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Influence of Interlayer on Mechanical Properties of Laminated Ceramic Matrix Composites

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Abstract. Influences of different interlayer materials on mechanical properties of SiC matrix laminated ceramic composites were investigated. Gelcasting and hot-pressure sintering technologies were used to obtain the laminated SiC matrix composites with 5 different components of BN-Al_2O_3-SiC interlayers. The BN-Al_2O_3-SiC interlayer block materials and the SiC matrix material were also prepared by hot-pressure sintering. Mechanical properties of the laminated composites and block ceramics were tested. It was shown that the property of the interlayer material has very important influence on the mechanical properties and fracture behavior of laminated ceramic composites. It will make against the improvement of the mechanical properties of composites that the strength ratio of matrix to interlayer is too high or too low. When strength ratio reaches about 4.1, which is the optimal value, the crack deflection effect caused by interlayer is very notable in the fracture process of laminated composites, and the fracture toughness and fracture work of laminated composite are improved essentially, as well as the flexural strength of laminated composite maintains its high level.

Introduction

The main factor that limits the application of structural ceramics in engineering is the brittleness. General method to improve the mechanical properties of ceramics is component adjustment such as adding the second phase particle, whisker, fiber etc. into the ceramic matrix. Laminated ceramic composite is a new way developed in recent years to toughen the ceramics by changing the structure of composite [1]. 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 [2]. Because of this particular configuration, the bending strength and toughness are increased by one order of magnitude relative to a single crystal of aragonite [3]. This illumes the idea that ceramic matrix composites with similar laminated structure maybe possess excellent mechanical properties. It has been demonstrated that laminated ceramic composites offer one of the most important approaches to the problem that ceramic materials lack damage-tolerance [4-6]. In this paper, influence of different interlayer materials on mechanical properties of a series of SiC matrix laminated composites was researched.

Materials and Experimental Procedures

Preparation of testing materials. The materials selected for this investigation are SiC matrix laminated ceramic composites with different BN-Al_2O_3-SiC interlayer materials. The matrix material of the composites is SiC with La_2O_3 and Y_2O_3 additives, and the average size of SiC particle is 1.0 μm. Aqueous Gel Casting (AGC) technology [7] was used to make the matrix material into flakes with a thickness of 0.4mm. After BN-Al_2O_3-SiC interlayer materials were deposited on the surface of matrix flakes by infusion method, the flakes were piled up and sintered by hot-pressed (HP) technologies of 1850°C, 25MPa, 1h with N_2 protection. The block specimens of SiC matrix and 5 interlayer materials were also prepared by the same HP technologies for measuring the mechanical properties of matrix and interlayer materials respectively.

Experimental method. The mechanical properties tests of the materials were carried out in MTS-

810 machine. The flexural strength of testing material was measured by three-point bending method with the specimen of 3mm by 4mm by 36mm, and the rate of loading is 0.5mm/min. 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, and the loading rate is 0.05mm/min. The loading direction of mechanical property tests is perpendicular to the layer plane of the composites. Microstructures of the laminated composites were observed by S-570 scanning electron microscope.

Table 1. Mechanical properties of SiC matrix ceramic

Material	Flexural strength [MPa]		Fracture toughness [$MPam^{1/2}$]		Young's Modulus [GPa]
	RT	1250°C	RT	1250°C	
M1	698	553	9.3	11.8	312

Table 2. Mechanical properties of the 5 interlayer material blocks

Materials	BN Content [wt%]	RT strength [MPa]	1250°C strength [MPa]	Young's Modulus [GPa]
I1	25	409	382	120
I2	45	200	135	59
I3	50	140	86	46
I4	55	160	92	45
I5	75	115	21	33

Results and Discussion

Mechanical properties of SiC matrix and interlayer materials. The mechanical properties of SiC matrix material at room temperature and elevated temperatures are listed in Table 1. The SiC matrix possesses high flexural strength and fracture toughness at room temperature. However, at 1250°C, its strength decreases to a certain degree, but its toughness is higher than that at room temperature.

Mechanical properties of the 5 interlayer block materials are given in Table 2. Fig. 1 shows the influence of BN content in interlayer materials on mechanical properties of interlayer block. The downtrend of flexural strength and Young's modulus of the interlayer block materials can be seen from the figure along with the increase in the content of BN. The drop rate of strength is faster at elevated temperature than it at room temperature. The strength of an interlayer material with 75wt% BN in it almost lose completely at 1250°C. The flaws in interlayer material increase with an addition of BN content because BN powder can't be sintered at material preparation conditions. Therefore, the strength and modulus of interlayer material decrease with an increase in BN content.

