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Thermal Shock Behaviors of AlN/BN Laminated Ceramic Composites

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AlN/BN laminated ceramic composites were fabricated by a flow casting method. The thermal shock behavior of both block AlN ceramics and AlN/BN laminated ceramic composites were carried out for comparison. To understanding the different of thermal shock resistance for the two materials, the microstructures were observed and the mechanical properties were tested. The results showed that, the thermal shock resistance of AlN/BN laminated ceramic composites was larger than that of block AlN ceramics. During the tests of residual strength after quenching from different temperatures, for the block AlN ceramics, the residual strength would decrease rapidly when the critical temperature difference ΔTc was larger than 450 °C, on the other hand, for the AlN/BN laminated ceramic composites, the residual strength would decrease slowly and there was no obvious ΔTc.

Key words: Aluminum Nitride, Boron Nitride, Laminated Composites, Thermal shock resistance.

Introduction

AlN ceramics are materials with an excellent thermal conductivity, thermal-expansion coefficient match with the silicon, low permittivity, good dielectric properties and good chemical stability [1-2] . Thus, they have been used in various fields, especially in electronic applications, where they could replace Al_2O_3 as a substrate. However, as with other ceramics with highly covalent bonds, they have the defects such as low toughness and weak thermal shock resistance. Therefore, it is very difficult to use in precise or high energy efficiency components. It have been reported [3-5] that laminated ceramic composites could improve the mechanical properties, cushion the stress concentration, counteract the crack propagation and increase the surface energy to fracture. Therefore, in order to enhance the thermal shock resistance and fracture toughness of AlN ceramics, in this study, AlN/BN laminated ceramic composites were fabricated, and the microstructure mechanical properties and thermal shock resistance were investigated.

Experimental Procedure

Preparation of Materials

AlN powder (0.5 μ), 3 wt.% Y_2O_3 and organic additives were mixed and cast into green tapes, and then coated with a BN-containing slurry. The tape-casting device is as shown in as Fig. 1. After coating, the green laminates were dried, stacked, and the organic additives removed. Finally, sintering was done in a graphite die, under 30 MPa pressure at 1,750 °C-1,850 °C for 1 hour in a nitrogen atmosphere. The specimens of AlN/BN laminated ceramic composites (ABL) were obtained by milling and polishing the hot-pressed bodies to 30 mm × 30 mm × 4 mm blocks.

Measurement of properties and observation of microstructures

The bending strength (σ_b) was determined by a three-point bending test (sample size 3 mm(height) × 4 mm(height) × 30 mm(length) at room temperature; with a span 20 mm; a load speed 0.5 mm/minute) averaged over 5 samples, on a INSTRON-1195, with the tensile surface of the specimens perpendicular to the hot-pressed direction. The specimen surfaces were finally ground on an 800 grit diamond wheel, and the edges were beveled. The fracture toughness (K_{1C}) was measured by single edge notched beam (SENB) method with a three-point bending test (sample size 3 mm(height) × 2 mm(width) × 30 mm(length); span 20 mm; gap width ≤ 0.3 mm; gap depth 0.5w ± 0.1 mm). The fracture toughness was averaged over 5 samples.

Fracture surface observations

The fractures surface were characterized by a scanning electron microscope (SEM, Model JSM 6460, JEOL Co. Ltd., Tokyo, Japan).

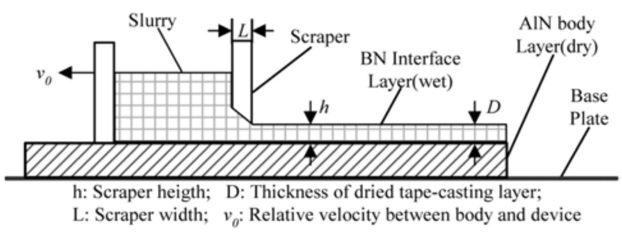

Fig. 1. schematic drawing of the tape-casting device.

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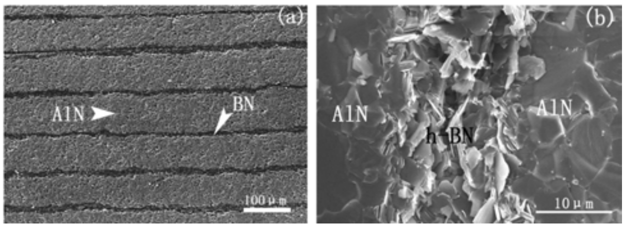

Fig. 2. SEM micrograph for AlN/BN laminated composites (a) Image of different layers; (b) Layer interfaces.

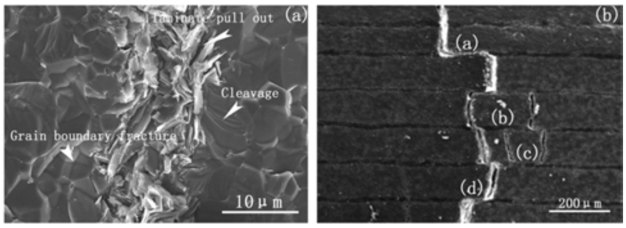

Fig. 3. SEM micrographs of crack propagation (a) Fracture surface; (b) crack propagation route.

Thermal shock resistance

The thermal shock resistance was investigated out by a quenching method. The test specimens were the same as the bending test specimens, they were heated up to expected temperature and held at that temperature for 20 minutes in an air furnace. Then the specimens were quenched into water at 20 °C. The residual strength was determined by a three-point bending test after thermal shock test. The thermal shock temperatures were from 200 °C to 700 °C.

Results and Discussion

Microstructure

Fig. 2(a) and (b) show the microstructure of ABL. Fig. 2(a) shows the thickness of AlN layer is about 10 times of thickness of BN layer. Details of the interfaces between the AlN layers and BN layers are shown Fig. 2(b).

