



Comparison of rare earth oxides on properties of vitrified diamond composites

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ABSTRACT

The role of rare earth oxides (CeO_2 and Y_2O_3) in the microstructures and properties of vitrified diamond composites was comprehensively investigated. The results revealed that the incorporation of appropriate amounts of CeO_2 or Y_2O_3 could not only decrease the refractoriness but also increase the fluidity of vitrified bonds. In comparison with composites containing Y_2O_3 , composites doped with CeO_2 possessed lower porosity and coefficient of thermal expansion. When adding 4 wt.% rare earth oxides, the flexural strength and thermal conductivity of composites containing CeO_2 simultaneously achieved the maximums, 102.5 MPa and $4.37 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$, respectively, which highly surpassed the values of composites without additives and composites containing Y_2O_3 . In general, the difference of CeO_2 and Y_2O_3 on properties of composites was mainly attributed to the different accumulation effects of corresponding cations. CeO_2 played greater impact than Y_2O_3 on the properties of vitrified diamond composites.

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1. Introduction

Vitrified diamond grinding tools have the common features of vitrified bonds and diamond abrasives. Compared with ordinary abrasives, diamond abrasives have more excellent abrasion resistance, better shape-keeping capability, and higher thermal conductivity [1–4]. Vitrified diamond grinding tools are mainly used in carbide, cermet, ferrite, and new engineering ceramic materials for grinding and processing [5–8]. The tools can also be used for the precision grinding of tractors crankshaft and hydraulic pumps gears neck. However, there quite high energy be incorporated in the grinding process, which results in heat gathering and high temperatures in the machining regions [9–14]. Therefore, in addition to the flexural strength, the thermal conductivity is another important parameter of vitrified diamond composites.

Since the vitrified bonds are often low-temperature inorganic materials, the introduction of a large number of alkaline substances may be volatile in smelting process of vitrified bonds, causing unstable performance of bonds prepared. In the manufacturing process of grinding tools, due to the inertness of the diamond, the wettability between vitrified bond and diamond was poor. The rare earth composites are considered as the treasury of materials for their special properties. Rare earth oxides can significantly reduce the surface tension of the glass, which make it easier for glass to wrap the diamond grains. Generally, rare earth elements can serve as network modifiers in the glasses and

enter into the interstitial site of network structure. On the other hand, there is a phenomenon of lanthanide contraction existing in lanthanides, which means that the ionic radii of lanthanide elements decrease with increasing atomic number. Thus, the cationic field strength ($CFS = Z/r^2$, Z is the valence of the corresponding element, r is ionic radius) of rare earth ions varies with different atomic number [15]. It can cause a series of variations in many properties of composites, such as refractoriness, fluidity, density, coefficient of thermal expansion (CTE) and so on [15–19]. At present, some researchers have studied the effects of rare earth oxides on the vitrified bonds [20–21]. These were very meaningful attempts. However, as far as we know, no previous research was reported to compare the effects of different rare earths oxides on vitrified diamond composites.

In our study, $\text{SiO}_2\text{—Al}_2\text{O}_3\text{—B}_2\text{O}_3\text{—Li}_2\text{O—Na}_2\text{O—CaO}$ vitrified bonds, with and without CeO_2 and Y_2O_3 additives, were prepared, as well as homologous vitrified diamond composites. The diamond composites prepared were sintered at 780 °C. The aim of this work is to focus on the distinction of different rare earths on properties of vitrified diamond composites.

2. Experimental procedures

2.1. Preparation of vitrified bonds and diamond composites

The basic vitrified bond consisted of SiO_2 , Al_2O_3 , B_2O_3 , Li_2O , Na_2O and CaO . The mass percentage was 44 wt.%, 6 wt.%, 30 wt.%, 11 wt.%, 5 wt.% and 4 wt.%, respectively. They were introduced in the form of SiO_2 ,

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Al_2O_3 , H_3BO_3 , Li_2CO_3 , Na_2CO_3 and CaCO_3 . The raw materials were weighed accurately and then uniformly mixed by ball milling for 10 h, followed by sieving with a 100 mesh. The mixture can be melted at 1400 °C for 5 h before pouring the melted glass into water. The quenched glass frits were dried at 80 °C for 48 h. The dried glass was ground into powers and sieved with a 160 mesh for three times to obtain the vitrified bonds.

The vitrified diamond composites were prepared by diamond grains (20–30 μm , Henan Funik Ultrahard Material Co. Ltd., China), vitrified bonds with rare earth oxides additives and temporary binder. The mass ratio of diamond grains, vitrified bonds and temporary binder was 100:20:7. In order to study the effects of CeO_2 and Y_2O_3 contents on the properties of diamond composites, 0–8 wt.% CeO_2 and Y_2O_3 (Shanghai Aladdin Biochemical Technology Co., Ltd., China) contents were selected. The composite samples were dry-pressed at 200 MPa for 2 min into rectangular bars with dimensions of 30 mm \times 6 mm \times 4 mm, followed by sintering in an electric furnace at 780 °C in the air for 2 h [22].