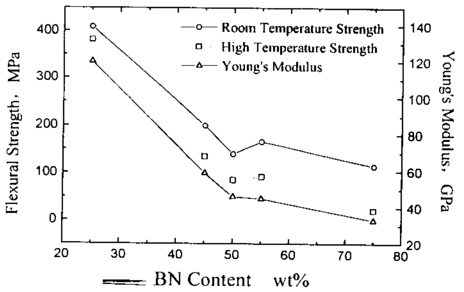


Fig. 1 Influence of BN content on mechanical properties of interlayer block materials.

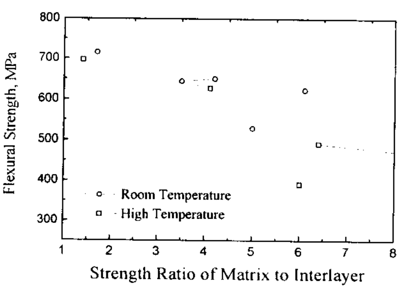


Fig. 2 Relationship between flexural strength of laminated composites and the ratio of matrix strength to interlayer strength.

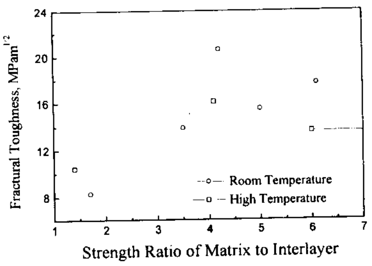


Fig. 3 Relationship between fracture toughness of laminated composites and the ratio of matrix strength to interlayer strength.

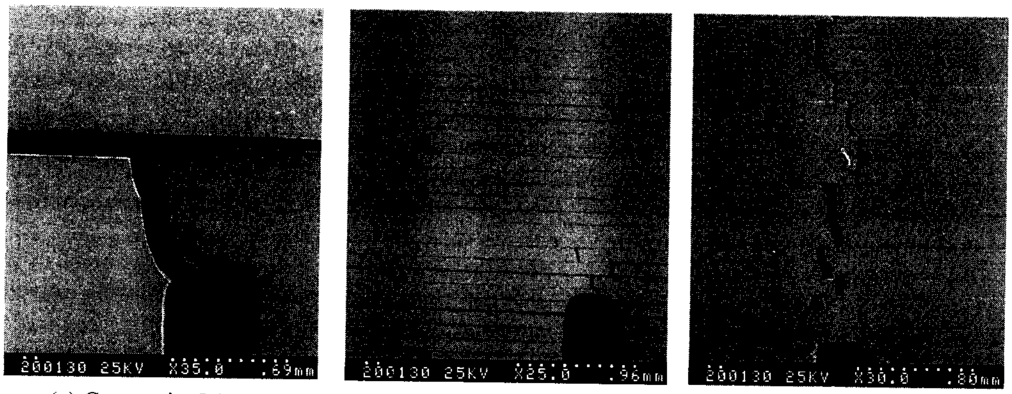
Influence of Interlayer Materials on Mechanical Properties of Laminated Composites. Five SiC matrix laminated composites L1~L5 were obtained with five different interlayer materials I1~I5 respectively as shown in Table 2. The improvement of fracture toughness in laminated ceramic composite is caused by adding weak interlayer into ceramic matrix. Therefore, the mechanical properties of laminated composite are closely related with the interlayer material. Figs. 2 and 3 show respectively the relationship between flexural strength and fracture toughness of laminated composites with the ratio of matrix strength to interlayer strength. It can be seen from Fig.2 that there is a general downtrend in the flexural strength along with the increase in strength ratio of matrix to interlayer both at room temperature and elevated temperature. However, in Fig.3, it is obvious that there are peaks in the two curves of fracture toughness, and the corresponding strength ratio is about 4.1 both at room temperature and elevated temperature.

Contrasting Fig. 2 with Table 1, it can be found that the room temperature flexural strength of composite L1 (There is 25wt% BN in interlayer) is a little higher than the matrix. Although strength of the others are lower than matrix, they still possess rather high flexural strength at room temperature. The strength of composites exceeds the matrix strength at high temperature when BN content in interlayer is low (Composites L1 and L2). Along with the increase in strength ratio of matrix to interlayer, flexural strength of composites decline more quickly at elevated temperature than it at room temperature. So there are marked influence of interlayer material on flexural strength of laminated composites at elevated temperature.

