



Effect of mullite particles on the mechanical strength and chemical durability of vitrified CBN composites



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ABSTRACT

The effects of mullite particles on the mechanical strength and chemical durability of vitrified CBN composites were investigated. Incorporating mullite particles to vitrified CBN composites contributes to an obvious improvement of the mechanical strength and the chemical durability of vitrified bond. The enhancement of the mechanical strength may be ascribed to the observed mechanisms including crack deflection and crack pinning. The improvement of chemical durability may be ascribed to the resistance of mullite particles to the dissolution of binders.

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1. Introduction

Vitrified bond CBN composite is applied as an important grinding tool for difficult-to-machine materials, which displays many outstanding properties including relatively high bonding strength, high elastic modulus, low fracture toughness, controlled porosity and good self-dressing capability [1,2]. To avoid oxidation of cubic boron carbide (CBN) abrasive grains and maximize the super-abrasive grinding capacity, vitrified CBN grinding tools are developing towards low-temperature sintering and high-strength [3]. Many research groups investigated the effect of alkali metal salts and alkaline-earth metal salts on vitrified bond grinding tools [4,5], and results showed that alkali metal salts and alkaline-earth metal salts can dramatically decrease the sintering temperature of vitrified bond superhard abrasive grinding tools. However, the decrease of the sintering temperature was accompanied by a decrease in strength, so optimizing the mechanical properties of vitrified grinding tools is a longstanding pursuit. In addition, the chemical durability of vitrified grinding tools is also one of the factors that need to be considered [6]. The solution of various ions in vitrified bond will seriously weaken the strength of vitrified grinding tools when the aqueous coolant is used in the process of grinding.

In the present study, an alternative design for vitrified CBN composites is proposed, where mullite particles are added into

the basic vitrified bond in the manufacturing process of vitrified CBN composites. In previous studies, few works had been done on mullite particles reinforced vitrified CBN composites [7]. Accordingly, the primary aim of this paper is to investigate the influence of mullite particles on the mechanical properties and chemical durability of vitrified CBN composites, and then reveal the strengthening mechanisms of mullite particles reinforced vitrified CBN composites.

2. Experimental procedure

Basic vitrified bond with composition $58.7\text{SiO}_2-4.0\text{Al}_2\text{O}_3-18.6\text{B}_2\text{O}_3-7.0\text{Na}_2\text{O}-10.0\text{Li}_2\text{O}-1.7\text{SnO}_2$ (mol%) glass was fired to pre-fritted glass, crushed, and seized to produce a fine, powder fritted glass. A part of the basic vitrified bond was then mixed with 3 wt.%, 5 wt.%, 7 wt.% and 9 wt.% mullite particles ($d \sim 1.0 \mu\text{m}$, 99%). Green samples composed of CBN grains and vitrified bond were dry-pressed into bars with dimensions of $30 \times 6 \times 4$ and sintered in electric furnace in air with 120 min holding at 780 °C. A part of as-sintered specimens were soaked in distilled water at 100 °C for 100 h.

Differential scanning calorimetry (DSC) was used to investigate the thermal behavior of pre-fritted glass with or without mullite particles. X-ray powder diffraction (XRD, Rigaku Geigerflex D/Mac, C Series, Cu K α radiation Japan) experiments were performed to identify the phase compositions in vitrified bonds after sintering at 780 °C. The bending strength of samples with and without soaking was measured by a three-point bending method

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with a span length of 20 mm and a cross-head speed of 0.5 mm min^{-1} in a universal tester. Furthermore, the microstructures of samples were observed by a field emission scanning electron microscopy (FESEM, TDCLS-48000).

3. Results and discussion

Fig. 1 shows the DSC curves of vitrified bond without and with 9 wt.% mullite particles. A broad exothermic peak can be observed at about 318°C and 346°C , respectively. The phenomenon may be explained as follows: The components of glass cannot completely decompose and react to form fully homogeneous phase due to the short reactive time in pre-fritted process, thus the undecomposed components of glass will continue to decompose and react in a second sintering, and as a general rule, the decomposed reactive will be accompanied by the exothermal process. There is an endothermic effect corresponding to the beginning melted point of vitrified bond in each DSC curve, and the peak temperature rises from 656°C to 661°C with the addition of 9 wt.% mullite particles. Therefore, it is indicated that the introduction of mullite particles do not dramatically raise the melting temperature of vitrified bond at least to the extent that it could be measured, thus the impact of the sintering temperature on the performance of as-sintered vitrified CBN composite can be neglected.

The XRD patterns of as-sintered binders without and with 9 wt.% mullite particles are shown in Fig. 2. It is clearly seen that the binder without mullite particles exhibits amorphous state, which is confirmed by the broad scattering spectrum in the XRD pattern; while the diffraction peaks of mullite phase are observed on the binder incorporating 9 wt.% mullite particles. The results indicate that after sintering at 780°C , mullite is still existed in binder, which is related to its excellent thermal and chemistry stability [8,9]. The existence of mullite can change the amorphous structure of monolithic binder and increase the inter-granular boundaries which will be more resistant to the brittle fracture of the monolithic vitrified bond.