Mechanical properties

In other research, it was found, that when the ratio of different layer thickness R (t_{AlN}:t_{BN}) was 10 and the total number of layers equals 60, the best synthetic mechanical properties would be obtained [4]. Table1 shows that the bending strength of ABL is about 92% of the AlN ceramic block (ANC), but the fracture toughness of ABL is about 3 times that of ANC. Therefore, a layered structure is one important way to toughen AlN ceramics.

The microstructure of ABL (Fig. 2(a), (b)) is different from ANC, and therefore, mechanical properties are different. Inside the ABL, the AlN layers are the strong phase with a higher strength and hardness, the BN layers are the weak phase with a lower strength and hardness. The weaker phase BN layers reduce the strength of the matrix AlN phase, on the other hand, because the interfaces between the AlN layers and BN layers have a good bond strength and BN layers have some flexibility, during any distortion is occurring, there is some coordination inside both layers [6], the BN layers can restrain the fracture. Therefore, after adding BN layers, the strength only drops slightly.

Table 1. Bending strength and fracture toughness of AlN block and AlN/BN laminated composites

Sample	σ_f (MPa)	K_{1C} (MPa·m^{-1})
ANC	418	3.0
ABL	387	9.1

For the fracture toughness, Fig. 3(a) shows SEM micrographs of crack propagation, where there are lots of river-like cleavage fractures inside the AlN grains and at the BN layer interfaces, grain boundary fractures inside the AlN grains, laminate pull out at the BN layer interfaces. The main toughening mechanisms of ABL is as shown in Fig. 3(b) including (a) delaminating, (b) crack branching, (c) crack parallel propagation, (d) crack deflection, all of these extend the crack propagation path and improve the fracture toughness of composites.

Thermal shock resistance

Fig. 4 shows the thermal shock curve of ABL and ANC. The critical fracture temperature difference of ANC is about 450 °C (ΔTc), when the thermal shock temperature exceeds this temperature, the residual strength of ANC decreases sharply, but there is no obvious critical fracture temperature difference for ABL. When the temperature difference is lower than 450 °C, the residual strength of ABL is lower than ANC slightly, and when temperature is higher than 450 °C, the residual strength of ABL is higher than ANC more obviously.

The mechanisms of thermal shock fracture for compact ceramics and laminated ceramic composites are different. For compact ceramics (AlN block), the appropriate thermal shock fracture resistance parameters depend on the heat flow conditions [7].

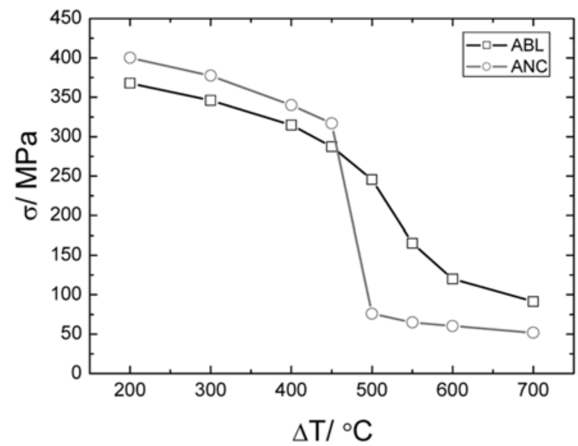

Fig. 4. Residual strength of ABL and ANC after thermal shock tests.

$$R = \sigma_f(1 - \mu)/(E\alpha) \quad (1)$$

Here, E is the Young's modulus; μ is Poisson's ratio and α is the linear expansion coefficient. To avoid fracture initiation by thermal shock, the favorable material characteristics include high values of strength and thermal conductivity and low values of modulus and thermal expansion coefficient. If the thermal shock stress exceeds a critical stress σ_c, catastrophic failure will occur in this type of material. Therefore, for ANC, there is a sharp decrease in the residual strength at the fracture critical temperature difference (ΔTc) of 450 °C.

But for laminated ceramic composites, the thermal shock damage resistance parameters are minimum elastic energy at fracture available for crack propagation and the minimum distance of crack propagation on the initiation of thermal stress failure:

$$R'''' = E \cdot \gamma_{eff}/(\sigma_f^2 \cdot (1 - \mu)) \quad (2)$$

Here, γ_{eff} is the surface work of fracture; σ_f is the fracture strength [7] . Fracture toughness $K_{1C} = (2E\gamma_{eff})^{1/2}$, and therefore, eq.2 can be changed to:

$$R'''' = K_{1C}^2/(\sigma_f^2 \cdot (1 - \mu)) \quad (3)$$

We can see, the thermal shock damage resistance is proportional to K_{1C}^2 and inversely proportional to σ_f^2.

Therefore, for ABL, due to the existence of the h-BN weak layers, the crack propagation is restrained and the propagation route is extended, the residual strength of ABL decreases slightly with a thermal shock temperature increase. We can see that the thermal shock resistance of ABL is better than ANC when the temperature difference is higher than 450 °C (ΔTc).

Conclusions

When thermal stress acts on AlN/BN laminated ceramic composites, because the BN weak layers can disperse the stress concentration, restrain crack propagation and extend the crack propagation route, fracture toughness is obviously increased, the thermal shock damage resistance of ABL is better than ANC.

Comparing the residual strength of ABL and ANC after quenching, there is a critical fracture temperature difference (ΔTc) of about 450 °C for ANC, when the thermal shock temperature exceeds this temperature, the residual strength of ANC decreases sharply and there is no obvious critical fracture temperature difference for ABL. This behavior is induced by the existence of weak BN layers which can disperse the stress concentration, restrain crack propagation and extend the crack propagation route.

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