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Science and technology in the recent development of boron nitride materials

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Abstract

In this paper, we review recent developments relating to cubic boron nitride (cBN) abrasive grains and sintered cutting tools. The demand for high-speed machining and the ecological benefits of using ferrous materials have led to developments in the area of heavy-duty dry cutting and grinding processes in recent years. Optimization of the process of manufacturing cBN materials is an important issue, both fundamentally and as regards applications. We review recent developments in cBN applications and discuss the challenges arising from new processes encountered in basic cBN study at high pressure and high temperature.

1. Cubic boron nitride (cBN) abrasive grains

As shown in figure 1, the morphology of cBN abrasive grains shows wide variability—ranging from cubo-octahedral-like to tetrahedral. A key aim in the production of cBN abrasives is finding a suitable process for synthesizing cBN with designed morphology and grain size at relatively low pressure. High-yield cBN production at lower pressure would have the benefit of reducing the production cost for cBN abrasives. Although many previous studies on various catalyst systems have been reported, no detailed report on the crystal morphology has appeared.

2. Non-binder-type cBN polycrystalline cutting tools

The reaction sintering process using a hot-pressed deoxygenated hBN mass as a starting material was developed by Akaishi *et al* [1]. This process resulted in superior TRS (transverse rupture strength) at high temperature and high thermal conductivity. Sumiya *et al* [2] analysed the average grain size of the sintered mass and found that the average grain size in the sintered body is less than $0.5\ \mu\text{m}$ when one selects an appropriate sintering temperature (see figure 2).

Sumiya *et al* [3] achieved cutting using grey cast iron produced using non-binder reaction sintered cBN (NBRS-cBN). BRS-cBN tools are superior in high-speed dry end-milling when working with grey cast iron.

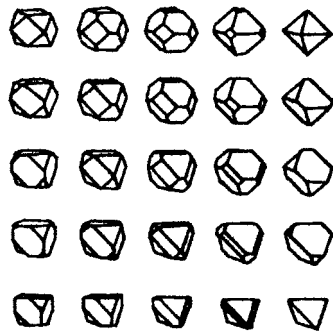


Figure 1. The morphology of cBN abrasive grains.

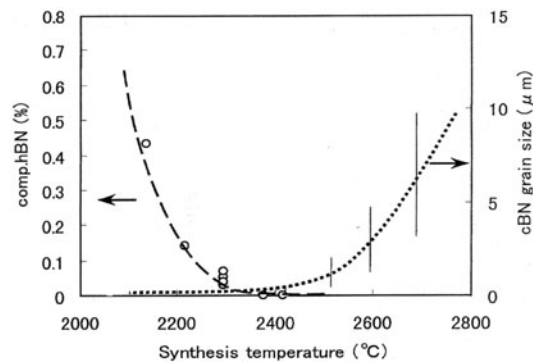


Figure 2. The grain size and amount of compressed hBN in the NBRs-cBN [2].

3. Non-binder sintering of cBN

Wakatsuki *et al* [4] reported on a NBRS process using hBN powder with an amorphous-like low degree of crystallization, but this process tends to result in there being residual hBN in the mass. Endo *et al* [5] developed a NBRS process using a small amount of Mg_3BN_3 catalyst. Sei *et al* [6] reported on a NBRS process using an hBN rod containing a small amount of HCl. With Endo and Sei's process, one can obtain fully dense cBN, but the grain size tends to increase up to 10–20 μm .

Taniguchi *et al* [7] reported on non-binder sintering of cBN powder at 7.7 GPa and between 1500–2400°C and concluded that fully dense cBN can be obtained between 2000 and 2350°C at 7.7 GPa.

Currently two issues—namely (i) grain size control by grain boundary trapping and (ii) the sintering condition at relatively low pressure—are of particular importance to realizing further development of this new class of cBN cutting tools.

4. The P – T conditions for formation and sintering of cBN

I have previously [8] presented a new hBN/cBN boundary line which can be expressed as

$$P \text{ (GPa)} = T \text{ (}^\circ\text{C)} / 465 + 0.79.$$

In the present report, additional experimental results supporting this phase boundary are given.

