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Effect of the cBN Content and Sintering Temperature on the Transverse Rupture Strength and Hardness of cBN/Diamond Cutting Tools

Durmuş Kır¹, Serkan Islak^{2*}, Halis Çelik³, Ertuğrul Çelik⁴

¹Kocaeli University, Gebze Vocational High School, 41400 Kocaeli, Turkey,

²Kastamonu University, Cide Rifat Ilgaz Vocational High School, 37600 Kastamonu, Turkey,

³Firat University, Faculty of Technology, Department of Metallurgy and Materials Engineering, 23100 Elazig, Turkey,

⁴Tunceli University, Faculty of Engineering, Department of Mechanical Engineering, 62000 Tunceli, Turkey,

Abstract:

The aim of this work was to investigate the effect of cBN content and sintering temperature on the transverse rupture strength (TRS) of cBN/diamond cutting tools produced by hot pressing. The segments containing different cBN content were manufactured under 35 MPa pressure at 600, 650 and 700 °C with a 3 minutes sintering time. The TRS of segments were determined using three-point bending test. Microstructure and phase composition of fracture surface of segments were determined by scanning electron microscopy (SEM), and X-ray diffraction (XRD) analysis. The obtained results show that the TRS of the segments with cBN were higher than that of the segments with diamond.

Keywords: cBN/diamond cutting tools, Hot-pressing, TRS

1. Introduction

Cubic boron nitride (cBN) is the second hardest material after diamond, and possesses numerous excellent physical and chemical properties, high resistance to chemical attack, and mechanical properties [1-3]. Surface graphitisation takes place for diamond grits at high temperatures; ultimately reducing its performance. However, graphitisation does not occur at high temperature when cBN is used, due to its properties such as high thermal and chemical stability [4-7]. The fundamental reason behind the bonding structure of cBN is that it has better thermal and chemical stability in comparison to diamond [8]. While diamond has covalent bonds, cBN has both covalent and ionic bonds [9]. The polycrystalline cubic boron nitride (PcBN) was produced using cBN and ceramic or metal binders under high pressure and high temperature. The cutting tools made from them are widely used for cutting, e.g. hardened steels, cast iron and others [10-12].

There are studies available in literature regarding the choice of suitable matrix for diamond cutting tools, the properties of synthetic diamond, the use of coated diamond, the manufacturing conditions of tools and the wear these tools are exposed to, and fracture

*) Corresponding author: serkanislak@gmail.com

mechanics [13-16]. There are no studies available in literature that addresses the usage of another hard grain instead of synthetic diamond, which carries out cutting procedure in diamond cutting tools.

The aim of this work was to investigate the effect of cBN content and sintering temperature on the transverse rupture strength (TRS) of cBN/diamond cutting tools produced by hot pressing. Different amounts of cubic boron nitride were added to the segment matrix. The hot pressing process was carried out at 35 MPa pressure, at 600, 650 and 700 °C temperatures and 3 minutes sintering time. A Scanning Electron Microscope (SEM) and an X-Ray Diffractometer (XRD) were used to analyze the microstructure, chemical compound, and fracture surfaces of each segment type.

2. Experimental Studies

Bronze powder (85% Cu + 15% Sn) with a grain size of -325 mesh was used as matrix material to manufacture diamond and cBN cutting tools. cBN grains were added to the bronze at amount of 0, 20, 40, 60, 80 and 100% (in weight) of cutting grains. The diamond grain and cBN grain (particle size 40/50 US mesh) were selected as concentrations of 30 (a concentration of 100 is conventionally defined as 0.88 g of diamond per cubic centimetre of impregnation: approximately 25% by volume). SEM micrographs of the diamond, cBN and the bronze powder are given in Fig. 1.

