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# Dynamic Observation of Fracture Process in Laminated Ceramic Matrix Composites

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## ABSTRACT

Laminated ceramic composite is a new type of material developed in recent years to improve the mechanical properties of structural ceramics. Gel casting and hot-pressure sintering technologies were used to obtain the laminated SiC/BN-Al2O3 composite. Mechanical properties of the laminated composite and monolithic SiC ceramic were compared, and the fracture toughness of the laminated composite is nearly one times higher than that of the monolithic ceramic. Dynamic process of crack propagation in laminated composite was observed in situ by SEM. The interfacial crack initiate first in interlayer near to the notch tip, and then the through layer crack formed in matrix layer at the notch tip. After the through layer crack grows across the first matrix layer, it can be deflected by the interlayer and becomes an interfacial crack again. The through layer crack and the interfacial crack are generated alternately until the failure of the composite. The load / displacement plot of laminated material possess several peaks, and each peak is caused by one propagation of the through layer crack. Toughening mechanisms of the laminated composite include crack deflection, interfacial crack, through layer branch crack and parallel main crack.

## INTRODUCTION

Some nature materials, such as marine shells and abalone shells, possess hierarchical structure formed by aragonite layers that are joined by a mortar of protein [1]. Because of this particular configuration, the bending strength and toughness are increased by one order of magnitude relative to a single crystal of aragonite [2]. In the last ten years, ceramic matrix composites with similar laminated structure have been developed and considered to offer one of the most important approaches to the problem that ceramic materials lack damage-tolerance [3-5]. Dynamic process of crack propagation in a SiC/BN-Al2O3 laminated composite was observed, and mechanical properties and toughening mechanisms of the laminated ceramic composite were studied in this paper.

## MATERIALS AND EXPERIMENTAL PROCEDURES

PREPARATION OF TESTING MATERIALS – The material selected for this investigation is SiC/BN-Al2O3 laminated ceramic composite .The matrix material of the composite is SiC with La2O3 and Y2O3 additives, and the average size of SiC particle is 0.9 mm. Aqueous Gel Casting (AGC) technology [6] was used to make the matrix material into layer with a thickness of 0.4mm. Then BN-25wt%Al2O3 was deposited on the surface of matrix layer by infusion method. The layers were piled up and sintered by hot-pressed (HP) technologies of 1850¡æ, 25MPa, 1h with N2 protection. The block material of SiC matrix was also prepared by the same HP technologies for comparing its mechanical properties to the laminated composite.

EXPERIMENTAL METHOD – Dynamic process of crack propagation in the laminated composite was observed by S-570 scanning electron microscope. The flexural strength of testing material was measured by three-point bending method with the specimen of 3mm by 4mm by 36mm, and the fracture toughness was measured by single edge notched beam (SENB) method with the specimen of 2.5mm by 5mm by 25mm with a notch 2.5mm in deep. The mechanical properties tests were carried out in MTS-810 machine.

## RESULTS AND DISCUSSIONS

MECHANICAL PROPERTIES OF TESTING MATERIAL – The mechanical properties of the SiC/BN-Al2O3 laminated ceramic composite and the SiC block material are given in table 1. It can be seen from the table that the flexural strength of laminated material is somewhat lower than that of block material. But the fracture toughness of the former is almost one times higher than that of the latter. Therefore, laminated composite is an efficient way to improve the fracture toughness of ceramics and maintain its strength meanwhile.

Table 1. Mechanical properties of block ceramic and laminated composite

| Material | Flexural strength (Mpa) | Fracture toughness ($MPam^{1/2}$) |
|---|---|---|
| SiC | 698 | 9.3 |
| SiC/BN-Al2O3 | 623 | 17.7 |

DYNAMIC OBSERVATION OF FRACTURE PROCESS IN LAMINATED COMPOSITE - The crack propagation in notched specimens of SiC/BN-Al2O3 laminated ceramic composite under three-point bending loading was observed in situ by SEM. Figure 1 shows the different stages of fracture process in the laminated composite. It can be seen that the laminated composite consists of alternate compact matrix layers and porous interlayer. The thickness of each matrix layer is about 0.15mm, and the thickness of interlayer is about 20mm. The notch tip of the testing specimen is at the center of a matrix layer (Fig.1a). After bending load applied to the notched specimen, interfacial crack initiate first in interlayer near to the notch tip (Fig.1b), and then through layer crack formed in matrix layer at the notch tip (Fig.1c). When through layer crack grows across the first matrix layer and reaches the next interlayer, the stresses act on crack-tip will change from three dimension to two dimension because the interlayer is very weak, so the crack should be blunted and deflected at weak interlayer oriented transversely to the main crack propagation direction and form a new interfacial crack (Fig.1d). Much energy is consumed in this process. Along with the increase in far field bending stress, through layer crack should be created again in next matrix layer. After the crack propagates through the new matrix layer, it should be deflected by the next interlayer again (Fig.1e). And then, such process is repeated continually until the failure of the laminated composite (Fig.1f).

