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Comparison of Cu and Zn on properties of vitrified diamond composites

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ABSTRACT

The microstructures and properties of vitrified diamond composites, which are composed of diamond grains and vitrified bonds with varying Cu and Zn doping amounts, were comprehensively investigated in this work. The results including TG curves indicated that compared with Zn, Cu powders were more beneficial to prevent the oxidation of diamond. Both of them could consume oxygen and be oxidized to CuO or ZnO, which would enter into the glass network but not damage the structure. Hence, the vaporization of metals, especially Zn, would remain tiny voids and the lower refractoriness could easily lead the glass to foam. The incorporation of Cu or Zn in appropriate amounts (4 wt.%) not only decreased the refractoriness of vitrified bonds but also increased the wettability between diamond grains and vitrified bonds. The flexural strength of the diamond composites incorporating 4 wt.% Cu could reach 60.35 MPa, which increased by about 19.6% than the basic diamond composite and its growth rate was also higher than the value of composites containing 4 wt.% Zn (7.8%). In general, the addition of Cu played greater role than Zn on the protection of diamond grains and properties of vitrified diamond composites.

1. Introduction

With the rapid development of science and technology, diamond tools have been widely used in industry for cutting, grinding and polishing of various materials such as cast iron and super alloys [1–3]. The diamond tools are a combination of composite materials that are composed of diamond grits and some certain types of bonds, including resin, metal and vitrified bonds. In comparison with resin and metal diamond composites, the vitrified bond ones has inimitable advantages such as relatively higher strength to hold the abrasive grains together and relatively easier dressing operation [4–5]. Now vitrified bond is becoming a challenging area for researchers due to their unique properties [6–8].

Recently, many efforts to improve vitrified diamond composites properties have been made [9–13]. In order to make the utmost of properties of diamond abrasives, low refractoriness vitrified bonds must be developed to prevent graphitization and oxidation of diamond abrasives during the sintering process. High sintering temperatures would lead to the degradation of diamond grains and produce numerous pores in the composites which would greatly reduce the strength of the diamond tools. In addition to refractoriness, the bond composition and content of each component also have important influences on the wettability which is a key determinant of the quality of the mechanical properties [14–16]. So it is crucial to select the appropriate composition of vitrified bonds. To improve interfacial wettability and protect the diamond from oxidation, the use of reducing metals is effective [17–18]. The reducing metals (such as Ti, Zn, Cu, Al etc.), not only have low melting temperatures, but also have a good affinity with oxygen, so the addition of them can consume oxygen and even reduce the sintering temperatures. Both of these are helpful to avoid the oxidation of diamond grits. Obviously different additives have different results. However, no previous research was reported to compare the effect of different reducing metals on vitrified diamond composites. Among above reducing metals, Zn and Cu have many similar physical and chemical characteristics. So they were the best choice for comparison study and then we can eliminate the effect of many factors.

In our work, SiO_2-B_2O_3-Al_2O_3-Li_2O-Na_2O-CaO vitrified bonds, with and without Cu and Zn additives, were prepared, as well as homologous vitrified diamond composites. The diamond composites prepared were sintered at 750 °C. The aim of this work is to discuss the role of Cu and Zn on the protection of diamond grains, on the basis of which compare the effect of different metals on properties of vitrified diamond composites. The microstructures and phase composition of the prepared vitrified diamond composites were analyzed. TG curves of different vitrified composites were also measured. Additionally, the effects of Cu and Zn on wettability and mechanical properties of vitrified diamond composites were comprehensively investigated.

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2. Experimental procedures

2.1. Preparation of vitrified bonds and diamond composites

Basic glasses consisting of SiO_2, B_2O_3, Al_2O_3, Li_2O, Na_2O and CaO which are introduced in the form of SiO_2, H_3BO_3, Al_2O_3, Li_2CO_3, Na_2CO_3 and $CaCO_3$, were used to prepare the vitrified bonds. The raw materials were weighed accurately, uniformly mixed by ball milling at 300 r/min for 30 h, and then placed into corundum crucibles. The corundum crucibles were put into an electric furnace and heated at a 5 °C/min rate until the melting temperature was reached (approximately 1400 °C). The samples were held at this temperature for 2 h before pouring the melted glass into water. The dried glass was ground into powers which were sieved with a 160 mesh for three times to obtain the vitrified bonds.

Diamond grains (120–140 μm, Henan Funik Ultrahard Material Co. Ltd., China) and vitrified bonds were homogeneously mixed with the additives at various contents. In order to study the effect of Cu and Zn contents on the properties of diamond composites, 0–8 wt.% Cu and Zn (Shanghai ST-Nano Science and Technology Co., Ltd., China) contents were selected. The diamond grains, vitrified bonds and metal powders were uniformly mixed by wet milling for 10 h at a speed of 300 r/min. The mass ratio of balls, ethanol and mixed powders was 2: 2: 1. Paraffin wax was served as a temporary binder and subsequently mixed with the powders at about 80 °C. The mass ratio of diamond grains, vitrified bonds and temporary binder was 100: 20: 7. Green samples were dry-pressed at 100 MPa for 3 min into rectangular bars ($30 \times 6 \times 4$ mm^3), followed by sintering in an electric furnace in the air for 2 h [19]. After exploring the effect of temperature on the properties of composites, 750 °C was chosen as the sintering temperature.

