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Effect of hot pressing temperature on microstructure, mechanical properties and grinding performance of vitrified-metal bond diamond wheels

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ABSTRACT

The self-sharpening vitrified-metal bond diamond wheels added with a 3 wt.% brittle Na_2O-B_2O_3-SiO_2-Al_2O_3-Li_2O vitrified bond were fabricated by hot pressed sintering technique. Using the methods of scan-electroscope, energy spectrum analysis, X-diffraction analysis, XPS analysis, Rockwell hardness test and three-point bending test, the effects of hot pressing temperature on the microstructure, hardness and the transverse rupture strength (TRS) of vitrified-metal bond were investigated. Then the grinding performance of cylinder of the diamond wheels was also studied. The results showed that, when the hot pressing temperature was 850 °C, a thin $FeAl_2O_4$ transition layer formed, which enhanced the interfacial bending strength between metal and glass phase, and the TRS of vitrified-metal bond reached the maximum value 826.54 MPa. Comparing with metal bond diamond wheel's, the average value of the roundness and straightness of the 50 cylinders ground by the vitrified-metal diamond wheel reduced from 3.1 μm and 2.5 μm to 2.7 μm and 2.1 μm.

1. Introduction

Due to high density and toughness of metal matrix, metal bond diamond grinding wheels have long service life and are widely employed in advanced precision machining of hard, fragile and some metal materials [1–5]. However, the high density and toughness of metal matrix cause poor self-sharpening and frictional heat generated during grinding, which led to poor machining efficiency and quality. So the metal bond diamond wheels need periodic dressing to keep good self-sharpening in grinding process. Two ways can improve its self-sharpening in present. One is increasing the content of brittle phase by changing the constituent of the matrix to decrease its abrasion resistance. The CuSn bond met the requirements of bonds for honing stones by increasing the content of Sn from 20% to 25%, which decreased the hardness of CuSn bond and further decreased its abrasion resistance [3] but the realistic grinding performance wasn't discussed. The other way is introducing the sponge-like structure to the wheels. Alumina bubble particles were used as pore-forming agents in Cu-Sn-Ti bond CBN wheel and decreased grinding forces and specific grinding energy [4] and the porous increased the storage space for chips which could reduce the frictional heat generated during grinding [4–5]. However, this way substantially decreased the holding force to diamond particles and transverse rupture strength (TRS) of wheels due to the pores in the bond bridge. This method reduced the speed and security of the wheels so a new method needs to be put forward to improve the self-sharpening of the metal bond wheels, meanwhile, the wheels should maintain high holding force to diamond particles and high TRS to meet the high speed and security.

Na_2O-B_2O_3-SiO_2-Al_2O_3-Li_2O vitrified bond has low expansion coefficient (CTE) and good wettability to diamond in high temperature, which can maintain high holding force to diamond particles, so it extensively services in vitrified bond diamond tools [6]. In addition, a thin $FeAl_2O_4$ layer formed between Fe and Al_2O_3 can enhance their interface bonding strength [7], which indicated the maximum high bonding strength between Fe-based bond and Al_2O_3. Therefore, Fe-based metal bond diamond wheels added with a small amount brittle Na_2O-B_2O_3-SiO_2-Al_2O_3-Li_2O vitrified bond [8] will meet the requirements of good self-sharpening and high TRS of wheels in theory.

In this paper, the Fe-based metal bond diamond wheels added with a 3 wt.% brittle Na_2O-B_2O_3-SiO_2-Al_2O_3-Li_2O vitrified bond were fabricated by hot pressed sintering technique. The effect of different hot pressing temperatures on the microstructure, interface structure, hardness and the TRS of vitrified bond were discussed. Meanwhile, the grinding performance of the cylinder of the vitrified bond diamond wheels was also studied. It's a new attempt to improve the self-sharpening of metal bond diamond wheels.

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Table 1
Chemical compositions of vitrified bond.

Composition	SiO_2	Al_2O_3	B_2O_3	Na_2O	Li_2O
Mole percentage (mol %)	58–62	5–8	18–21	6–8	3–6

Table 2
Characteristics of vitrified bond.

Average particle size	T_g/°C	T_f/°C	CTE/k	Hardness/HRB	TRS/MPa
0.5 μm	670	770	6.14×10^{-6}	83	106.75

2. Experimental procedure

2.1. Raw materials

Atomized Fe powders (Tianjin FuChen Chemical Reagent Factory, China) and electrolytic Cu, Ni, Sn powders (Guangdong Guanghua Chemical Reagent Factory, China) with the maximum size of 43 μm were used as the metal matrix. Diamond particles (CRIMM superhard materials plant, China) with an average size of 62 μm were chosen.

The chemical composition and characteristics of Na_2O-B_2O_3-SiO_2-Al_2O_3-Li_2O vitrified bond were listed in Tables 1 and 2, respectively.