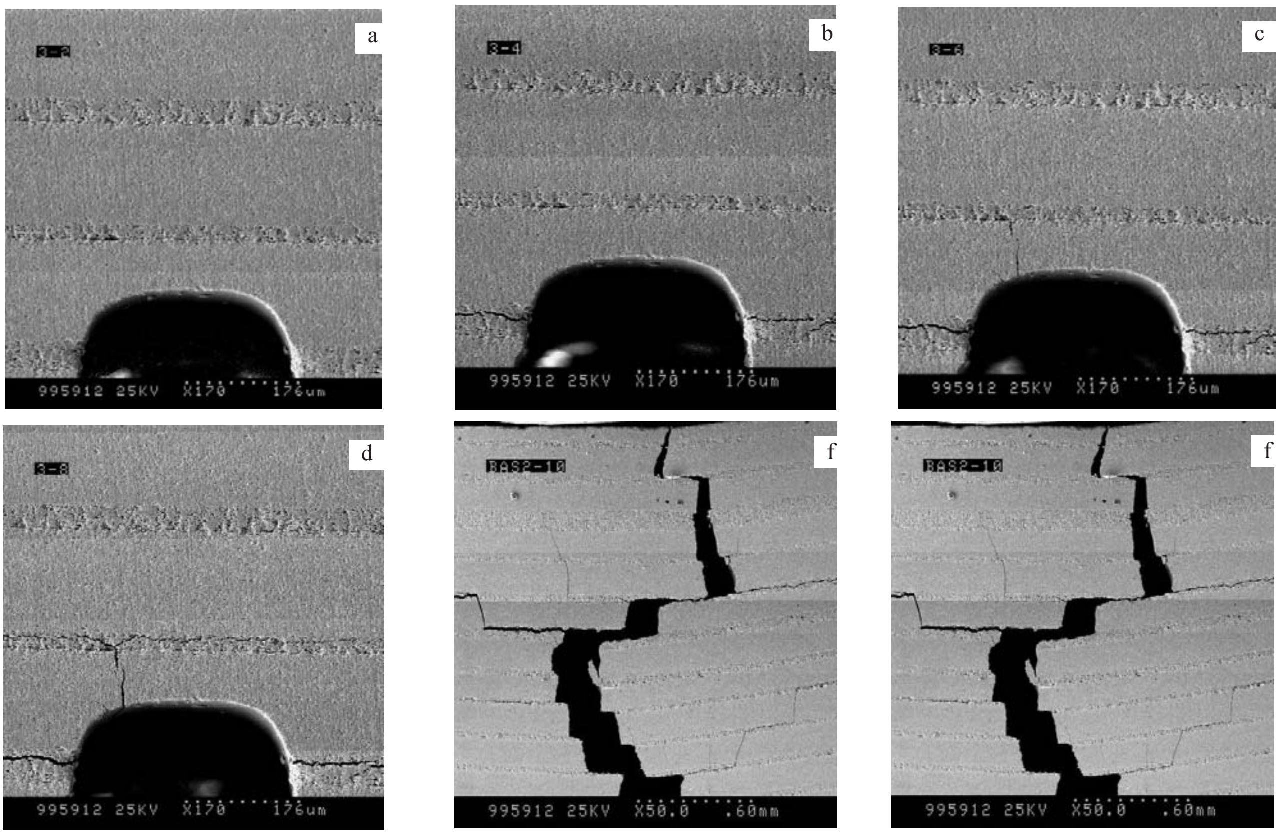
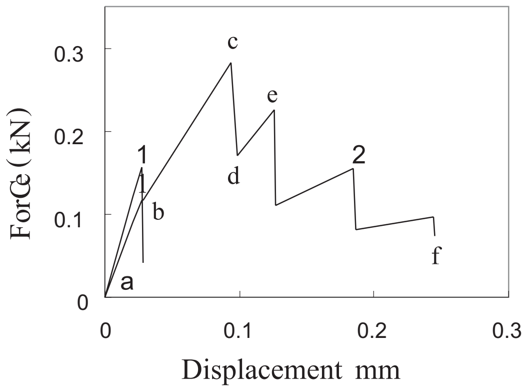



Figure 1. Dynamic process of crack propagation in the laminated composite.a. Before loading b. Interfacial crack initiation in interlayer c. Through layer crack formed in matrix layer d. Crack deflection in next interlayer e. Crack crosses matrix layer and deflects again f. Laminated composite failure

TOUGHENING MECHANISMS - Figure 2 shows the load / displacement plots for notched specimens of monolithic and laminated materials in three point bending test. It is very clear that the fracture mode of monolithic SiC ceramic is typical brittle fracture (curve 1), and the fracture process is finished for an instant. The Young's modulus of monolithic material is a little higher than that of the laminated composite. The crack propagation in laminated SiC composite possesses a sinuous process. The load / displacement plot of laminated material (curve 2) has several peaks. The maximum load of laminated composite is almost one times higher than that of the monolithic material, and the displacement of the former is increased by one order of magnitude relative to the later. Therefore, the fracture toughness and fracture work of laminated composite are improved essentially by its special structure Figure




