

## Effect of SnO on Mechanical Properties of Low Melting Vitrified Bond

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In this work, the effect of SnO on mechanical properties of low melting vitrified bond for grinding tools were investigated. Alumina composites were prepared by sintering alumina abrasive grains with low melting  $\text{Na}_2\text{O-B}_2\text{O}_3\text{-SiO}_2$  vitrified bond in air. The refractoriness and fluidity of vitrified bond were measured by traditional method. The Rockwell hardness of sintered specimens was examined by HR-150A. Moreover, the bending strength of specimens was tested by three-point bending strength tester and the microstructure characteristics of specimens were observed by scanning electron microscopy. The results showed that SnO, which was beneficial to reducing the refractoriness and improving the fluidity of vitrified bond, had a major effect on properties of low melting vitrified bond. Therefore, the specimens with favourable properties were obtained, because the interfacial bonding between abrasive grains and the vitrified bond was strengthened.

**Key Words:** Vitrified bond, Low melting, Mechanical strength, Microstructure.

### INTRODUCTION

Grinding tools, involving common grinding tools-alumina or silicon carbide abrasive tools and superhard grinding tools-cubic boron nitride (cBN) or diamond abrasive tools, are widely applied to modern processing industry<sup>1-3</sup>. These tools are composed of abrasive grains and a certain type of bond, including metal, resin, vitrified glass and electro-plated<sup>4-6</sup>. Because vitrified bond abrasive tools have satisfying properties over the others, such as higher hardness, higher grinding efficiency, lower fracture toughness and more excellent self-dressing capability<sup>7,8</sup>. It is proverbially used in automotive, machine tools, aerospace and other industry with efficiency and high precision machining. However, vitrified bond abrasive tools are still in face of some challenges<sup>9</sup>, such as production innovation, production process improvement, reduction of energy consumption and environmental pollution. In addition, diamond abrasive tools can not be heated in high temperature taking account of being oxidized easily<sup>10</sup> and sintering cubic boron nitrate abrasive tools should be carried out at relatively low temperature in case of boron nitrate abrasives undergo thermal degradation<sup>11</sup>. To solve the problems above, low melting vitrified bond abrasive tools had been put forward.

Low melting vitrified bond abrasive tools, referring to a group of vitrified bond abrasive tools sintered below 1000 °C, can save energy, improve the performance of abrasive tools and prolong the life of furnace<sup>12</sup>. According to the conventional

ways, alkali or alkali-earth metal oxides are introduced into vitrified bond in order to reduce the sintering temperature<sup>13-15</sup>. Nevertheless, as the addition of those fluxing agents, the strength of vitrified bond decrease. The properties of vitrified bond is one of vital factors to obtain high quality abrasive tools, therefore, low melting vitrified bond with outstanding performance is critical for the application of low melting vitrified bond abrasive tools.

In this work, basic  $\text{Na}_2\text{O-B}_2\text{O}_3\text{-SiO}_2$  system vitrified bond featured with high strength and low melting with and without SnO were prepared. The effect of SnO on properties of  $\text{Na}_2\text{O-B}_2\text{O}_3\text{-SiO}_2$  system low melting vitrified bond was investigated.

### EXPERIMENTAL

Basic vitrified bond of  $\text{Na}_2\text{O-B}_2\text{O}_3\text{-SiO}_2$  system was prepared by traditional method, including screening the raw materials, weighing accurately, ball milling and firing at 1300 °C for 4 h and then cooling in the water. Finally, the cooled glass was dried, crushed and seized to produce a fine, powdered vitrified bond. With the same method, a part of basic vitrified bond was melted with 5 wt. % or 9 wt. % SnO to prepare another two vitrified bond for comparison. The vitrified bond with and without SnO were uniaxially pressed into tapered columns and cylinders, which were sintered in an electric furnace used for measuring refractoriness and fluidity.

Specimens were prepared by mixing with alumina abrasive grains, vitrified bond and temporary bond (paraffin wax), then the powder was pre-pressed to form the rectangular bars with the dimensions of 30 mm × 6 mm × 4 mm. Then the specimens were heated to the sintering temperature (700–780 °C) in air, at the rate of 3 °C/min, holding for 2 h at the sintering temperature and then naturally cooled to the room temperature.

