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Study the microstructure and mechanical properties of vitrified bond Ti-coated CBN composites for grinding process

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Abstract:
This work studies the microstructures and mechanical property of the vitrified bond Ti coated CBN composites under various sintering conditions. Experimental process of bending at three points of the sintered vitrified bond Ti-coated CBN composite, in addition to components: the microstructure, phase composition, energy spectrum was analyzed by means of SEM and X-ray diffraction. Experimental results show that the mechanical properties of vitrified bond Ti-coated CBN composites have changed better as temperatures rise, and then show a downward trend. It has been found that the titanium grade provides protection and wear protection to CBN. During sintering, as temperatures rise, titanium in the titanium coating exists not only on the surface of abrasive CBN but also diffused into a glass phase. And there are stronger oxidation reactions with higher sintering temperatures. Therefore, the sintering temperature of vitrified bond Ti-coated CBN composites materials should not be too high. It is better to sinter vitrified bond Ti-coated CBN in the vacuum than in air. The Ti-coated CBN particles are not suitable for vitrified bonding with low refraction.

***Key Word**: CBN grains; Vitrified bond; Bending strength; Ti-coated; Microstructure*

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I. Introduction

Vitrified bond CBN composites have a wide range of applications in the field of grinding because of its excellent mechanical, thermal properties, chemical stability and ease of dressing [1-4]. Although vitrified bond CBN composites have good grinding performances, alkali metals and alkaline-earth metals in the vitrified bond react with the CBN abrasives during sintering. The reaction erodes the CBN abrasives surface and affects the abrasives performances [5]. Therefore, it is necessary to use surface-treated CBN abrasives in vitrified bond composites. Xu et al. [6] studied the microstructure of the sintered body of Ti-coated CBN abrasives and vitrified bond, and found that the TiB appeared on both sides of the Ti-coated layer. Li et al. [7] observed the microstructure of the CBN abrasives before and after titanium coating, and analyzed the effect of the Ti-coated layer on the strength of the ultra-high-speed grinding wheel. Guo et al. [8] prepared a variety of coated CBN with vitrified bond by hot-pressed sintering, and measured the flexural strength. Ding et al. [9] investigated the reaction mechanism and morphology of the solid interface between CBN grains and Ti-coated layer. Wang et al [10] coated the CBN abrasive grains uniformly through vacuum slow vapor deposition and observed the interfacial structure of the Ti-coated grains at different temperatures.

With the application of coated CBN, the related preparation and performance testing of coated CBN abrasive grains have been paid attention to. However, the study of vitrified bond Ti-coated CBN composites can be supplemented. In this work, the vitrified bond CBN composites were prepared with different proportions of SiO2; Al2O3; B2O3; Na2O; Li2O; TiO2 as the basic vitrified bond. The effects of Ti-coated CBN abrasives at different sintering temperatures on the mechanical property of CBN composites were studied. The microstructures of the Ti-coated CBN composites were also observed. In addition, vitrified bond Ti-coated CBN composites were vacuum sintered and analyzed by XRD diffraction.

II. Experimental procedures

1. Composites preparation

The basic vitrified bond is composed of SiO_2; Al_2O_3; B_2O_3; Na_2O; Li_2O; TiO_2, the form of introduced raw materials are shown in Table 1.

Table 1 Chemical composition of vitrified bond [%, mass fraction]

Samples	SiO_2	Al_2O_3	B_2O_3	Na_2O	Li_2O	TiO_2
1#	55-60	9-10	14-16	7.3-8	5.5-6	0
2#	55-60	9-10	14-16	7.3-8	5.5-6	2

3#	55-60	9-10	14-16	7.3-8	5.5-6	4
4#	55-60	9-10	14-16	7.3-8	5.5-6	6

First, the basic vitrified bond raw materials were weighed, mixed and ball milled for 12 hours. Second, the mixtures were dried for 6-8 hours and screened (200#) and then the basic vitrified bond powders were prepared. The screened powders were mixed with CBN grains in a 1:1 ratio. Finally, the powders were pressed into rectangular bars (37×5×6 mm) at 60 MPa, and these were vitrified bond CBN composite samples. The samples were heated at 100℃ for 0.5h and finally sintered at the temperature which was 70-100℃ higher than refractoriness for 1.5h. The heating rate for the sintering was maintained at 3-5℃/min. After sintering, the samples were cooled to room temperature in the furnace.

