*Key Engineering Materials* *Online: 2008-02-11*
*ISSN: 1662-9795, Vols. 368-372, pp 1855-1857*
*doi:10.4028/www.scientific.net/KEM.368-372.1855*


# Fabrication and Mechanical Properties of $B_4C$/BN Laminated Ceramics

Wei-Liang Liu [1,2,a], Jun Tan [2,b], Chun-Bao Tang [2,c] and Chang-Chun Ge [1,d]

[1] University of Science & Technology Beijing, Beijing 100083, China

[2] Jingdezhen ceramic institute, Jingdezhen 333001, China

[a]jdzweiliang@163.com, [b]tony77980@163.com, [c]tcb2002315@163.com, [d]ccge@mater.ustb.edu.cn

**Keywords:** Laminated ceramic; Tape casting; $B_4C$/BN; Composites

**Abstract.** The $B_4C$/BN laminated ceramics were prepared by tape casting/coating. The effect of structure on the mechanical behavior of the $B_4C$/BN was studied. The results showed that the fracture toughness and bending strength are optimal when the layer thickness ratio ($e_{B4C}/e_{BN}$) is 15. The SEM photographs of $B_4C$/BN laminated ceramic indicated that the high fracture energy mainly resulting from crack deflection and crack delamination at the BN weak interface.

## Introduction

$B_4C$ is a covalently bonded compound with high melting point, extremely high hardness, low density, and high neutron absorption cross section [1]. However, low toughness significantly limits its potential applications. The laminated ceramic composites offer the best prospect for rational use of the unique physical mechanical properties of monolithic ceramics and ceramic-matrix composites which providing a way to improve the durability, toughness, wear, corrosion and thermal resistance, etc[2–6]. Therefore, a design of the laminated composites to improved mechanical performance such as SiC/C may be promising [7].The use of weak interface or interlayer can improve mechanical properties of laminates effectively. Graphite [7], boron nitride [8] or oxide ceramics ($LaPO_4$ or $YPO_4$) [9] as the weak interface were widely used in the laminated ceramics. In these materials, crack deflection occurred at the weak interface which resulting in the increase of fracture toughness.

The effect of the microstructure on the mechanical behavior of the $B_4C$ laminates was studied by others [10–11], but they merely observed the fracture behavior and the influence of porous interlays on the materials mechanical properties. The $B_4C$/BN laminates were fabricated by the tape-casting technique and hot-pressed processing in this study. The influence of the structure and the layer thickness ratio ($e_{B4C}/e_{BN}$) to the mechanical properties of laminates were investigated.

## Experimental

Boron carbide ($d_{50}$=1.5μm) powder was ball-milled for 24 hours with the organic solvent (MEK-Ethanol azeotrope, 60vol% butanone and 40vol% ethanol) and the triethyl phosphate (TEP) as dispersant to achieve a better dispersible effect. The polyvinyl butyral (PVB) as the cohesion, the polyethylene glycol (PEG) and the diethyl phthalate (PHT) were used to ensure the flexibility of the tape. After tape casting, the tape were cut into squares with a dimensions of 35×35mm, coated with slurry of BN, stacked in a predefined sequence and thermo-compacted under a pressure of 30MPa at a temperature of 80°C. Finally, the samples were debindered, pyrolyzed at a slow heating rate and sintered in graphite furnace under argon atmosphere at 2100°C under a pressure of 30MPa for 1 h.

Densities of the sintered samples were measured by the Archimedes' method. The bending strength was measured by three-point bending. The fracture toughness was measured by indentation-strength method. Microstructure analysis was carried out by scanning electron microscopy (SEM) after the samples was etched with NaOH solution.