2. Typical load / displacement plots for notched specimens of monolithic and laminated materials in bending test.

1. Monolithic material 2. Laminated ceramic composite

Contrasting the Fig.2 and the Fig.1, We can find that point b in curve 2 is a turning point of slope, and it is caused by the initiation of the interfacial crack in Fig.1b. Point c, which is the first peak of curve 2, is formed by the first drop of far field stress because the through layer crack grows across the first matrix layer in Fig.1c. After the stress descends to the point d in curve 2, the stress reincreases again because the through layer crack is deflected by interlayer and become an interfacial crack in Fig.1d, so the first minimum point in curve 2 appears. When the through layer crack reconstructs and propagates through the second matrix layer in Fig.1e, the second peak in curve 2 is formed at point e. Finally, at the point f in curve 2, the laminated composite fail completely as shown in Fig.1f. Along with the propagation of through layer crack, the carrying capacity and the stiffness of laminated composite become lower and lower, so the height and slope of the peaks in curve 2 decrease in turn.

The increases in fracture toughness and fracture work of the laminated composite are mainly caused by the crack deflection and the interfacial crack propagation oriented transversely to the main crack propagation direction. In addition, through layer branch crack (shown in Fig.3) and parallel main crack (shown in Fig.4) contribute partly to the improvement of the fracture toughness and fracture work. In the two cases, one matrix layer can break at two or more places, so the sum of the fracture area increase greatly and more energy is consumed.

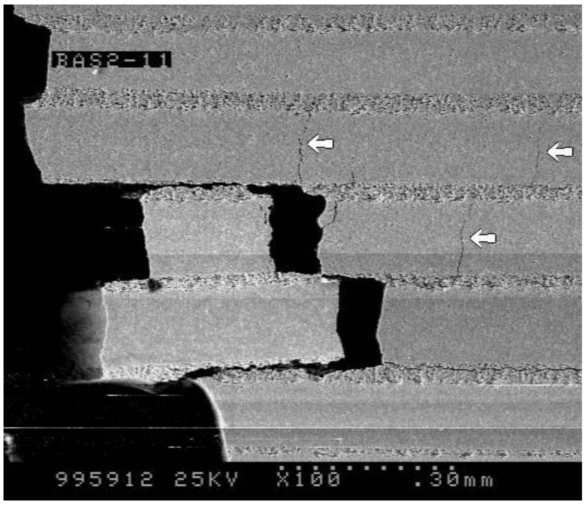



Figure 3. Through layer branch crack in SiC/ BN-Al2O3 laminated composite.

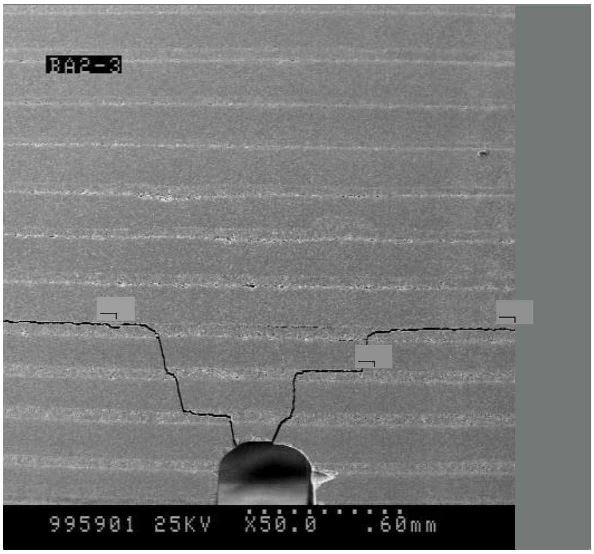



Figure 4. Parallel main crack in SiC/ BN-Al2O3 laminated composite.

## CONCLUSIONS

As a result of this study, the following conclusions are reached:

1. Laminated composite is an efficient way to improve

the fracture toughness of ceramics. The fracture toughness of a SiC matrix laminated composite is almost one times higher than that of the monolithic SiC ceramic. Meanwhile, the flexural strength of the former is somewhat lower than that of the latter.

2. Dynamic process of crack propagation in laminated composite was observed in situ. The interfacial crack initiate first in interlayer near to the notch tip, and then the through layer crack formed in matrix layer at the notch tip. Because the weak interlayer can deflects the crack, the interfacial crack and the through layer crack are generated alternately until the failure of the composite.

3. The load / displacement plot of laminated material possess several peaks, and each peak is caused by one propagation of the through layer crack. The displacement of the laminated composite is increased by one order of magnitude relative to the monolithic ceramic, so the fracture work of laminated composite are improved essentially.

4. The toughening mechanisms of laminated ceramic composite include crack deflection, interfacial crack, through layer branch crack and parallel main crack.

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