2. Sample characterization

The bending strength of specimens was measured by three-point bending tester at a speed of 0.05 mm/min with the span of 20 mm, and the average value was obtained from five samples. The microstructures were observed by scanning electron microscope. Diffraction analysis was performed by X-ray polycrystal diffractometer.

III. Results and discussions

1. Bending strength

Ti-coated CBN grains were mixed with different groups of powders which obtained according to the vitrified bond formula 2#; 3#; 4#. After a series of steps as described in section 2.1, Ti-coated CBN composites were prepared and marked as ABC respectively. Ordinary CBN grains were mixed with 3# powder and pressed. These ordinary CBN composites were marked as D. Four groups samples, ABCD, were sintered at 660℃-720℃. Fig.1 shows the bending strength curve of vitrified bond composites with different sintering temperatures. With rising temperature, the bending strength curves of four composites all show a tendency to increase first and then decrease as seen in Fig.1. At the sintering temperature of 700 ℃, samples BCD showed the best bending strength, the bending strength was 43, 38, and 26 MPa respectively.

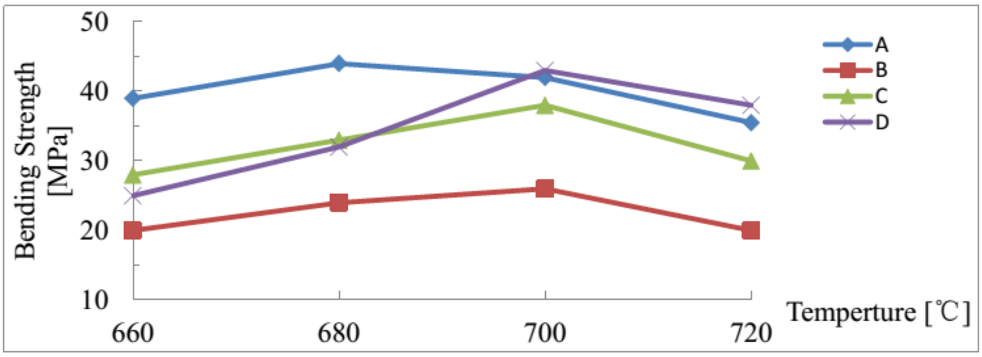

Fig.1 Bending strength curve of vitrified bond CBN composites with different sintering temperature

The highest bending strength of sample A was 44 MPa when the sintering temperature was 680 ℃. At the lowest sintering temperature, 660℃, the bending strength of BCD was the minimum value. When the temperature is low, the vitrified bond is not melted completely and its fluidity is small. The vitrified bond cannot be filled evenly between abrasive grains [11]. The vitrified bond bridge is not fully formed, so wrapping extent and holding force of the vitrified bond to grains are not enough. As a result, the bending strength of the composites at low temperature is relatively poor. As the temperature increases, the vitrified bond melts gradually and the fluidity enhances. Molten bond fills uniformly around the abrasive grains and narrows the pores, so that the structure of CBN composites is more compact. Accordingly, the bending strength of CBN composites is improved. However, as the temperature continues to rise, the production of liquid phase increases and results in excessive liquidity. There are some volatiles in vitrified bond [12], which are easy to form bubbles to remain in the bond after cooling. Distortion and foaming are induced [13], large pores are also generated. These lead to expansion of the samples that severely reduces the bending strength. In addition, when the temperature is high, the activation energy increases at that time. The ability of alkali metal ions to move freely in vitrified bond improves greatly, increasing the contact area with CBN abrasives. CBN abrasives are be corroded and eventually influence the bending strength of the samples.

The relevant experiences show that the combination between uncoated CBN abrasives and vitrified bond is purely mechanical [14]. The combination between Ti-coated CBN abrasives and vitrified bond is not only single mechanical, and there is also adhesion of chemical bond [15]. If under the same conditions, the mechanical property of Ti-coated CBN composites should be better than ordinary CBN composites. In this experiment, Ti-coated CBN composites and ordinary CBN composites were the same formula and the same sintering conditions. However, the experimental result showed that the mechanical property of the Ti-coated CBN composites were slightly worse than that of the ordinary CBN composites. This was mainly due to the limitation of the vitrified bond components. The basic vitrified bond had a low refractoriness, but the titanium layer and the vitrified bond could not achieve chemical combination in the low-temperature sintering state. The advantages of the coating cannot be fully exploited, so Ti-coated grains are not suitable for vitrified bond with low refractoriness.