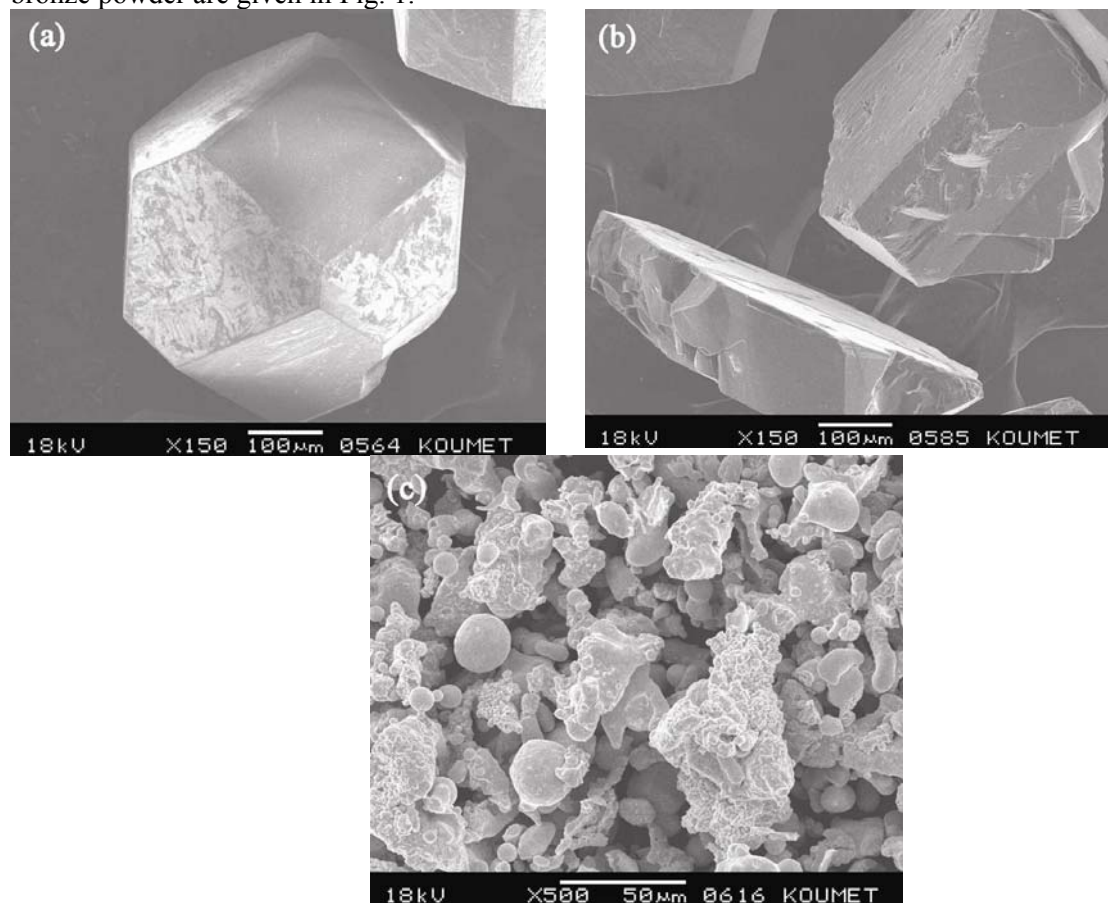


Fig. 1. SEM micrographs of (a) diamond grain, (b) cBN grain, and (c) bronze powder

As shown in the SEM micrographs, the bronze powder has a spherical structure, the cBN grains have a variable structure and are sharp-edged, and the diamond grains have a cubic octahedral structure.

Bronze powder, diamond, and cBN grains were mixed together with the addition of a 1 wt.% of paraffin wax, at a speed of 20 rpm, for 30 minutes. Firstly, the segments were prepared via cold press with a pressure of 15 MPa. Then, the cold-pressed segments were hot pressed in graphite moulds for 3 min at 600, 650 and 700 °C, with an applied pressure of 35 MPa using an automatic hot pressing machine. Fig. 2 illustrates the cold pressing of the segments, and the hot pressing.

