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Study of Ti-coated diamond grits prepared by spark plasma coating

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ABSTRACT

A new method for coating diamond grits with metallic layers, referred to as spark plasma coating (SPC), was introduced in this paper. By controlling the Ti powders content in the mixture of diamond grits and Ti powders, the Ti-coated diamond grits were prepared in a spark plasma sintering system. The coatings were chemically bonded with diamond grits, which were constituted with the TiC and elemental Ti phases. When the mixture containing 10 wt% Ti powders was treated at 800 °C for 60 min, the compressive fracture strength and toughness index of the prepared Ti-coated diamond grits were higher than in the cases of the raw diamond grits by 15.7% and 6.4%, respectively.

1. Introduction

Due to the outstanding performances, such as high hardness and wear resistance, low surface friction coefficient, high chemical inertness and thermal conductivity, the diamond has been applied in fields of cutting, grinding, drilling, thermal management and so on [1–4]. For synthetic diamond grits, they are often embedded in a metal matrix to form a composite by means of powder metallurgy [5–7]. But the poor interfacial bonding between the diamond grits and the metal matrix is detrimental to the mechanical properties of the composites [8,9]. Coating diamond grits with carbide-forming metal layers is an effective method to improve the interfacial bonding between the diamond grits and the metal matrix in composites [10–12].

Currently, there are several methods reported for coating diamond grits with metal layers, including physical vapor deposition (PVD), chemical vapor deposition (CVD), chemical plating, electroplating and so on, but most of them entail certain some shortcomings in the case of carbide coatings [13–20]. For instance, the gases used by the PVD or CVD methods could not homogenously penetrate into the bottom of the packed diamond grits, thus leading to heterogonous coatings being formed on diamond grits [18–20]. Meanwhile, the coatings prepared by the chemical plating or electroplating are merely mechanically bonded on diamond grits rather than chemically bonded, suggesting that the carbide coatings could not be prepared by these methods [16,17,21]. Therefore, it is necessary to explore a new method to coat diamond grits with carbide-metal layers.

Spark plasma sintering (SPS), an environment-friendly and rapid sintering technology for bulk materials, has been developed in recent years for ceramic, functionally gradient materials, nano-materials and so on [22–25]. Due to the action of uniaxial pressure and pulsed direct current (DC) power, the powder sample could be sintered as a bulk at a lower temperature when compared with the conditional hot pressing [26–29]. If the diamond grits together with the carbide-forming metal powders are treated in the SPS system, the mixture may not be sintered as a bulk, while the metal powders content is reasonably controlled. Meanwhile, the diamond grits in the mixture are separated by sieving after sintering since their sizes were different from the cases of the metal powders. Moreover, the mass transfer among the particles still occurs in the mixture, such that the metallic layers may be formed on the diamond grits after being treated in the SPS system.

Based on these characteristics, a new method for coating diamond grits with Ti layers (substituted with Ti-coated diamond grits), referred to as spark plasma coating (SPC) based on the SPS system, is introduced in this work. The Ti-coated diamond grits were prepared by means of an electro-discharge treatment on a mixture of diamond grits and Ti powders in the SPS system. Besides, the formation mechanism of Ti-coated diamond grits was also studied in this instance.

2. Materials and methods

2.1. Preparation of Ti-coated diamond grits

The synthetic diamond grits with sizes of 90–106 μm and the Ti powders with mean sizes of 38 μm were used as raw materials. The flow chart for preparing Ti-coated diamond grits is shown in Fig. 1a. The diamond grits together with different Ti contents were used as mixtures

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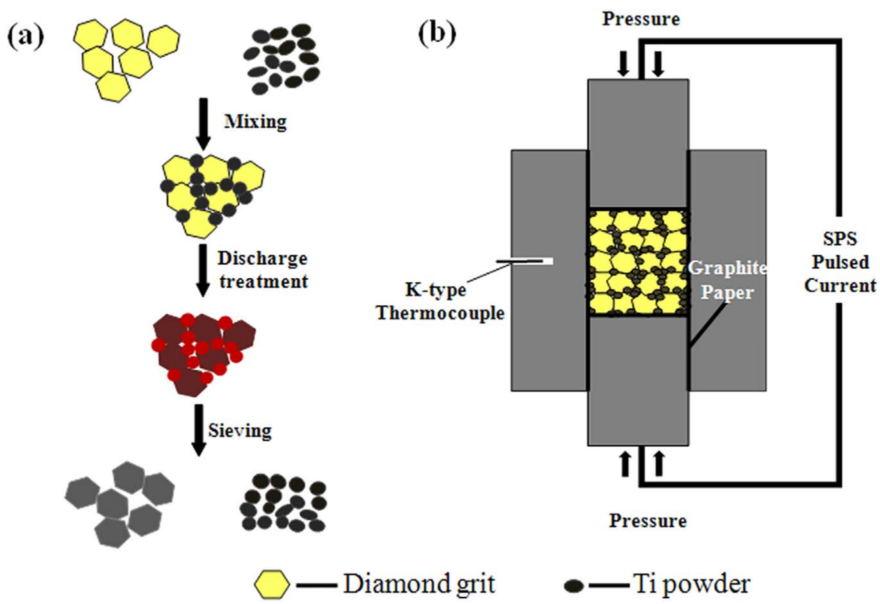

Fig. 1. (a) Flow chart for preparing Ti-coated diamond grits by SPC, (b) Sketch of the mixture of diamond grits and Ti powders under electro-discharge treatment.