## Results and Discussion

**Mechanical properties.** The macrostructure of $B_4C$/BN laminates are showed in Fig.1. The $B_4C$

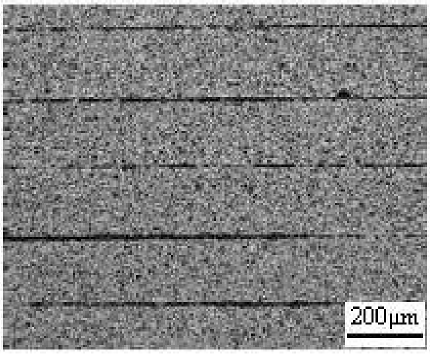


Fig.1. Macrograph of $B_4C$/BN laminates

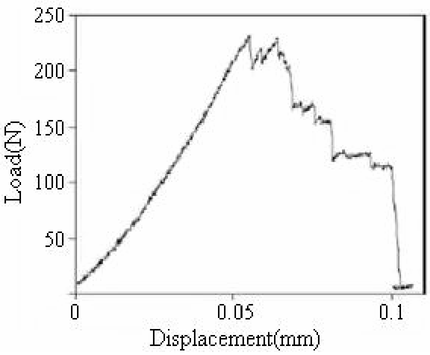


Fig.2. Load-displacement curve of laminates

layers show grey and the BN layers appear as thin and bright layers which separating the $B_4C$ layers. The BN layers in the laminates are aligned in the horizontal direction. The thickness of $B_4C$ layer is about 200μm, and the thickness of BN interlayer is about 20μm. The density of the sintered materials is 2.42 g/cm$^3$ by hot pressing at 2100 $^o$C.

In this study, the BN layer is fixed for 20μm, the influence of the layer thickness ratio ($e_{B_4C}/e_{BN}$) to the bending strength and fracture toughness are studied. Fig.2 shows a typical load-displacement curve of laminates during a three-point bending test. The crack is initial occurring on the tensile surface, and then it deflects along the weak interface. As the crack advances, the load drops owing to the increasing of specimen compliance. As the displacement further increases, the load and stress increase. Therefore, the crack propagation is assumed to occur when the load on the intact portion of the beam gives rise to a stress equal to a critical failure stress. Thus, the laminated ceramics possess plastic characteristic which shows a non-catastrophic fracture.

The influence of the layer thickness ratio ($e_{B_4C}/e_{BN}$) to the bending strength and fracture toughness is elaborated in the Fig.3. The bending strength of the laminates are mainly decided by the cooperation strength of $B_4C$ and BN, which have a very high sensitivity to the $e_{B_4C}/e_{BN}$. The bending strength increased as the value of $e_{B4C}/e_{BN}$ increase. The bending strength obtains the maximal value (418MPa) which is slightly lower than the monolithic boron carbide when the $e_{B_4C}/e_{BN}$ is 25. The fracture toughness and bending strength are up to 7.86 MPa·m$^{1/2}$ and 386MPa respectively when the layer thickness ratio ($e_{B4C}/e_{BN}$) is 15.

**The microstructure.** The SEM micrographs of $B_4C$ surface is shown in Fig.4. The grain size of boron carbide in the $B_4C$ layers is about 0.8μm. The small grain size of $B_4C$ gives the higher mechanical properties to the laminates. Fig.5 indicates that the weak layer is obtained by the skeleton of boron nitride and some pores which formed in the sintering process. The phase of boron carbide diffused into the BN interface and integrated with BN which offered the higher bending strength to the laminates.

Reinforcement by crack deflection is observed on the load–displacement curves, the succession of crack deflections and delaminating enhanced the load resistance. An example of cracking propagation along BN layer is showed in Fig.6. The crack deflectes and branches in the BN layer, and then the crack deflection and propagation occurred inside the interface, which result in lengthening the crack expansion way and increasing the fracture toughness of $B_4C$/BN laminates.