The bending strength of vitrified CBN composites sintered at 780°C is listed in Table 1. The bending strength of vitrified CBN composites without mullite particles exhibited only 52.34 MPa, while the bending strengths of vitrified abrasive composites containing different contents of mullite particles are all above 65 MPa. Particularly, the bending strength of composites with 9 wt.% mullite particles reaches value as high as 70.21 MPa, which is enhanced by 34% compared with that without mullite particles. The improvement of the bending strength in composites containing mullite particles is associated with the resistance of mullite particles to brittle fracture of vitrified CBN composites [10–12].

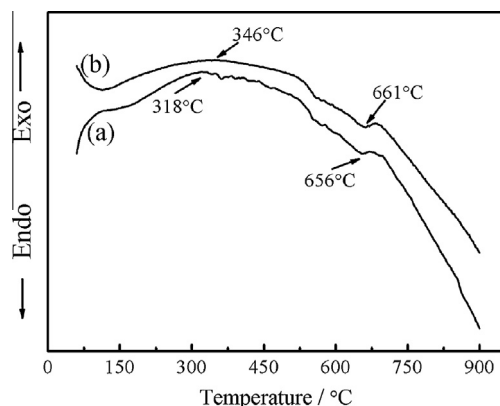


Fig. 1. DSC curves of as-prepared vitrified bond: (a) without mullite particles and (b) with 9% mullite particles.

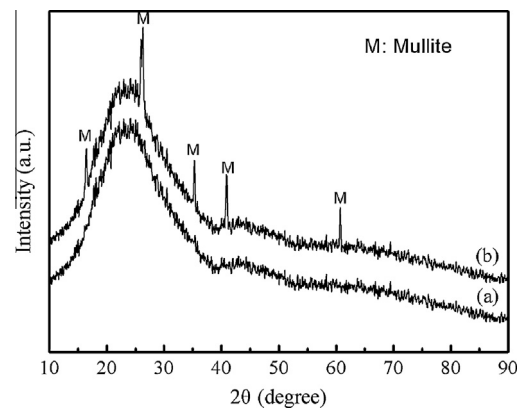


Fig. 2. XRD patterns of specimens of vitrified bond after sintering: (a) without mullite particles and (b) with 9 wt.% mullite particles.

As we all know, vitrified bonds are not easy to make cracks bifurcate due to their amorphous structure, and once the main crack forms, the crack spreads rapidly and fractures immediately [13–15]. As a general rule, the brittle fracture surfaces appear very flat as shown in Fig. 3a. However, compared with Fig. 3a, crack deflection and crack pinning can be observed in Fig. 3b, when mullite particles are introduced into binders. Crack deflection and pinning dissipate the propagation energy of the main crack, and effectively resist the brittle fracture of the monolithic vitrified bond [16].

Chemistry durability of vitrified bond is a determining factor influencing the mechanical strength of vitrified CBN composites when aqueous solution is used in the grinding process. Table 1 also lists the bending strength of different vitrified CBN composites after water-soaking. Compared with the bending strength before water-soaking, vitrified CBN composites exhibit different levels of strength degradation after water-soaking. The bending strength of composites without mullite particles decreases from 52.34 MPa to 28.21 MPa, which falls by about 46%. However, the strength degradation for the composites containing mullite particles is all beneath 35%, especially the strength of composites with 9 wt.% mullite particles only falls by 27.28% after water-soaking. On the other hand, just taking account of the bending strengths after water-soaking, it is found that the strength of composites containing 9 wt.% mullite particles reaches value as high as 51.06 MPa, which is enhanced by 81% compared with that of composites without mullite particles. Therefore, it is concluded that the introduction of mullite particles can sharply improve the mechanical strength of composites after water-soaking, which may be attributed to the improvement of the chemical durability of composites.

Fig. 4 shows the microstructure of vitrified CBN composites without and with mullite particles after water-soaking. The bond surfaces of composites without mullite particles exhibit a porous structure and lots of cracks as shown in Fig. 4a, while the bond surfaces with mullite particles are relatively dense as shown in Fig. 4b–e. The formation of the porous structure and cracks is ascribed to ion exchange and network hydrolysis reaction which are the predominant mechanisms of glass dissolution [17]. Ion exchange reaction involves a hydronium ion from a water molecule exchanging with the alkali metal such as Na^+ , Li^+ in the glass matrix [18,19]. Through an ion-exchange process, the rest of silicon, aluminum and boron occupy large proportions and form the porous skeleton on the bond surface [17,20]. Network hydrolysis reaction releases silicon, aluminum and boron to break down the glass network, which leads to the formation of cracks in the porous skeleton. It is inferred the formation of the porous structure and cracks in vitrified bond are the main reasons for the sharp strength degradation after water-soaking. The numerous pores and cracks in the

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