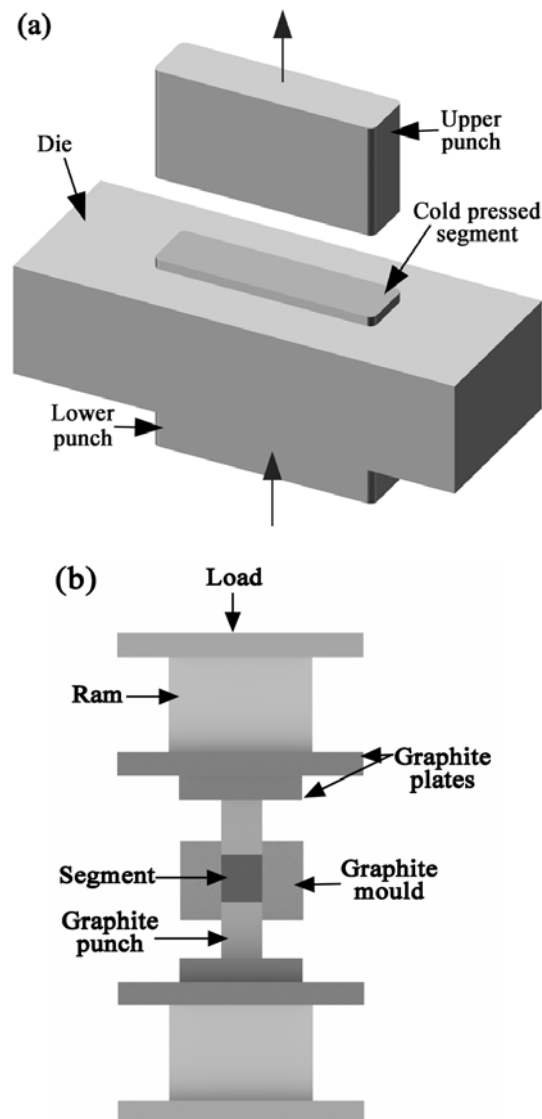


Fig. 2. (a) The cold pressing of the segments, and (b) the hot pressing

The relative density, hardness, and transverse rupture strength of the segments were determined. The relative densities of segments were measured by Archimedes' principle. Hardness measurements were performed in Brinell scale with a ball diameter of 2.5 mm and a load of 62.5 kg. Three-point bending tests were performed using an Instron 4411 universal testing machine, at a loading rate of 1 mm/min, at room temperature, to determine the transverse rupture strength (TRS) of the segments. Five tests were repeated for each

specimen, and the results were averaged. The size of the hot-pressed segment for the three-point bending test was 40 x 7 x 3.2 mm. Fig. 3a displays the three-point bending test setup and fracture sample.

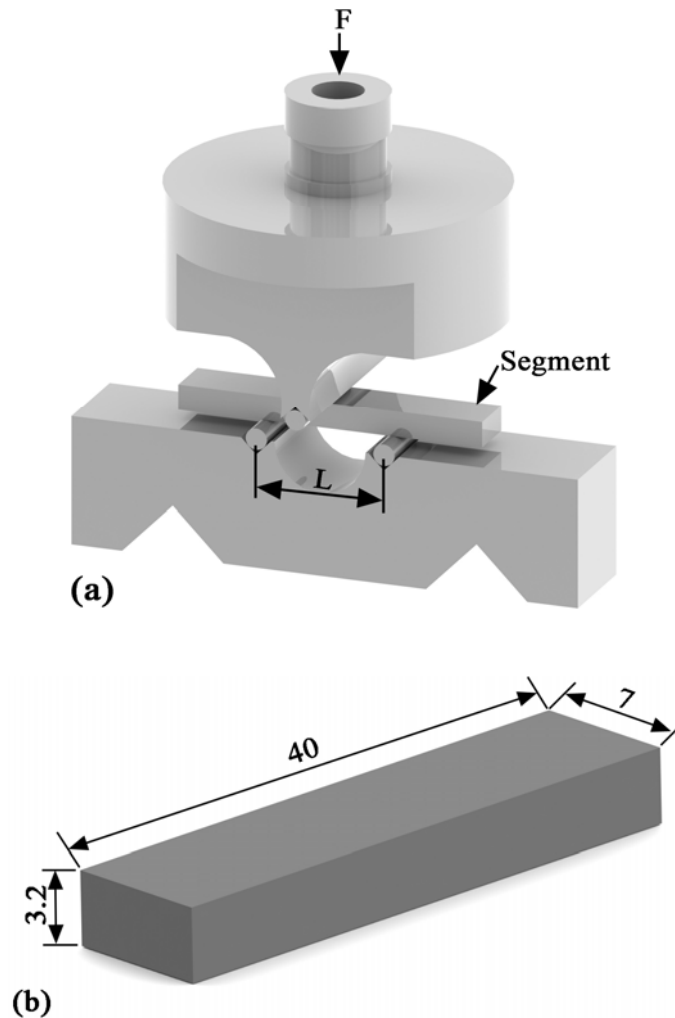


Fig. 3. (a) Three-point bending test setup and (b) the fracture sample

A scanning electron microscope (SEM) (JEM-2100F, JEOL, Japan) and an X-ray diffractometer (Bruker AXS D8 Advanced System, Germany) were used to investigate the fractured surfaces, identify the phase structures, and how the microstructure of segments changed based on the cBN content and sintering temperature.