Hardness of sintered specimens was studied using Rockwell hardness method according to HR-150A. Bending strength of specimens was measured by means of three-point bending method which was carried out on C158ASTMinMTS machine at a crosshead speed of 0.6 mm/min. The interface microstructures and bonding state of the sintered specimens were observed by scanning electron microscope (Phillips XL30E).

## RESULTS AND DISCUSSION

### Studies of vitrified bonds' refractoriness and fluidity:

Sintering of low melting vitrified bond abrasive tools should be carried out at relatively low temperature. Reducing vitrified bond' refractoriness was critical for this purpose. In order to evaluate the proper sintering temperature of the vitrified bond abrasive tools, refractoriness of vitrified bond were studied. In this experiment, the refractoriness was measured by triangle cones. Fig. 1 showed the refractoriness of  $\text{Na}_2\text{O-B}_2\text{O}_3\text{-SiO}_2$  system vitrified bond with different contents of SnO. It could be seen that the refractoriness of basic vitrified bond was 662 °C, while refractoriness of vitrified bond with 5 and 9 wt. % SnO addition reduced to 657 and 647 °C, respectively. To some extent, it is presumed that the refractoriness of vitrified bond decreased with the increase of SnO. When the addition of SnO reached 9 wt. %, the refractoriness reduced by 15 °C. That was because  $\text{Sn}^{2+}$  ions, acted as network modifier, destroyed the liquid-like network of the basic bond system. When SnO was introduced into the  $\text{Na}_2\text{O-B}_2\text{O}_3\text{-SiO}_2$  system,  $\text{Sn}^{2+}$  ions could dissolve boron-oxygen polyhedra or silicon-oxygen polyhedra by means of making extra  $\text{O}^{2-}$  ions dangle off the network and form a mass of non-bridging oxygen in the glass network. Compared with tradition flux agents (*e.g.*,  $\text{Li}^+$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Zn}^{2+}$ ,  $\text{F}^-$  etc.), such function of  $\text{Sn}^{2+}$  ions was less obvious. The characteristics of SnO could account for it. In crystal structure,  $\text{Sn}^{2+}$  ions was surrounded by eight  $\text{O}^{2-}$  ions, among which four  $\text{O}^{2-}$  ions were close to  $\text{Sn}^{2+}$  ions and four  $\text{O}^{2-}$  ions were apart from  $\text{Sn}^{2+}$  ions, which led to the formation of asymmetric coordination. Due to repulsion of four  $\text{O}^{2-}$  ions which were close to  $\text{Sn}^{2+}$  ions, the outer inert electron pair of  $\text{Sn}^{2+}$  ions were excluded to the other side,  $[\text{SnO}_4]$  structural units was engendered, which was helpful to form a spiral chain structure linking with  $[\text{SiO}_4]$  through sharing an angle or an edge in glass system. It made a special network formed in glass system, which was beneficial to reducing the melting point of glass. Consequently, when the  $\text{Sn}^{2+}$  ions were introduced into the glass network, it promoted the homogenization of the bonding glass, which made the refractoriness of vitrified bond reduce to some extent.

Previous studies had demonstrated that another characteristic, affecting the ability to manufacture the abrasive product