2. Topography analysis of cross section

As shown in Fig. 2, the vitrified bond composites from group B and D after sintering were selected for analysis of the cross-sectional structure. Fig.2 (a) and Fig.2 (b) represent the cross-sectional structure of the Ti-coated CBN composite and the ordinary CBN composite respectively which sintered at 720℃. The pores in Fig.2a are slightly larger than those in Fig.2b, and the combination of vitrified bond and CBN abrasives is poor in Fig.2a. The CBN grains in Fig.2a and Fig.2b are marked respectively. There is more obvious edge angle and smoother surface of the Ti-coated CBN grains than that of the ordinary CBN grains. The ordinary CBN grains were damaged more than the Ti-coated CBN grains. Titanium layer has a protective effect on CBN grains, making CBN grains are not damaged at a high temperature. And titanium layer helps keep abrasive cutting edge to make grinding performance better.

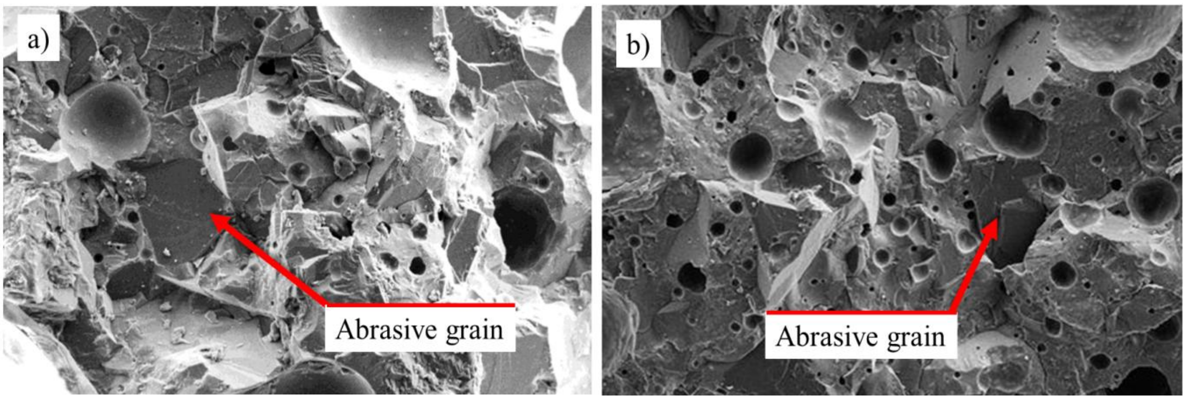

Fig. 2 Microstructure of vitrified bond CBN composites

3. Surface scanning analysis

Fig.3 shows the surface scanning analysis of the sintered 2# vitrified bond Ti-coated CBN composites at 700℃ and 720℃ sintering temperature. As shown in Fig.3a, b, c and d represent the surface scanning results of titanium and nitrogen of the cross sections of the composites at 700°C and 720°C, respectively. Fig.3 shows that the surface of abrasive grains had a large amount of nitrogen. Titanium is enriched around the abrasive grains, but the content is less than nitrogen. It is found that the areas where nitrogen is enriched in the Fig.3b and Fig.3d are the locations of the CBN abrasive grains. In contrast, the distribution of titanium in Fig.3c is more uniform than that of Fig.3a, but the degree of enrichment of titanium around abrasive grains is reduced. As the temperature increases, titanium in the titanium layer not only exists on the CBN abrasive surface but also spreads to the glass phase.