Contrasting Fig. 3 with Table 1, it is obvious that the fracture toughness of the testing laminated composites is higher than the matrix both at room temperature and elevated temperature except the composite L1. The room temperature toughness of composite L4 increases by one times over the matrix. The toughness of composites is higher at elevated temperature than it at room temperature when BN content in interlayer is low (Composites L1 and L2). Therefore, the laminated composite is an effective process to improve the toughness of ceramics.

Generally, when the strength of interlayer material approach the strength of matrix, laminated composites possess high strength but low toughness. With the increase in strength ratio of matrix to interlayer, there are a slight drop in strength and a rapid rise in toughness for the laminated composites. When strength ratio reaches 4.1, the fracture toughness of laminated composite attain its maximum value both at room temperature and elevated temperature, while the flexural strength of composite maintains higher level, so the strength and toughness are a good match. Augmenting the ratio to 5~6, there are a marked decline both in strength and toughness of composites, and minimum points appear in curves. Therefore, if the strength of interlayer material is too high or too low, it will make against the improvement of the mechanical properties of laminated ceramic composites. To guarantee high mechanical properties in laminated composite, it is very important that the strength ratio of matrix to interlayer is controlled accurately in a proper level in the material design and preparation processes.

Influence of Interlayer Materials on Fracture Behaviors of Laminated Composites. Introducing weak interlayer into ceramic matrix can induce the change of fracture behavior when material is broken, and it will make the difference in mechanical properties between laminated composites and matrix material. The crack propagation in notched specimens of laminated composite under three-point bending loading is observed by SEM. The typical crack propagation path in composite L1, L4 and L5 are shown in Fig. 4. For the composite with less BN in the interlayer (Composite L1), it is very difficult to distinguish the matrix layer and the interlayer from outside, because the two kinds of layer become almost a block material by HP sintering. The fracture behavior of composite L1 is also similar with the matrix material, and there is no crack deflection or only 1 or 2 crack deflection in the failure process, as shown in Fig. 4(a). Therefore, the toughening effect is not distinct and the composite L1 possess high strength and low toughness.



(a) Composite L1 (b) Composite L4 (c) Composite L5

Fig. 4 Crack propagation path in Composite L1, L4 and L5

For composite L4, room temperature strength ratio of matrix to interlayer is within the optimal range. It can be seen from Fig. 4(b) that the laminated composite consists of alternate thick matrix layers and thin interlayer, and the crack propagation in the composite possesses a sinuous process. After crack initiates under the maximum bending load, the crack can't pass through the whole specimen immediately as it does in block material. When through layer crack grows across the matrix layer and reaches the next interlayer, the crack will be blunted and deflected at interlayer oriented transversely to the main crack propagation direction and become an interfacial crack because of the deflection effect caused by interlayer. There are several large crack deflections and series of small crack deflection in the fracture process, as shown in Fig. 4(b). Therefore, the fracture toughness and fracture work of the composite outclass the matrix material.

If there is too much BN in the interlayer (Composite L5), the strength ratio of matrix to interlayer will go beyond the proper range. Although the interlayer has ability to deflect crack, it consume less energy than composite L4 because the interlayer is too weak. It can be seen from Fig. 4(c) that there are many small crack deflection but no large crack deflection in composite L5. Therefore, the toughening effect and the mechanical properties are not so good as the composite L4.

Conclusions

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

The property of the interlayer material has very important influence on the mechanical properties of laminated ceramic composites. Along with the increase in the ratio of matrix strength to interlayer strength, there is a downtrend in flexural strength of laminated composites, especially at elevated temperature; meanwhile, there is a peak in fracture toughness. It will make against the improvement of the mechanical properties of composites that the strength ratio is too high or too low. When strength ratio reaches 4.1, the fracture toughness and the flexural strength of laminated composite are a good match.

There is a close relationship between the property of interlayer material and the fracture behavior of laminated ceramic composites. The fracture behavior of composite is similar with the matrix material when the strength ratio of matrix to interlayer is too low. The crack deflection effect caused by interlayer is not marked when the strength ratio of matrix to interlayer is too high. There are several large crack deflections and series of small crack deflections in the fracture process of laminated composites when the strength ratio is within the optimal range, so the fracture toughness and fracture work of laminated composite are improved essentially.

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