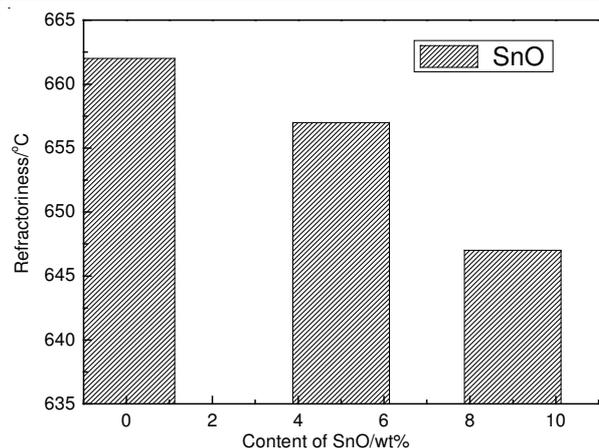


Fig. 1. Refractoriness of vitrified bond with different contents of SnO

was the fluidity of vitrified bond at optimal sintering temperature. Vitrified bond was required to coat each abrasive grains adequately and a uniform distribution of vitrified bond was helpful to producing a homogeneous structure abrasive tools. It was believed that appropriate fluidity was propitious to the formation of stronger bonding bridges between abrasive grains by distributing vitrified bond among abrasive tools evenly. However, the higher fluidity vitrified bond was, the more susceptible the abrasive tool became distortion and the more possible it suffered cracking and mass loss. So research on fluidity of vitrified bond was extremely vital. According to the published studies, the adaptive fluidity ranged from 90–280 %<sup>16</sup>. As a general rule, a mass of grinding wheels, such as high porosity wheels, large diameter wheels, deep wheels, should be made using less fluid vitrified bond in order to eliminate cracking and distortion during sintering. Fig. 2 displayed the fluidity of various vitrified bond. It was obvious that the fluidity of vitrified bond decreased from 226.75 to 192.79 % when the addition of SnO was 5 wt. %, while the fluidity reached 174.125 % when the addition of SnO was 9 wt. %. As usual, the vitrified bond with lower refractoriness had higher fluidity. However, in this study, the result was reversed. Just as the analysis above, the spiral chain structure was formed by sharing an angle or an edge between  $[\text{SnO}_4]$  structural units and  $[\text{SiO}_4]$  structural units in glass system. This resulted in the decrease of vitrified bond fluidity, which was helpful to improving the properties of vitrified bond. From the results above, adding

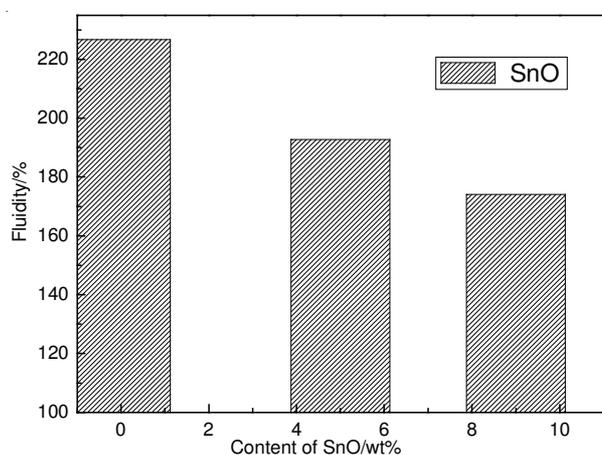


Fig. 2. Fluidity of vitrified bond with different contents of SnO

SnO not only affected vitrified bonds' refractoriness but also affected vitrified bonds' fluidity.

**Effect of SnO on bending strength of specimens:** The bending strength of specimens with different contents of SnO sintered at different temperatures was shown in Fig. 3. It was obvious that sintering temperature as well as the content of SnO had great effect on the bending strength of specimens. It was clear that the bending strength of vitrified bond specimens increased remarkably as the sintering temperature increased in a certain extent. But the bending strength decreased if the sintering temperature exceeded the optimal temperature (the optimal temperature was 760 °C in this experiment). It could be attributed that the fluidity of vitrified bond was better with the increase of sintering temperature. Nevertheless if the sintering temperature was too high, the specimens would be over sintered, leading to the specimens foaming and deformation, which was harmful to the strength of specimens.

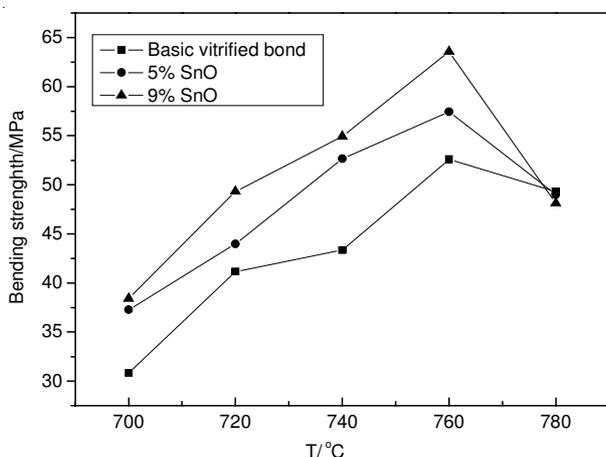
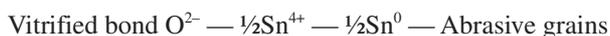


