

Influence of Al₂O₃ on the structure and the physical properties of low-temperature ceramic vitrified bond

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ABSTRACT

The SiO₂-B₂O₃-Al₂O₃-CaO vitrified bonds with low sintering temperatures and high strength are widely used in the manufacture of diamond abrasive tools. The effects of Al₂O₃ on the microstructure, crystallization, phase-separated and mechanical properties were comprehensively investigated by DSC, FTIR, XRD, SEM and EDS in this paper. The results showed that the addition of Al₂O₃ promoted the accumulation and enhanced the binding of structure, inhibited crystallization and phase-separated. Performance analysis showed that the thermal expansion coefficients decreased with increasing Al₂O₃ content, the minimum value was $6.8074 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}$. When the content of Al₂O₃ was 5 wt%, the vitrified bond had the best mechanical properties, the maximum bending strength reached 113 MPa and effectively improved the wettability between vitrified bond and diamond grains.

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1. Introduction

Vitrified bond diamond abrasive tools are essentially high-performance super hard composite materials for its outstanding properties, such as excellent grinding ability, high grinding accuracy, high durability, long operating life and easy reforming and dressing, etc. [1–5]. Therefore, the study and development of the vitrified bond diamond wheels is prevailing in the world. The properties of the vitrified bond directly affect the excellent properties of the diamond abrasive tools, and its performance directly influences the structure and properties of diamond abrasive tools. Therefore, it is necessary to develop a reasonable composition of vitrified bond to satisfy the demands of the high speed automatic precision grinding. Great efforts have been made in recent years to obtain the vitrified bonds of low sintering temperature, high strength and appropriate thermal expansion coefficients by scientists [6–8]. Shan [9] reported that the incorporation of TiO₂ in appropriate amount (4 wt%) was beneficial to the improvement on flowing ability, thermal expansion property and mechanical properties of the vitrified bond systems. Liu [10] suggested the addition of ZrO₂ increased the bending strength of vitrified bond, and decreased the expansion coefficient and the wetting angle with the diamond. He [11] reported the influence of boron and silicon ratio on the structure evolution and properties of SiO₂-

B₂O₃-CaO vitrified bonds. Although several efforts have been made to improve some properties of vitrified bonds such as calcium oxide, zinc oxide, bismuth oxide, iron, metal powders, alkaline earth metal oxides, etc. [12–17], there have been few studies on methods to decrease the sintering temperature as well as the thermal expansion coefficients.

According to the network theory of glass structures [18], Al₂O₃ is a network formation in the glass structure, which can decrease the thermal expansion coefficients and enhance the strength of vitrified bond appropriately. Moreover, Al₂O₃ has an important influence on phase-separated and crystallization of the vitrified bonds. So it is significant to study the effect of Al₂O₃ on the structures and properties of vitrified bond which has some reference value for developing high performance diamond grinding wheel.

2. Materials and methods

2.1. Preparation of vitrified bond

Table 1 showed the chemical compositions of vitrified bond in this experiment. The basic vitrified bond was prepared by traditional method, accurate weighing, mixing and melting in 300 ml alumina crucible at 1500 °C for 2 h. The molten was rapidly quenched in water and then dried in dry box. The dried sample was grinded for 8 h using a grinding machine (XM-4) at a speed of

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Table 1
Chemical compositions of different vitrified bonds (wt%).

Sample number	SiO ₂	B ₂ O ₃	CaO	Na ₂ O	ZnO	Al ₂ O ₃	Others
1#	60.00	10.00	10.00	5.00	4.00	5.00	6.00
2#	60.00	10.00	10.00	5.00	4.00	10.00	6.00
3#	60.00	10.00	10.00	5.00	4.00	15.00	6.00
4#	60.00	10.00	10.00	5.00	4.00	20.00	6.00

45 r/min and sieved (240#) to obtain the vitrified bond powder. The vitrified bond with 5 wt% Al₂O₃, 10 wt% Al₂O₃, 15 wt% Al₂O₃ and 20 wt% Al₂O₃ were marked as 1#, 2#, 3# and 4#, respectively. The vitrified bonds were dry-pressed into the form of rectangular bars (40 mm × 6 mm × 5 mm) under 40kN of pressure. The compacted specimens were sintered in an electric furnace in air at different sintering temperatures and then cooled to room temperature naturally.

2.2. Measurement methods

X-ray diffraction was utilized to determine the phase structure of the vitrified bond and the vitrified bond sinters. X-ray diffraction spectra was acquired using an X-ray diffraction system (XRD, D/Max-2500 pc diffractometer, Japan) with Cu K α radiation source. The samples were scanned over a 2 θ range of 10–80° at a rate of 2°/min.

Thermo-gravimetric analysis was measured by differential scanning calorimetry (DSC, STA 449 F1, Netzsch, Germany), operating at a heating rate of 10 °C/min from room temperature to 700 °C in air.

Infrared spectra of the powdered glass samples was carried out at room temperature over the wave number range of 400 cm⁻¹–1600 cm⁻¹ using a Fourier transform infrared spectrometer (Nicolet Nexus FT-IR, Thermo, USA).