2.2. Sample characterization

Phase composition of the vitrified diamond composites was analyzed by X-ray diffraction (XRD, D/MAX-2500, Rigaku, Japan). The refractoriness and fluidity of vitrified bonds with various additives were investigated by the Seger-Cone and plane flowing methods. Measurements of the contact angle were obtained by applying the sessile drop method with high-temperature microscopy (EM201, Hesse Instruments, Osterode, Germany) in the air and the Archimedes immersion method was used to measure the porosity of composites. Furthermore, the microstructures and interfacial bonding states of vitrified diamond composites were evaluated via scanning electron microscope (SEM, Nanosem 430, FEI, USA) at an acceleration voltage of 40 kV. The flexural strength of the composites sintered at 750 °C was examined by use of three-point bending test method with a universal testing machine (XWW, Beijing, Jinshengxing Detecting Instrument Co., Ltd., China; the results are the average of at least five measurements) at a crosshead speed of 0.5 mm/min [19]. The thermal behaviors of the diamond composites were analyzed using TG (449C, NETZSCH STA, Germany). The composites were heated at 10 °C per minute up to 1000 °C in flowing air.

3. Results and discussions

3.1. Refractoriness and fluidity of vitrified bonds

Refractoriness is an important parameter of vitrified bonds which is used to determine the sintering temperature of composites. It well known that the diamond composites could be easily oxidized and graphitized above 800 °C, so it is necessary to ensure that the vitrified bonds have low refractoriness so that the structure of diamond grains would not be damaged. Fluidity is a reflection of the viscosity, which is a key factor to realize uniform distribution of the bonds around the grains.

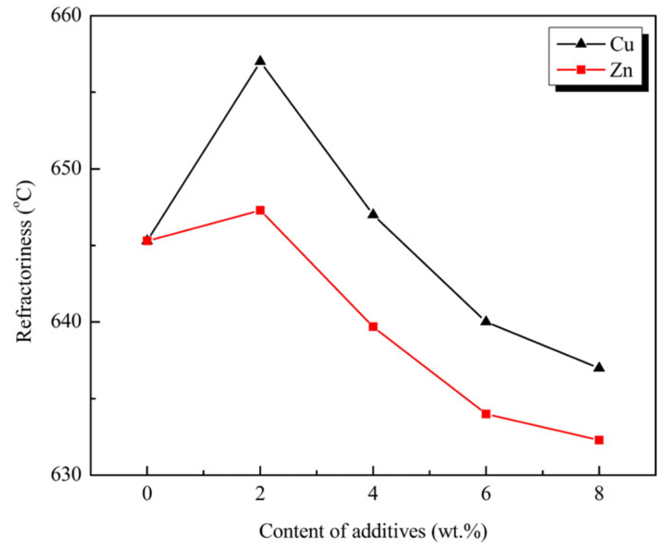

Fig. 1. Effect of Cu or Zn on the refractoriness of vitrified bonds.

The refractoriness of vitrified bonds with different amounts of Cu or Zn is given in Fig. 1. It can be seen that with the increase of Cu or Zn content, the refractoriness of vitrified bonds rises from 645 °C at first and when the amount of Cu or Zn is 2 wt.%, the refractoriness reaches a maximum of 657 °C and 647 °C respectively. Hence, when the loading of metals exceeds 2 wt.%, it declines sharply to be less than 645 °C, which is even lower than the basic vitrified bond. In comparison, the refractoriness of vitrified bonds doped with Cu is higher than those containing Zn. Fig. 2 shows the fluidity of vitrified bonds. With increasing Cu additive content, the fluidity of vitrified bonds gradually increases. However, with the increase of Zn content, the fluidity of vitrified bonds rises at first and then decreases. When the content of Zn is 2 wt.%, the fluidity of vitrified bonds can reach 268%, which is 17% higher than that of vitrified bonds without Zn. Generally speaking, vitrified bonds doped with Cu display more prominent fluidity over those adding Zn.

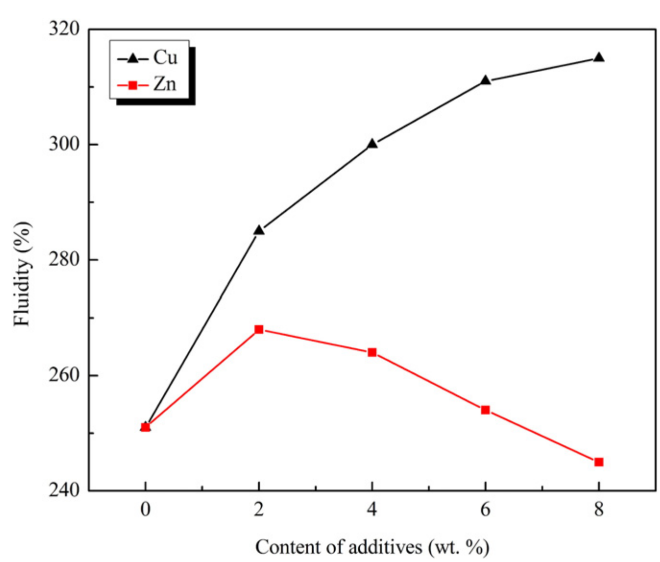

Fig. 2. Influence of Cu or Zn contents on the fluidity of vitrified bonds.