Mechanical properties and cutting performance of cBN – TiN composites sintered using HPHT technique

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Summary
Cubic boron nitride (cBN) – based ceramic composites in different modifications are still promising materials for high performance cutting applications [1-4]. CBN-TiN composites with different cBN volume ratios were formed by high pressure – high temperature sintering (HPHT) with the application of Bridgman anvils cell. From the microscopic observation it could be concluded that the samples exhibited a poreless and dense structure. Mechanical investigations of BN - TiN composites were performed using a hardness test and an ultrasonic method based on the measurement of the velocity of ultrasonic waves transition through the samples. Young’s modulus and the hardness of the investigated composites strictly depended on the cBN contents and on the synthesis parameters. Characteristic, optimum conditions which gave good mechanical properties for composites with different cBN ratios were determined. Cutting test conducted on tools made of selected cBN-TiN composites showed that a composite with volume ratio of cBN equal 65% exhibited the best cutting performance.

Introduction
Sintered cubic boron nitride (PCBN) has many outstanding properties, combining hardness and abrasion resistance with excellent toughness [1-6]. These products have been available commercially for many years and are useful in a wide variety of machining, drilling, and wire die applications. Cubic boron nitride – based ceramic composites in different modifications are still promising materials for high performance cutting applications. Research on properties improvement of this group of materials and of their behavior in different machining processes are being continuously conducted [1-4]. As with any ceramic, consistent performance depends on the reliable control of material properties and their synthesis parameters.

Experimental
Composites preparation procedure
The cBN-TiN composites were prepared using 38/62 and 65/35 volume ratios of boron nitride (ABN-300, De Beers, 3-5 µm) and TiN (H.C. Starck, B-grade, 1.3-1.9 µm). Powders were mechanically mixed in ethanol. Homogeneous mixtures were dried and preliminary consolidated into pallets of the diameter of 15 mm and the height of 5 mm under the pressure of 200 MPa. The composites were formed by high pressure – high temperature sintering (HPHT) with the application Bridgman anvils cell under the pressure of 7.5 GPa and a temperature range from 1400 to 2000 ºC. Sintered composites were grinding into compacts of diameter 12.7 mm and height 3.2 mm.
SEM observations
The microstructure of sintered BN-TiN composites has been studied using scanning electron microscopy (Philips, type XL-30, BS-mode).

Fig. 1. SEM microstructure of composites: a) 38BN/62TiN, b) 65BN/35TiN.

The microstructure of the cBN-TiN composites shown in Figs. 1 (a, b) is compact, dense without any pores and cracks. The binding material (light areas) is located between cBN grains (dark areas).

Mechanical investigations
1) Young’s modulus determination
CBN composites present considerable difficulties for conventional material testing methods. They are produced in the form of cylindrical compacts, the sizes of which are too small to prepare samples for standard mechanical tests. In view of these problems the ultrasonic method became one of the most important testing techniques for cBN - based super-hard materials. Ultrasonic techniques can be used for detection of defects in sintered compacts as well as for determination of elastic constants of their material. Elastic properties of composite material are directly related to its composition and microstructure [5, 6].

The Young’s modulus of cBN-TiN composites was determined by measuring the velocity of the longitudinal and transversal ultrasonic waves transition through the sample [6]. The probe sets worked together with the ultrasonic flaw detector Panametrics Epoch III connected to the controlling PC. The calculations are carried out according to the following formula:

\[
E = \rho C_T^2 \frac{3C_L^2 - 4C_T^2}{C_L^2 - C_T^2},
\]

where: E - Young’s modulus; \(C_L\) - velocity of the longitudinal wave; \(C_T\) - velocity of the transversal wave; \(\rho\) - density of the material.
Fig. 2. Dependence Young’s modulus values of 38cBN/62TiN and 65cBN/35TiN composites on their sintering temperature.

It is possible to conclude on the base of the presented diagram (Fig. 2.), that Young’s modulus values of composites are correlated with their sintering temperature and the amount of binding phase. Characteristic, optimum conditions which gave good mechanical properties for composites with different cBN ratios were determined. Average Young’s modulus values for the best 65BN/35TiN and 38BN/62TiN composites are 619 GPa and 534 GPa respectively.

2) Hardness tests

Hardness is the second parameter of the evaluation of the composites. The hardness measurements are usually used to study the plasticity and cracking phenomena of super-hard materials [6].

The hardness of the composites was measured by Vickers method using an indentation load of 9.81 N.
Fig. 3 shows a comparison of hardness values of two composites groups (with higher and lower cBN contents). The hardness of the investigated composites grows along with the growth of contents of the cBN phase significantly. Average hardness values for the best 65BN/35TiN and 38BN/62TiN composites are 31.3 GPa and 23.5 GPa respectively.

3) Cutting tests

As a tool life criterion of cBN composites were performed cutting tests by continuous dry cut of hardened steel NC6 (56 HRC); cutting speed \( v_c = 150 \) m/min; feed rate \( f = 0.15 \) mm/rev; depth of cut \( a_p = 0.3 \) mm; wear threshold \( VB = 0.2 \) mm.
The cutting tests consistently showed that composites with 65% vol. of cBN perform better than those with 38% vol. of cBN. The tool life of inserts made of composites with 65% vol. and 38% vol. of cBN is 28 min. and 11.5 min. respectively. The growth of amount of cBN in composites from 38% to 65% increased the tool life about 2.5 times (Fig. 4).

**Conclusions**

The SEM observation allowed to evaluate the microstructure of the composites in the context of homogeneity ingredients distribution and flow detection (e.g. microcracks, porosity).

The mechanical investigations of the cBN composites included: the determination of the Young's modulus, hardness tests and cutting tests showing that value of the mechanical parameters strongly depends on the quantity of the cBN phase. With increasing cBN quantity from 38% vol. to 65% vol.:

- Young's modulus increasing from 534 to 619 GPa,
- Vickers hardness increasing from 23.5 to 31.3 GPa,
- tool life increasing about 2.5 times.

Owing to complex control both sintering parameters and mechanical properties of composites labour absorbing cutting test were limited to an essential minimum. Cutting test conducted on the best composites of each group shows that 65BN/35TiN composites have the best cutting performance.
References


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