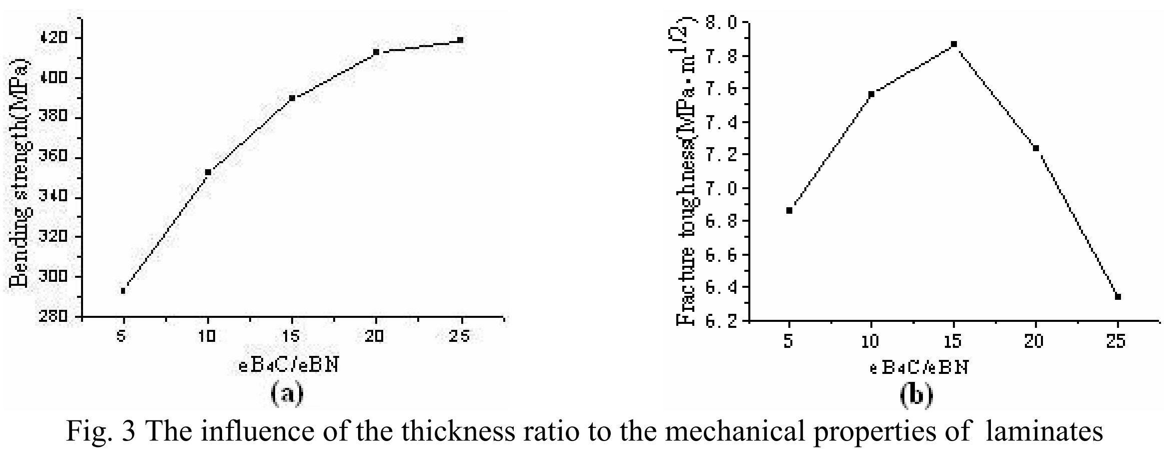


Fig. 3 The influence of the thickness ratio to the mechanical properties of laminates

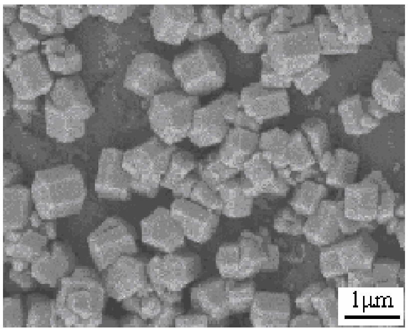


Fig.4.The SEM micrographs of $B_4C$ surface

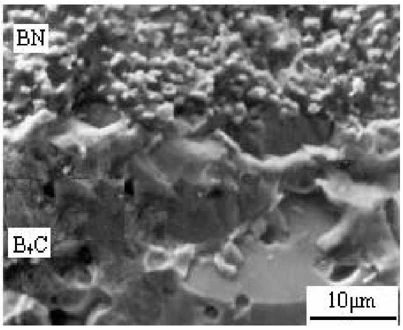


Fig.5. The SEM of fractured surface of laminates

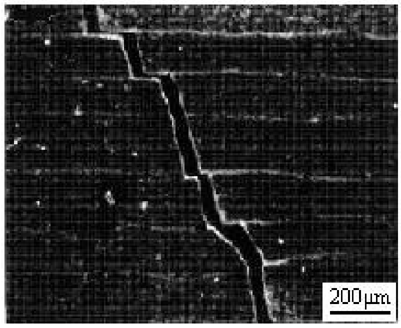


Fig.6. The cracking propagation of laminates

## Conclusions

$B_4C$/BN laminated ceramics are prepared by tape casting and hot pressing at 2100°C under a pressure of 30MPa for 1 h. The bending strength and fracture toughness of the laminates are closely related to the layer thickness ratio. The fracture toughness as high as 7.86 $MPa \cdot m^{1/2}$ is achieved and the bending strength reaches 386MPa when the $e_{B4C}/e_{BN}$ is 15. The SEM photographs of $B_4C$/BN laminated ceramic indicates that the high fracture toughness mainly resulting from crack deflection and crack delamination at the BN weak interface.

## References

[1] F.Thevenot: J. Eur. Ceram. Soc. Vol. 6 (1990), p.205.
[2] M.P. Harmer, H.M. Chan and G.A. Miller: J. Am. Ceram. Soc. Vol. 75(1992), p.1715.
[3] H.M. Chan: Annu Rev Mater Sci. Vol. 27 (1997), p.249.
[4] Y.Shigegaki, M.E. Brito, K. Hirao, *et al.*: J. Ceram. Soc. Jpn. Vol. 105 (1997), p.824.
[5] D.F. Lii, J.L Huang and F.C. Chou: J. Ceram. Soc. Jpn. Vol. 104(1996), p.699.
[6] V. Yaroshenko and V. Katashinskii: Can. Ceram Q J Can Ceram Soc. Vol. 66(1997), p.292.
[7] W.J. Clegg: Acta Metall. Mater. Vol. 40 (1992), p.3085.
[8] H.Y. Liu and S.M. Hsu: J. Am. Ceram. Soc. Vol. 79 (1996), p.2452.
[9] D.H. Kuo and W.M. Kriven: Mater. Sci. Eng. A. Vol. 241 (1998), p.241.
[10] S. Tariolle, F. Thevenot, T. Chartier, *et al.*: J. Eur. Ceram. Soc. Vol. 25 (2005), p.3639.
[11] S. Tariolle, C. Reynaud, F. Thevenot, *et al.*: J. Solid State Chem. Vol. 177 (2004), p.487.