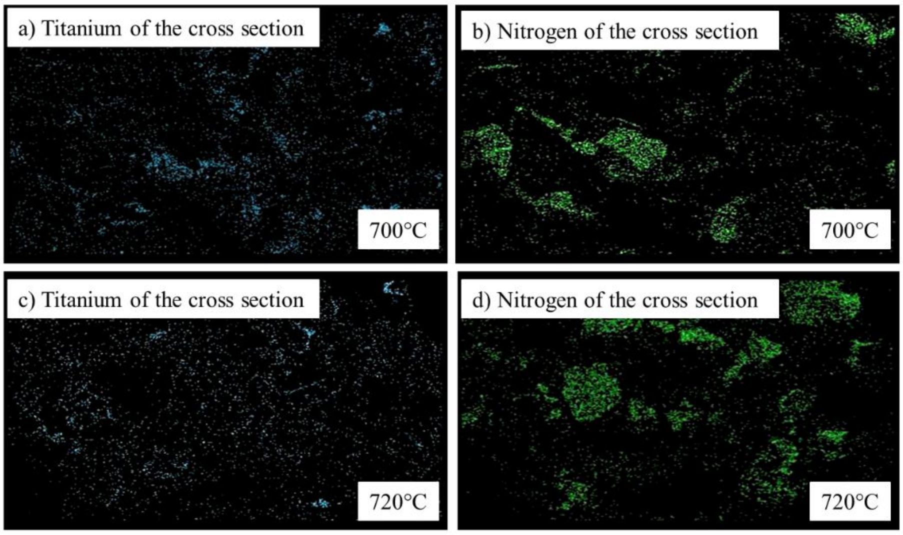

Fig. 3 Surface scanning analysis of the composite at 700°C and 720°C

4. Energy spectrum analysis

The content of the elements on CBN grains surface is shown in Fig. 4. Fig.4a, b and c respectively represent the results of energy spectrum analysis of 2# vitrified bond Ti-coated CBN composites which were unsintered, sintered at 700℃ and sintered at 720℃. Before sintering, the titanium content on surface of Ti-coated CBN grains is very high as seen in Fig.4a. After sintering, the content of titanium reduces significantly as seen in Fig.4b. It is shown that titanium in the titanium layer left the surface of the abrasive grains to diffuse into the glass phase. And the content of titanium in Fig.4c is lower than that in Fig.4b. As the temperature rises, the diffusion amount of titanium increases. In addition, the content of oxygen on the surface of the abrasive grains after sintering is increased. This shows that the titanium on the surface of the abrasive grains is oxidized. And the reaction is more intense as the temperature increases.

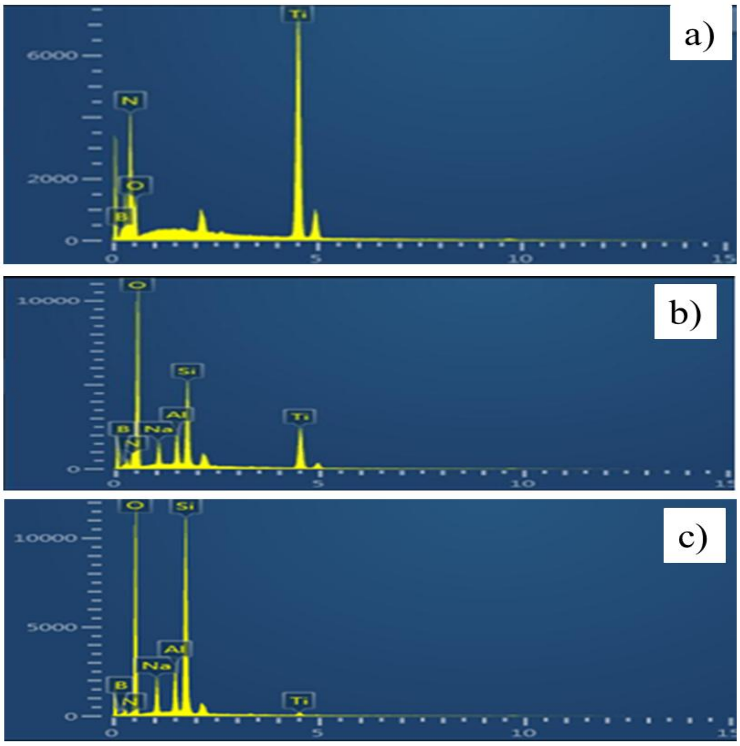

Fig. 4 Energy spectrum of the composites

5. Vacuum sintering

By the above analysis, titanium in the titanium layer is easy oxidized when the vitrified bond Ti-coated CBN composites are sintered in air, influencing the bending strength of the composites. The vitrified bond Ti-coated CBN samples from group A and group B were selected for vacuum sintering. The sintering temperature was 700℃ and held 1.5h. As shown in Fig.5, the upper and lower samples are vacuum sintered and air sintered samples. The sample is angular which was sintered in vacuum environment. The sample in the air environment is obviously expanded and pores are large.