Fig. 3. Effect of sintering temperature and SnO on bending strength of vitrified bond

The strength of specimens improved with the increase of SnO. The bending strength of specimens increased from 52.6 to 57.4 Mpa when 5 wt. % SnO were imported at 760 °C. The highest value of bending strength increased by 11 Mpa when SnO was introduced by 9 wt. %. Two reasons could account for it. From the studies of the influence of SnO on vitrified bond' refractoriness and fluidity, it could be seen that the refractoriness of vitrified bond reduced properly and the vitrified bond' fluidity was ameliorated preferably, which was helpful for the formation of stronger bonding bridges between abrasive grains. In addition, as previous analysis, it was believed that in the square pyramidal structure of SnO, inert electron pair of  $\text{Sn}^{2+}$  ion closed to  $\text{O}^{2-}$  ions was pushed off, so  $\text{Sn}^{2+}$  could be approximated as  $\text{Sn}^{4+}$  ion on the side, meanwhile,  $\text{Sn}^{2+}$  on the other side was similar to SnO. Therefore,  $\text{Sn}^{2+}$  ion in the square pyramidal structure could be considered as  $1/2\text{Sn}^{4+}-1/2\text{Sn}^{0}$  and  $1/2\text{Sn}^0$  was named as metal bridge. Due to crystalline SnO with asymmetric tetragonal crystal structure,  $\text{Sn}^{2+}$  had characteristics of metal bridge.  $\text{Sn}^{2+}$  ions enhanced the connection between vitrified bond and abrasive grains, when SnO was imported into basic vitrified bond. The state of combination was as follows:



As a result, the bending strength of specimens was enhanced.

However, the sintering process parameter was not affected by the introduction of SnO. The bending strength of specimens with basic vitrified bond reached the highest value when the sintering temperature was 760 °C, while the optimal sintering temperature did not change when SnO were introduced. That was because the refractoriness of vitrified bond did not change notably (the highest value of refractoriness reduced by 15 °C in this study), which led to sintering process parameters varying little. Consequently, the bending strength of specimens with SnO strengthened, while it did not affect the sintering process parameters.

**Effect of SnO on hardness of sintered specimens:** Hardness of grinding tools referred to the ability that abrasive grains resisted pulling off from the surface of grinding tools under external force. The hardness of grinding tools could largely reflect the grinding performance. The higher hardness the grinding tools possessed, the more difficult the abrasive grains would pull off from the surface of grinding tools, which contributed to the decrease of grinding tool mass loss when it was working. Meanwhile, hardness of grinding tools also determined the self sharpness of grinding tools.

In order to evaluate the influence of SnO on the hardness of specimens, Rockwell hardness test was carried out on HR-150A. Fig. 4 presented the Rockwell hardness of specimens with different contents of SnO sintered at optimal temperature (760 °C). It was clear that SnO had great influence on the Rockwell hardness of specimen. From Fig. 4, the average Rockwell hardness of specimens was only 43.5 (HRA), while the value increased to 65.5 (HRA) with 5 wt. % SnO, moreover the average Rockwell hardness of specimens attained 80 (HRA) with 9 wt. % SnO. Owing to the vitrified bond had better properties with the addition of SnO, the ability that abrasive grains resisted pulling off from the surface of grinding tools was strengthened. Therefore, the results indicated that the addition of SnO yielded the higher Rockwell hardness of grinding tools.

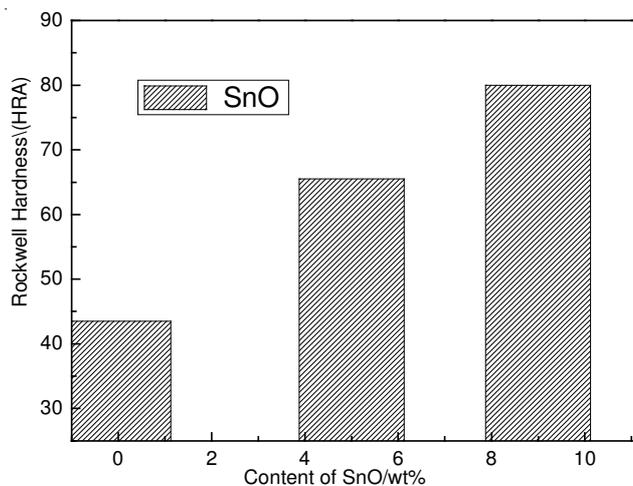


Fig. 4. Effect of SnO on Rockwell hardness of vitrified bond sintered at 760 °C

**Microstructure analysis:** The state of interfaces between the vitrified bond and the abrasive grains were very important.