The bending strength of samples was tested using a ceramics test system (MTS810, MTS Co, U.S.A.) by a three-point test method at a crosshead speed of 0.5 mm/min, a fulcrum span of 30 mm, a loading speed of 9.8 ± 0.1 N/S, the specimen were rectangular bars (40 mm × 6 mm × 5 mm) prepared as described above, which were sintered before cooled.

The coefficient of thermal expansion (TEC) of vitrified bonds was measured using a thermal dilatometer (DIL-402C, NETZSCH Germany), at a heating rate of 5 °C/min from room temperature to 700 °C.

Scanning Electron Microscopy (SEM, ULTRA Plus-43-13, Zeiss, Germany) equipped with an Energy dispersive spectrometer (EDS, X-Max 50, Oxford) was used to observe the interface of the vitrified bond and diamond abrasive of the vitrified diamond composites. The vitrified diamond composites were prepared by the following methods: combining diamond abrasives, the prepared vitrified bonds and temporary binders (dextrin), then the mixture were dry-pressed into rectangular bars with dimensions of 40 mm × 6 mm × 5 mm. Before the compacted specimens were sintered in air using the electric furnace with a predetermined firing schedule, the last step was cooling the composites to room temperature in air.

3. Results and discussions

3.1. Effect of Al₂O₃ on vitrified bond structure

3.1.1. Thermal analysis of vitrified bond

Fig. 1 showed the DSC curves of vitrified bonds with different Al₂O₃ content. The exothermic peak between 450 °C and 550 °C

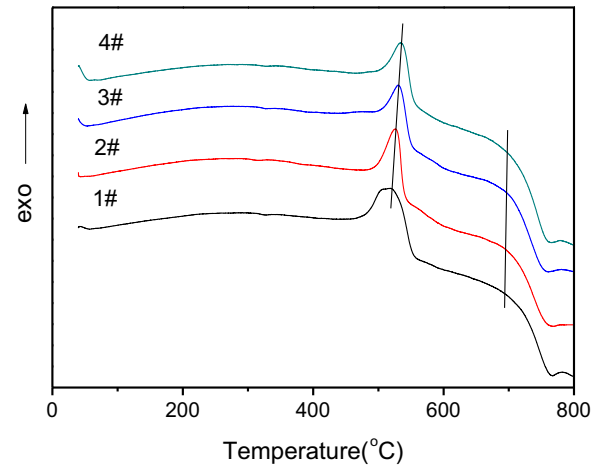


Fig. 1. DSC curves of vitrified bonds with different Al₂O₃ content.

was associated with the crystallization process in glass. It was observed from Fig. 1 that the exothermic peak position of the curves moved to higher temperature with increasing Al₂O₃ content, which indicated that the crystallization needed higher temperature to provide energy. Moreover, the crystallization peak area also decreased, which indicated that the crystallization quantity was gradually reduced. In short, the addition of Al₂O₃ inhibited crystallization of the vitrified bond.

3.1.2. Structure of vitrified bond analyzed by FTIR and XRD

There are ordinarily many kinds of structural units in the base vitrified bond structure. The molecular structures and structural unit of the materials can be analyzed by FTIR. The peak wave numbers and their assignments for borosilicate glass were listed in Table 2 [19–21]. Fig. 2 showed the room temperature FTIR absorption spectra of SiO₂-B₂O₃-Al₂O₃-CaO vitrified bond. The peak near 1415 cm⁻¹ arose due to the antisymmetric stretching vibration of [BO₃]. When the content of Al₂O₃ exceeded 15%, this peak shifted towards higher wave number with increasing amounts of Al₂O₃ revealed that. To a certain degree, the [BO₃] existed in a triangular configuration, the [BO₄] in the glass was directly connected with [BO₄], [BO₄] gradually decreased and [BO₃] increased with increasing Al₂O₃. Furthermore, the B–O bond strength in the [BO₃] was higher than that of the [BO₄], which was thought to make the absorption near the 1415 cm⁻¹ shifting towards high wave numbers. The absorption bands close to 1200 cm⁻¹ in borate glass represented the [BO₃] bonding with the neighboring groups, and this band's vibrational frequency was affected by the type of coupling atom. The 1154 cm⁻¹ peak was the antisymmetric stretching vibration of Si–O–Si between the [SiO₄] units. The peaks near 1030 cm⁻¹ represented the overlapping bands of the antisymmetric stretching vibration of [BO₄] and the antisymmetric

Table 2
Assignment of FTIR absorbance spectra of borosilicate glass.

Wave number (cm ⁻¹)	Assignment
460	Bending vibration of Si–O–Si between the [SiO ₄] unit
700	Bending vibration of [BO ₃] unit
770	stretching vibration of O–Si–O
1020	Antisymmetric stretching vibrations of Si–O–Si within [SiO ₄] tetrahedron and B–O in [BO ₄] tetrahedron
1154	Antisymmetric stretching vibration of Si–O–Si between the [SiO ₄] unit
1200	Bonding interaction of [BO ₃] triangle with neighboring groups
1400	Antisymmetric stretching vibration of [BO ₃] unit

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