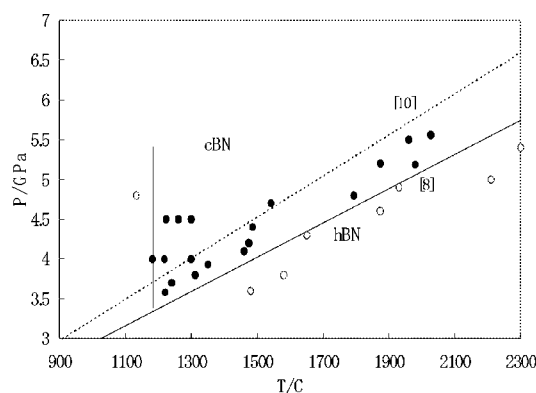


Figure 3. The P - T region for cBN formation using Mg_3BN_3 as the catalyst.

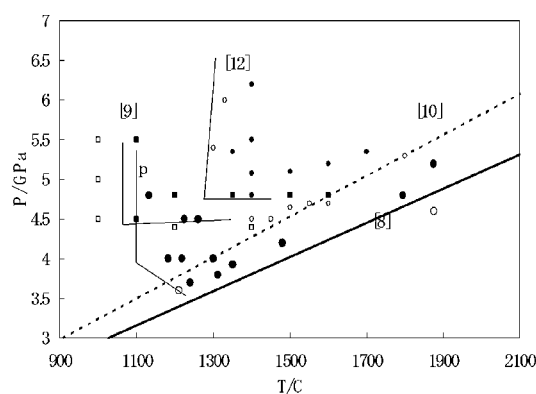


Figure 4. The P - T region for cBN formation using $Ca_3B_2N_4$ as the catalyst.

Experiments were performed using an FB25H-type belt apparatus. The catalyst powder, about 0.5 mm thick, was sandwiched by hBN plates 7 mm in diameter and 1.8 mm thick. In the cBN-forming P - T region, cBN crystals were formed at the hBN/catalyst boundary and extended into the hBN zone with increasing reaction time.

Figure 3 shows the P - T conditions for cBN formation using Mg_3BN_3 as the catalyst.

The threshold pressure of cBN formation reported by Nakano *et al* [9] was not found in this study. The threshold pressure presented previously resulted from the lower rate of reaction from hBN to cBN in the presence of catalytic melts.

As shown in figure 4, similar results on the formation and sintering of cBN can be obtained using $Ca_3B_2N_4$ as the catalyst. It was found that the rate of reaction from hBN to cBN is slow in the Mg- and Ca-catalyst systems at lower pressure. At 4 GPa of pressure, no cBN was found for a 20 min run and a very small amount of cBN was detected for an 80 min run. The content of cBN reached about 70–80% for 500 min.

The results in figures 3 and 4 indicate new scope for cBN formation. First, the sintering temperatures of cBN in both NBRs and NBS processes are extended to 2600 °C at 6.5 GPa and 2400 °C at 6 GPa and 2100 °C at 5.5 GPa, respectively. These P - T conditions are located in the stable region of hBN, based on the Bundy-Wentorf boundary line [10]. Second, if we carefully inspect the cBN formation with longer reaction time (up to 10 h), cBN was formed under P - T conditions very close to the phase boundary.

Although the rate of reaction in the lower-temperature region (1200–1300 °C) was slow, it would be of interest to find suitable additions for increasing the rate of reaction.

5. Emergent subjects to be confirmed by HPHT experiments

It is very important to determine the P – T region for formation of cBN in systems with various catalysts. Many data on this subject reported previously must be re-examined critically, because almost all available data lack results on the rate of reaction from hBN to cBN. Certainly, the P – T region of cBN formation decreases to the P – T points close to equilibrium. This subject will provide important information on the process of synthesis of cBN abrasives.

Study of the sintering conditions and microstructure observed for sintered cBN is another area to be examined. In particular, NBS and NBRS processes will be suitable for analysis from basic and applications points of view, because in a no-binder system it is simpler to study the transformation and sintering process of cBN.

In a NBRS process, it is important to check the behaviour of the direct phase transformation from hBN to cBN over a wider P – T region. The rate of conversion will be affected by the impurity and crystal structure of the starting hBN. The relation between the degree of conversion to cBN and the microstructure of the cBN compact will provide useful information on the non-binder reaction sintering process.

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