Fig. 5 Morphology of two samples after vacuum sintering and air sintering

Table 2 shows the bending strength of two groups of samples after vacuum sintering and air sintering. Compared with the air sintering, the bending strength of the vacuum- sintered vitrified bond Ti-coated CBN composites is greatly improved. According to the comparison of the morphology and bending strength, the Ti-coated CBN composites are more suitable for vacuum sintering.

Table 2 Bending strength of samples after vacuum sintering and air sintering [MPa]

Samples	Vacuum sintering	Air sintering
Group A	40	25
Group B	52	38

6. Phase analysis

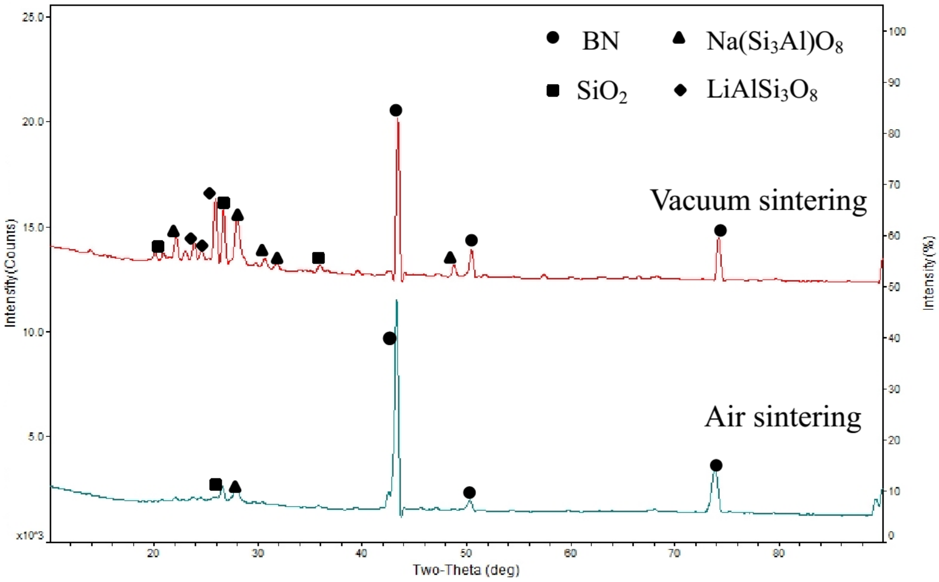

Fig.6 XRD analysis of two kinds of sintering

The XRD patterns of the vitrified bond Ti-coated CBN composites under vacuum and air sintering methods is shown in Fig.6. There were four phases in the vacuum, namely, BN、 Na(Si3Al)O8、 LiAlSi3O8 and SiO2. And in air sintering environment there were BN、 Na(Si3Al)O8 and SiO2. It can be seen from Fig.6 that the change of the diffraction peak of BN crystalline phase is small. While the changes of the diffraction peaks of Na(Si3Al)O8 and SiO2 are large. From another aspect of the analysis in section 3.1, titanium in the titanium layer of CBN abrasives does not react chemically with the components in the vitrified bond, and there is no generation of the crystalline phase associated with titanium element in the diffraction curve.

IV. Summary

The experiments show that the effect of temperature on the mechanical property of vitrified bond CBN composites, as well as the microstructure. The summary is as follows:

When the vitrified bond Ti-coated composites are sintered at different temperatures, the mechanical property of the Ti-coated CBN composites increases first and then decreases as the temperature rises. Ti-coated CBN abrasive grains are not suitable for vitrified bond with low refractoriness.

Through SEM, it is found that the titanium layer has protective effect on CBN abrasive. As the temperature increases, titanium in the titanium layer not only exists on the CBN abrasive surface but also spreads to the glass phase, so the sintering temperature should not be too high.

According to the morphology and bending strength of the sintered composites, it can be concluded that Ti-coated CBN composites are more suitable for sintering in a vacuum environment. The grinding tests for the vitrified bond titanium-coated CBN composites will be carried out in subsequent studies.

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