high hardness and wear resistance [3,4]. Chemical vapor deposition (CVD) diamond is one of the ideal superhard materials for its unique chemical and physical characteristics, such as high hardness and wear resistance, good thermal conductivity, low friction, thermal expansion coefficient, and so on. Although CVD diamond is much harder than ordinary PCD, its application is limited by its weak fracture toughness [5,6].

The wear mechanisms of PCD and CVD diamond in grinding have been reported in many references [7–13], as well as the comparative studies of the wear properties of these two materials [14,15]. Deng et al. [7] researched the tribological behaviors of PCD milling against Al_2O_3 ceramic ball at high temperatures. The extrusion of Co phase resulted in the surface damage at 600 °C, and the graphitization occurred when the temperature exceeded 700 °C. Uhlmann et al. [11] tested thin and thick CVD diamond coating in grinding AlSi17Cu4Mg. They found that the main wear mechanism of thin, thick CVD diamond was surface adhesion. The long-term use of CVD diamond was affected by the increasing of roughness and rounding of cutting edge during wear. Arumugam et al. [14] researched the machining properties of PCD and CVD diamond in dry machining Al–Si alloy by presenting the correlation among diamond tool morphology, machining parameters, nonferrous workpiece properties, and particulate emission. The primary wear mechanism of the PCD inserts was abrasive wear, and for CVD diamond inserts was massive delamination of the coating. During tests different kinds of chips were generated, and PCD exhibited better cutting continuity than CVD diamond. CVD diamond induced more brittle fracture in the chips due to its higher thermal conductivity. PCD and CVD diamond presented extremely different wear mechanisms due to the compositions and structures. It is supposed that a superhard material which possesses a higher hardness as well as a higher toughness would exhibit excellent antiwear properties.

A novel superhard material which was composited of PCD and CVD diamond, noted as the ultrahard polycrystalline diamond (UHPCD), was proposed by Shulzhenko et al. [16]. The UHPCD was sintered by two-anvil high-pressure and high-temperature (HP/HT) press facility with CVD diamond inside the diamond powder. This material had a good wear resistance reaching 0.6 mg/km, which was much lower than that of the PCD material produced in the same synthesis process.

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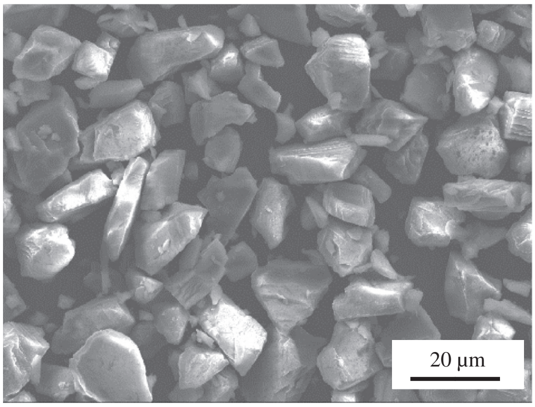

Fig. 1. SEM image of diamond powder.

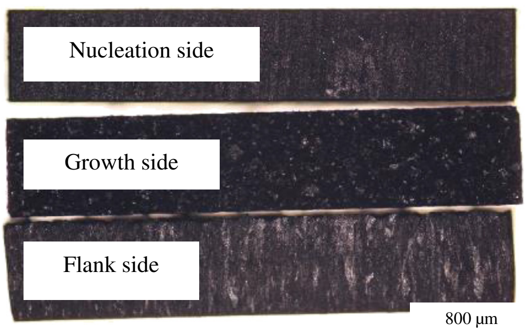

Fig. 2. Optical image of CVD diamond.

Meng et al. [17] had studied the thermal stability of UHPCD made by the two-anvil press facility. They found that the hardness of CVD diamond in UHPCD decreased from 133 ± 7 GPa to 109 ± 3 GPa after thermal treatment at 1200 °C in argon for 10 min, but it was still higher than 94 GPa the hardness of the CVD diamond. However, the wear mechanism of UHPCD in grinding against rock has not been reported.

The wear properties of UHPCD and PCD were tested by grinding granite on lathe, which corresponds to the working condition simulation of the drilling bit. The wear ratio, hardness, Raman spectra as well as the wear morphologies were applied to identify the wear characteristics and wear mechanisms. Moreover, the effects of the field application of UHPCD and PCD on the drilling bits were assessed. It aims to obtain the further understanding of the wear properties of UHPCD in geological application.

Fig. 3. Physical image of cubic press.

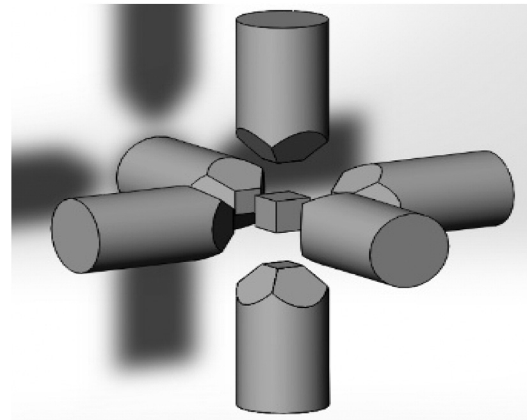

Fig. 4. Schematic diagram of cubic press.

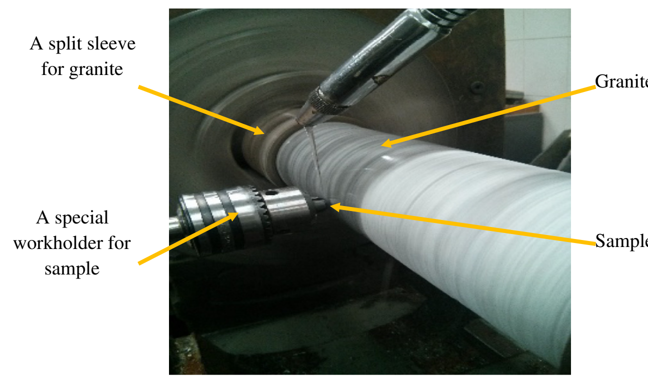

Fig. 5. Photo of the test bench.

2. Experimental details

2.1. Materials synthesis

Diamond micron powders mixed with Si micron powder and CVD diamond were used as the raw materials. The Si with purity of 99.99% was adopted here as binder. During the high-temperature and high-pressure synthesis process the Si–C bonds form between the melting Si and diamond, which ensures the bonding of diamond particles. The synthesis technology of PCD with SiC bonding phase was proposed early and has been applied commercially [18,19]. The size of diamond powder ranged from 20 to 30 μm as shown in Fig. 1. The weight proportion of Si in mixed synthetic powder was 5 wt.%. The mixed powder was

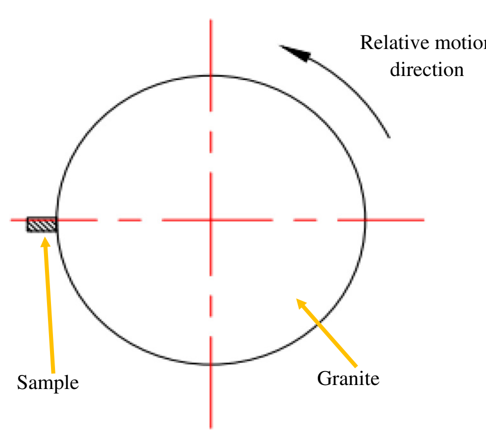

Fig. 6. Schematic of relative position between sample and granite.