If the vitrified bond did not join with abrasive grains well, in some cases the abrasive grains pulled out and lost easily before completing their effective working life, which led to excessive tool costs. Besides, once large amount of pores formed during the sintering process, the mechanical properties of grinding tools would be weakened. Fracture surfaces microstructure of specimens was a necessary means to observe the combination state between abrasive grains and vitrified bond. Fig. 5 presented the fracture surfaces of specimens sintered at optimal temperature (760 °C). There were significantly differences in microstructure of specimens with different contents of SnO (0, 5 and 9 wt. %). From Fig. 5(a-c), it was clear that the abrasive grains were better wetted by vitrified bond with the introduction of SnO. Compared with the specimens without SnO (Fig. 5a), the structure of specimens with 5 wt. % SnO (Fig. 5b) was denser. When the addition of SnO reach 9 wt. % (Fig. 5c), the abrasive grains were fully coated with vitrified bond and the fracture surface images showed the least pores and the best densification. It demonstrated that the vitrified bond with SnO exhibited very good fluidity and wettability to abrasive grains, which was favourable to mechanical properties of specimens. Namely, these fracture surfaces morphology explained the reason why the bending strength and Rockwell hardness increased with the addition of SnO ulteriorly. In conclusion, proper content of SnO could be attributed to the improved properties of vitrified bond such as fluidity and wettability, leading to a denser structure of grinding tools, which was beneficial to improving the mechanical properties of grinding tools.

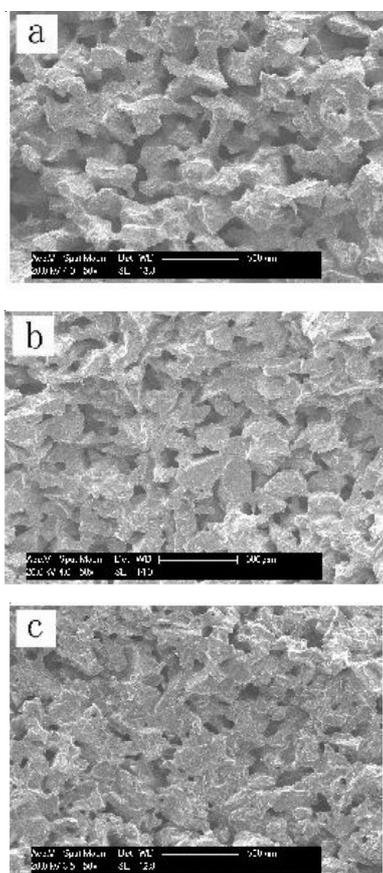


Fig. 5. Fracture surface images of specimens with different content of SnO (a) 0 % SnO; (b) 5 % SnO; (c) 9 % SnO

## Conclusion

The effect of SnO on the mechanical properties of Na<sub>2</sub>O-B<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> vitrified bond was investigated. It had indicated that the proper amount of SnO introduced into the basic Na<sub>2</sub>O-B<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> vitrified bond could decrease the refractoriness of vitrified bond, so low melting vitrified bond was obtained. Moreover, it could improve the fluidity of vitrified bond which was beneficial to the improvement of combination stat between abrasive grains and vitrified bond. Adding SnO in low melting vitrified bond was propitious to improve the various mechanical properties of vitrified bond. On one hand, it was helpful to promote the Rockwell hardness of specimens during sintering process, the improved value reached 36.5 (HRA) with 9 wt. % addition of SnO sintered at 760 °C. On the other hand, SnO was also helpful for the improvement of the bending strength. Compared with specimens without SnO, the bending strength increased 11 Mpa at the optimal temperature when the addition of SnO was 9 wt. %. Based on the above results, it has shown that appropriate amount of SnO introduced into vitrified bond resulted in obtaining satisfying properties vitrified bond with low temperature and high strength.

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