3. Results and discussion

Fig. 4 illustrates the XRD graphs of cubic boron nitride and diamond cutting segments. XRD analyses identified cBN, diamond, α -Cu, and Cu_3Sn phases in the segments. The fact that there was no phase between bronze, diamond, and cBN is due to the fact that the chosen sintering temperature was low. In other words, there was only a mechanical bonding between the cutting grains and the matrix (bronze). XRD graphs show that there was an increase in the intensity of cBN peaks together with the increase in the amount of cBN added to the matrix.

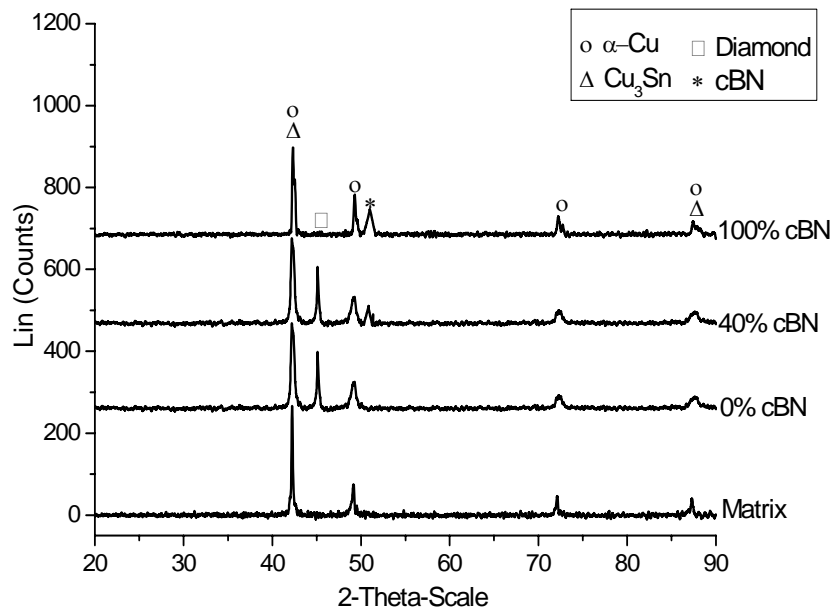


Fig. 4. XRD graphs of segments

The effect of sintering temperatures and cBN on relative densities of segments is shown in Fig. 5. When the cBN is introduced to the segments, it doesn't change the relative densities. This is due to the fact that the diamond and cBN have similar densities. The density of diamond is 3.52 g/cm^3 , while the density of cBN is 3.48 g/cm^3 [7]. As the sintering temperature increases, the two adjacent particles begin to form a good bond by diffusion in a solid-state bonding process, the relative densities of the segments increases [17].

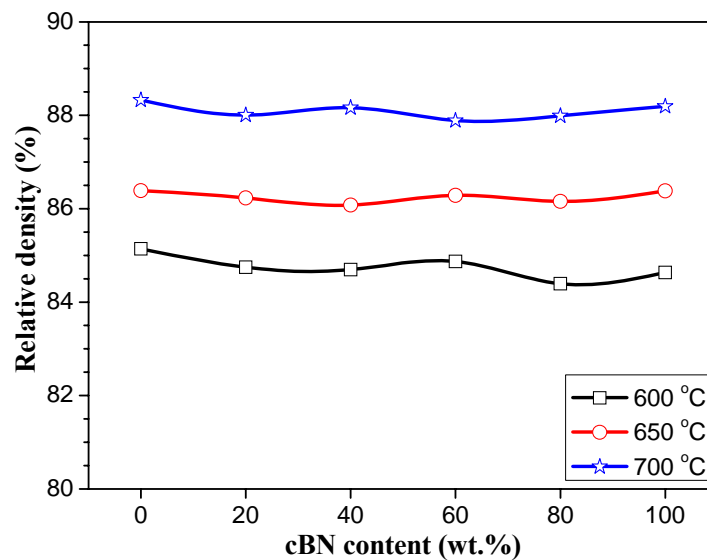


Fig. 5. The relative densities of the diamond and cBN cutting segments

The hardness graph of segments produced by the addition of different cBN contents and at different sintering temperatures is depicted in Fig. 6. Hardness values were determined by taking the average of six different measurements on each segment. When the cBN grains are added to the matrix, it causes in a decrease in the hardness of segments. It is a expected