2.2. Specimen fabrication

The metal bond (Fe, 24 wt.% Cu, 14 wt.% Ni and 6 wt.% Sn) and vitrified bond (Fe, 23.28 wt.% Cu, 13.58 wt.% Ni 5.82 wt.% Sn and 3 wt.% Na_2O-B_2O_3-SiO_2-Al_2O_3-Li_2O) were hot-pressed in graphite molds for 3 min at 750, 800, 850 and 900 °C under 25 MPa. The sintered specimens were cooled down to room temperature at a cooling rate of 125 °C/min, and then the pressure was relieved. The size of the two rectangular specimens was 40 mm × 11 mm × 5 mm. Then the metal bond diamond specimens (Fe, 24 wt.% Cu, 14 wt.% Ni, 6 wt.% Sn and extra 6 wt.% diamond particles) and vitrified-metal bond diamond specimens (Fe, 23.28 wt.% Cu, 13.58 wt.% Ni 5.82 wt.% Sn, 3 wt.% Na_2O-B_2O_3-SiO_2-Al_2O_3-Li_2O and extra 6 wt.% diamond particles) were sintered with the same process parameters. The size of the two cylindrical wheels was 40 mm × 11 mm × 5 mm.

2.3. Characterization

The microstructures and interface structures of specimens were observed by a scanning electron microscope (SEM; FEI QUANTA-200). The element composition of the different color areas was analyzed by the energy disperses spectroscopy (EDS). The crystal structures were identified by an X-ray diffractometer (XRD, SIEMENS D-5000) with a standard CuKα radiation source, 2θ angle from 20° to 80°. The valence analysis of Fe element was observed by X-Ray Photoelectron Spectrometer (XPS, K-Alpha 1063). The transverse rupture strength (TRS) of specimens was observed by a three point bending test machine (DKZ-5000, China), according to ASTM B528-12. The TRS can be calculated by the following equation: $TRS = 3PL / 2\ wt^2$, where P is the loading force, L is the length of specimen, t is the thickness of the specimen, and w is the width of the specimen. The hardness of the specimen was observed by Rockwell apparatus specimens (HR150DT, China) with a steel ball diameter of 1.588 mm and a load of 100 kg, according to ASTME18-12. The CTEs were measured by a thermal analysis apparatus (NETZSCH-DIL402PC) with a heating rate of 10 °C/min from 25 to 950 °C. The Mo-doped wear resisting cast iron cylinder stators were machining by M2011 grinding machine with a wheel speed of 60 m/s, a workpiece speed of 1500 rpm/min, a feed rate of 0.2–0.4 mm and an axial feed rate of 3 mm/min. The roundness and straightness of the cylinder were measured by RA-120 Pneumatic Roundness Detector.

3. Results and discussion

3.1. Effect of hot pressing temperature on the microstructure and composition of vitrified-metal bond

The microstructure and composition of vitrified-metal bond sintered at different temperatures were shown in Fig. 1. According to EDS and XRD analysis (Fig. 2), the white phase was the metal phase due to it

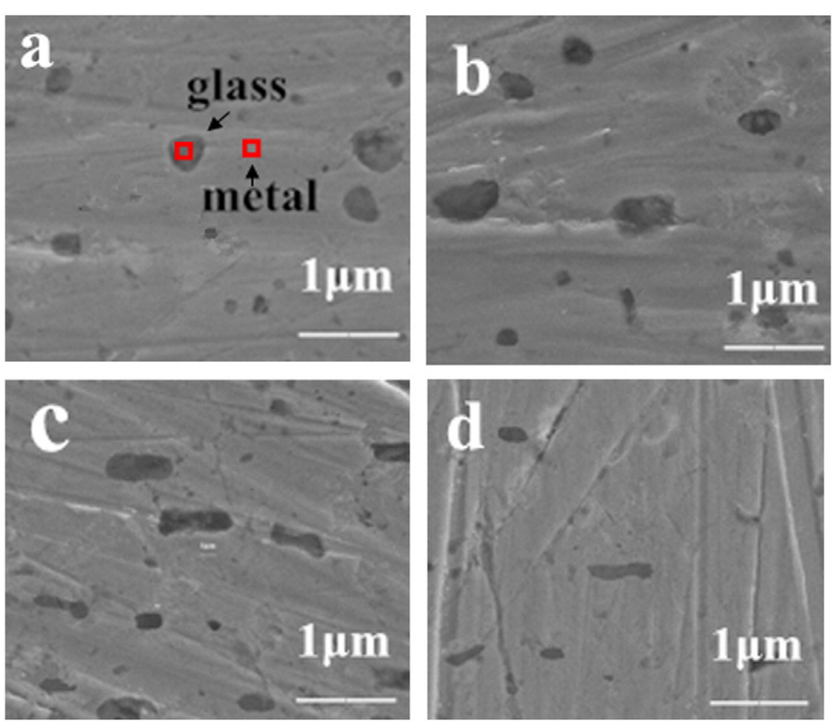

Fig. 1. SEM of vitrified-metal bond hot pressed at different temperatures after polishing: a. 750 °C, b. 800 °C, c. 850 °C, and d. 900 °C.