2.2. Sample characterization

The refractoriness and fluidity of vitrified bonds were analyzed by the Seger-Cone method and plane flowing method respectively. X-ray diffraction (XRD, D/MAX-2500, Rigaku, Japan) experiments were conducted to identify the phase compositions of vitrified diamond composites. 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 tungsten filament scanning electron microscopy (SEM, SU1510, Hitachi, Japan). The coefficient of thermal expansion of vitrified diamond composites was measured using a NETZSCH DIL-402C (Germany), at a heating rate of 5° per minute from room temperature to 500 °C. The EDS line scan was processed on the interface between diamond grains and vitrified bonds. Measurements of the thermal conductivity were obtained by the solid thermal conductivity equipment with hot wire methods (TC-3000, Xi'an Xiaxi Electronic Technology Co., Ltd., China). The flexural strength of the composites sintered at 780 °C was measured by use of three-point bending test method with a universal testing machine (XWW, Beijing, Jingshengxing Detecting Instrument Co., Ltd., China; the results are the average of at least five measurements) at a crosshead speed of 0.5 mm/min [21].

3. Results and discussions

3.1. Refractoriness and fluidity of vitrified bonds

Refractoriness and fluidity are important parameters of vitrified bonds, which reflect the relative merits of them to a certain degree. Refractoriness reflects the resistance of vitrified bonds to high temperatures without melting. Low refractoriness is necessary for vitrified diamond composites to sinter below 800 °C. And fluidity is the inverse phase of the viscosity of vitrified bonds. It is a key factor to realize uniform distribution of the vitrified bonds around the grains.

The average of refractoriness of vitrified bonds with different amounts of rare earth oxides are given in Fig. 1. It can be seen that the refractoriness of vitrified bonds decreases at first and then rises with the increase of additives content. When 4 wt.% CeO_2 or Y_2O_3 added to the vitrified bonds, the refractoriness drop to the lowest values, 688 °C and 690 °C, respectively. In comparison, the refractoriness of vitrified bonds doped with CeO_2 is lower than those containing Y_2O_3 . Fig. 2 shows the difference of fluidity of vitrified bonds containing CeO_2 or Y_2O_3 . With increasing rare earth oxides content, the fluidity of vitrified bonds changes in the opposite trend simultaneously with the refractoriness. And when the content of additives was 4 wt.%, the fluidity of vitrified bonds reaches the maximums of 305% and 301%. Overall, vitrified bonds doped with CeO_2 have better fluidity over those adding Y_2O_3 .

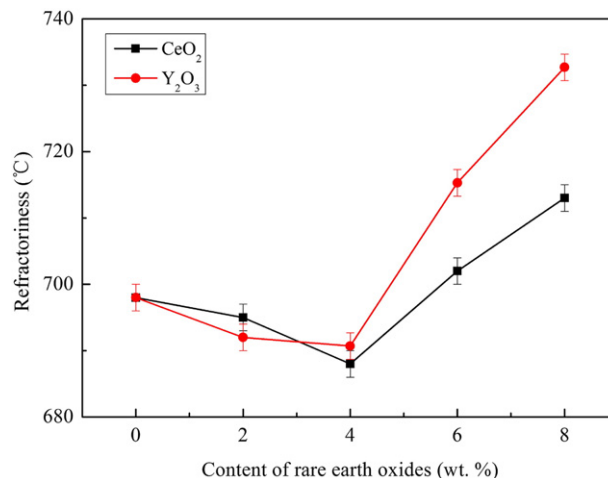


Fig. 1. Effects of rare earth oxides on the refractoriness of vitrified bonds.

CeO_2 and Y_2O_3 both belong to rare earth oxides, so they have many similar physical and chemical properties. Rare earth ions have larger radius than Si^{4+} and B^{3+} and can be served as network modifier in the glass structure. That is to say, the addition of rare earth oxides will destroy the network structure of the glass, leading to the generation of more non-bridging oxygen. Hence, the addition of CeO_2 or Y_2O_3 can make the structure of glass be more loose and lower the viscosity of glass, which is conducive to the diffusion of ions. This is the reason that the refractoriness of vitrified bonds decreases and the fluidity increases with the loading of rare earth oxides. However, when the content of rare earth oxides exceeds a certain value, on account of the higher melting points of them, the refractoriness of vitrified bonds presents an increasing trend. Besides, the accumulation effects of cerium and yttrium ions prompted them to absorb the non-bridging oxygen to form high coordination structure into the glass network. So the glass network structure can be densified, resulting in the decreasing of vitrified bonds fluidity. In fact, the sintering temperatures have a significant impact on the viscosity. The lower the melting temperature of vitrified bond, the greater the viscosity decreases under the sintering temperature. Thus, refractoriness and fluidity always show opposite trends.

3.2. Microstructures and porosity of diamond composites

Fig. 3 shows the microstructures of the fracture surface of composites doped with CeO_2 or Y_2O_3 , respectively. As shown in the picture,

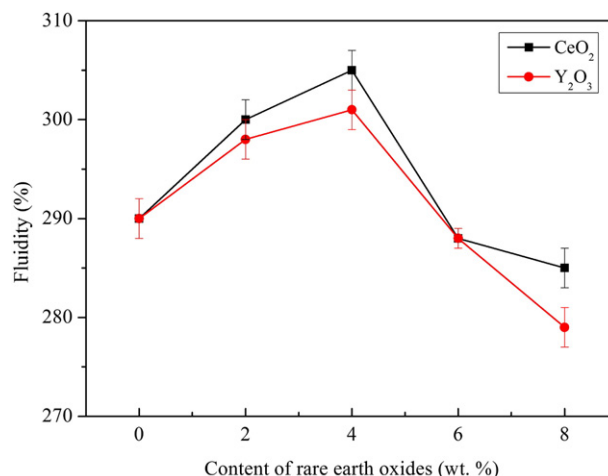


Fig. 2. Influence of rare earth oxides contents on the fluidity of vitrified bonds.

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