consequence that diamond cutting tools are harder than cBN cutting tools because the hardness of diamond is higher than that of cBN. With increasing of sintering temperature, the hardness of cutting tools increased because of a denser structure.

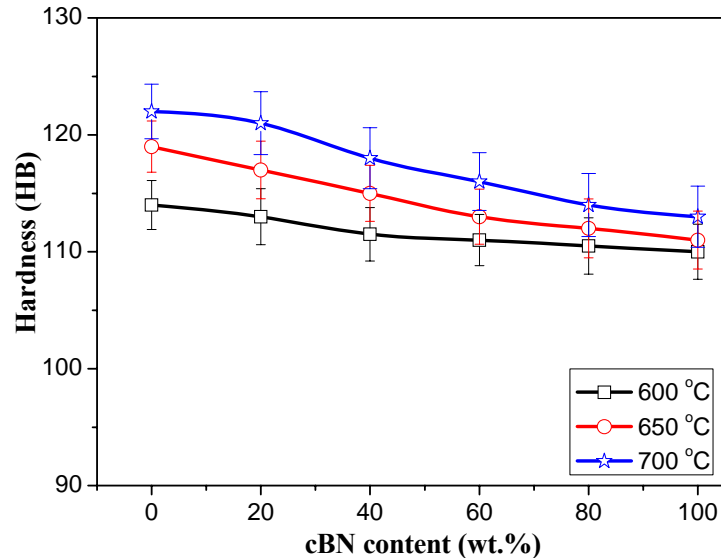


Fig. 6. The effect of sintering temperature and cBN content on the hardness of segments

Fig. 7 illustrates the transverse rupture strength (TRS) of segments versus cBN content. It can be seen that the TRS of cBN segments was higher in comparison to diamond segments. The TRS of the 100% cBN segment was approximately 30% more than the TRS of the 100% diamond segment; the possible reason behind this is that cubic boron nitride forms a better mechanical bonding with the matrix in comparison to diamond. With increasing of the sintering temperature, the TRS values of segments increased. This is because of good bonding between the bronze and cBN/diamond particles in case of high temperature.

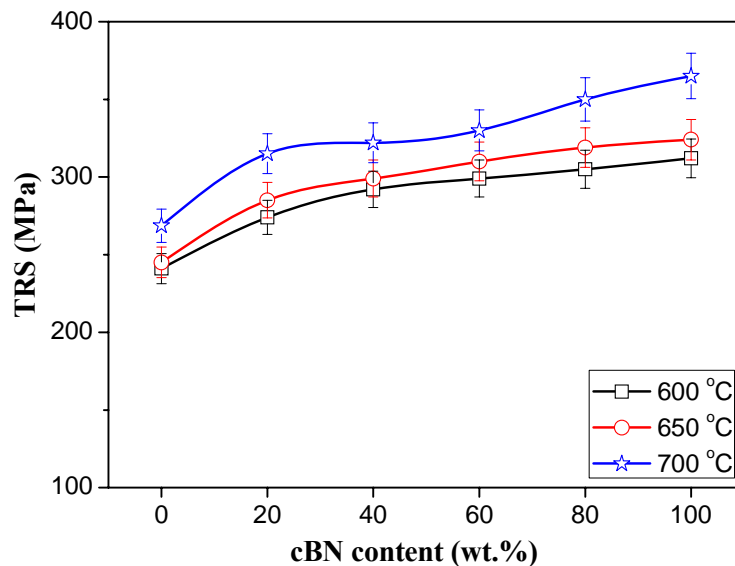


Fig. 7. The effect of sintering temperature and cBN content on the TRS of segments