Table 1
Mixtures with different Ti contents during the electro-discharge treatment.

Mixtures	Weight percent/wt%	
	Diamond	Ti
A	80	20
B	90	10
C	95	5
D	97.5	2.5

to prepare the Ti-coated diamond grits in this work, and were marked as A, B, C, and D in Table 1, respectively.

Before the electro-discharge treatment, the diamond grits and Ti powders were weighted as Table 1 first and then mixed by a No. 100 mesh US standard sieve until a homogeneous mixture was obtained. The mixture was filled into a graphite mould with an inner diameter of 30 mm, while a carbon sheet with a thickness of 0.2 mm was inserted between the mixture and the graphite die to make them segregate. Then the mould was put into the SPS system for the electro-discharge treatment with a constant heating rate of 100 °C/min under a vacuum of less than 10 Pa. The schematic for the electro-discharge treatment on the mixture in the SPS system (Model: SPS-3.20MK-IV, Sodick Co. Ltd., Japan) is shown in Fig. 1b. The temperature during the electro-discharge treatment was measured at a little hole in the lateral side of the die where the K-type thermocouple was inserted, and the mixture was treated at 700–850 °C for 30–90 min under a pressure of 30 MPa. After the electro-discharge treatment, the mould was not taken out until the temperature was dropped 100 °C. Finally, the mixture in the graphite mould was sieved in order to separate the Ti-coated diamond grits and Ti powders.

2.2. Characteristics of Ti-coated diamond grits

The compressive fracture strength (CFS) and toughness index (TI) were used to evaluate the properties of the diamond grits before and after the electro-discharge treatment [30,31]. The CFS was measured by the single grit method on a diamond compressive strength tester (JDY-1, China). The diamond grit was first placed between the two cemented carbide anvils and then loaded in compression. The value of the load was recorded when the failure of the diamond grit occurred. Forty repeated tests were performed randomly for each sample, and the value of the CFS was the average of the obtained values.

The TI was measured at room temperature through the toughness index measurement apparatus (CYCJ-04A, China). The diamond grits with a mass of 0.4 g, together with a steel ball (8 mm in diameter), were placed into a sealed steel chamber, then the steel chamber began to move to-and-from at a fixed frequency of 2000 r/min for 30s. After the impact, the sample was sieved on a No. 230 mesh US standard sieve. The weight of the diamond grits before and after the impact was determined by the electronic balance. And the TI could be expressed by Eq. (1).

$$\mathrm{TI} = (M_1/0.4) \times 100\% \tag{1}$$

In this case, M_1 was the weight of the diamond grits on the screen, while the value of TI was the average of the five tests.

The phase constitution of the Ti-coated diamond grits prepared by SPC was identified by means of X-ray diffraction (XRD) (D/Max-2500pc, Japan). And a field emission scanning electron microscope (FESEM) (S-4800, Japan) equipped with an energy-dispersive X-ray spectrometer (EDS) was used to characterize the surface morphologies of the Ti-coated diamond grits.

3. Results and discussion

3.1. Effect of the Ti content on the Ti-coated diamond grits

Fig. 2a presents a digital picture of the raw diamond grits, which were yellow in color. When the diamond grits together with the Ti powders were treated at 800 °C for 30 min in the SPS system, mixture A (Fig. 2b) was sintered as a bulk other than mixtures B, C, and D. By sieving, the black (Fig. 2c) and black-yellow (Fig. 2d) Ti-coated diamond grits were obtained after treating mixtures B and D, respectively. Meanwhile, the black Ti-coated diamond grits were also obtained after mixture C was treated in the SPS system. Therefore, the Ti content in the mixture determined whether the Ti-coated diamond grits were prepared or not, and their color turned black gradually in line with the increase in the Ti content.

Furthermore, the raw diamond grits were transparent when they were applied in the backlight (the inset in Fig. 2a), whilst the black Ti-coated diamond grits were no longer transparent, as displayed by the inset in Fig. 2c, indicating that the coatings were formed on diamond grits during the electro-discharge treatment. In addition, the weight gain of the Ti-coated diamond grits prepared with mixtures B, C, and D was 1 wt%, 0.9 wt%, and 0.3 wt%, respectively. These results suggested that the coatings were increased as growing contents of the Ti powders