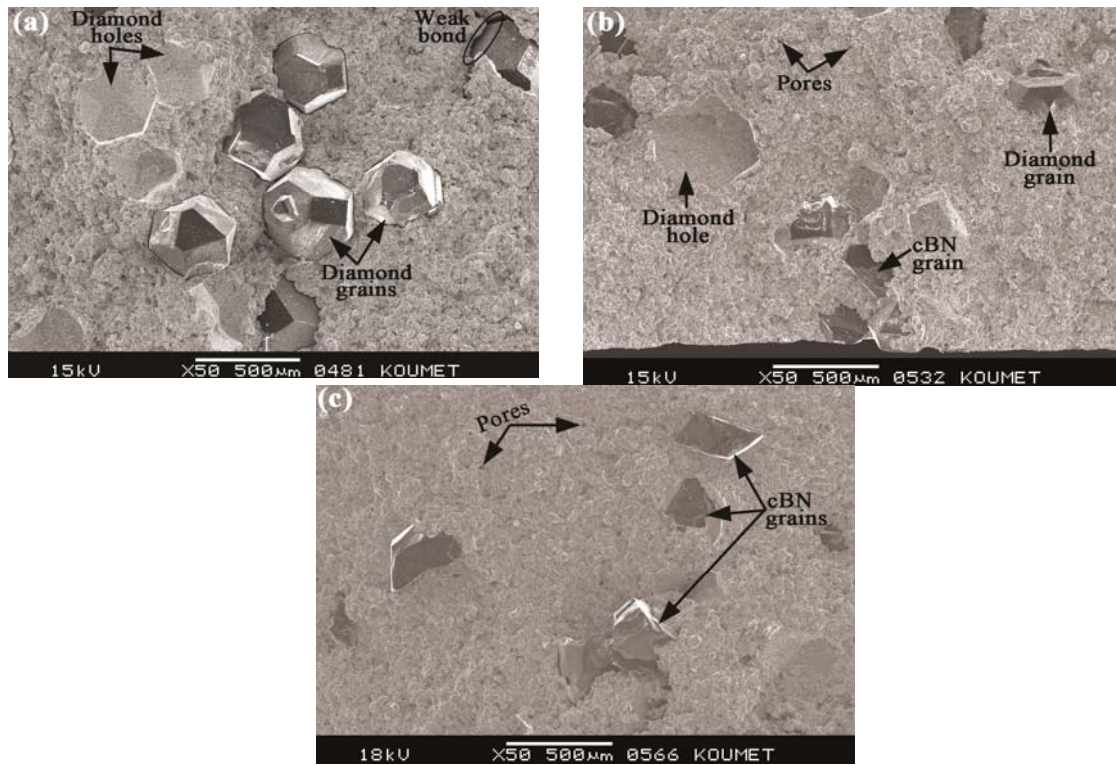


Fig. 8. The SEM images of the fracture surfaces of the segments: (a) 0% cBN, (b) 60% cBN, and (c) 100% cBN sintered at 600 °C

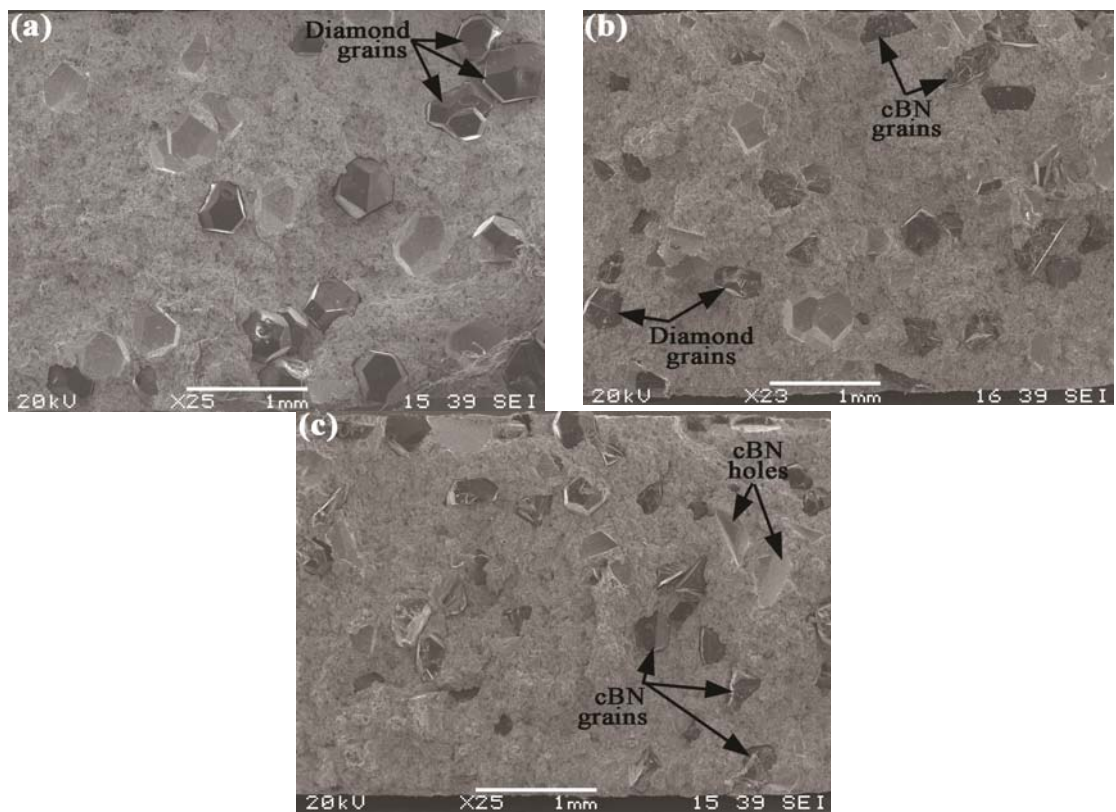


Fig. 9. The SEM images of the fracture surfaces of the segments: (a) 0% cBN, (b) 60% cBN, and (c) 100% cBN sintered at 700 °C

The SEM images regarding the fractured surfaces of diamond and cBN cutting segments are shown in Figs. 8 and 9. As illustrated in Fig. 8, clear gaps appear between the grain and matrix and the pull-out pits are very deep, which means that the diamond retention to the matrix is poor. This is related to the fact that the cBN grains used in this study have a larger bonding surface in comparison to diamond grains. The fracture images in Fig. 8 prove that bonding between the matrix and cutting grains was weaker than the desired level. The excessive porosity in the matrix also raises attention in the SEM images of fracture surface; the reason being inadequate sintering conditions. With increasing of the sintering temperature, the good bonding between the matrix (bronze) and cutting grain is shown in Fig. 9. Besides, the amount of pore decreased at a high sintering temperature, which lead to high speed solid-state diffusion. While the cBN content increase, the amount of cutting grain hole decrease (Figs. 8 and 9).

4. Conclusions

The following conclusions can be drawn after conducting the experiments and analyzing the resulting data:

1. The cBN and diamond cutting segments were manufactured successfully at different sintering temperature by hot pressing technique.
2. XRD analysis concluded that α -Cu, Cu₃Sn, diamond, and cBN phases formed in the microstructure, no phases formed between the cutting grains and matrix, and accordingly that the bonding between the cutting grain and the matrix was only mechanical.
3. The TRS of segments was increased as the sintering temperature and amount of cBN increased. Three-point bending tests concluded that the 100% cBN segments had the highest TRS; the reason is that cBN forms a better mechanical bonding with the matrix in comparison to diamond. SEM images of fracture surfaces proved that the matrix sintered at 600 °C had a porous structure; this was related to inadequate sintering conditions. the amount of pore decreased at at 700 °C

Acknowledgments

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5. References

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Садржај Циљ овог рада је је био испитивање утицаја садржаја кубичног бор-нитрата (cBN) и температуре синтеровања на чврстоћу дијагоналног пресека (TRS) cBN/дијамантског резног алата добијеног топлим пресовањем. Сегмент који садржи различит садржај cBN је направљен под притиском од 35 МПа на температурама од 600, 650 и 700 °C са 3 минута временом синтеровања. Чврстоћа дијагоналног пресека утврђена је методом савијања у три тачке. Микроструктура и фазни састав површине пресека одређена је СЕМ методом и рендгенском дифракцијом. Добијени резултати су указали на то да је сегмент са cBN имао веће вредности чврстоће дијагоналног пресека од сегмента са дијамантским садржајем.

Кључне речи: карбон бор-нитрат/дијамант резни алат, топло пресовање, чврстоћа дијагоналног пресека.
