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Effect of fiber characteristics on fracture behavior of C_f/SiC composites①

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[Abstract] C_f/SiC composites were prepared by precursor pyrolysis-hot pressing, and the effect of fiber characteristics on the fracture behavior of the composites was investigated. Because the heat treatment temperature of fiber T300 (below 1500 ℃) was much lower than that of fiber M40JB (over 2000 ℃), fiber T300 had lower degree of graphitization and consisted of more impurities compared with fiber M40JB, suggesting that T300 exhibits higher chemical activity. As a result, the composite with T300 showed a brittle fracture behavior, which is mainly ascribed to a strongly bonded fiber/matrix interface as well as the degradation of fibers during the preparation of the composite. However, the composite with M40JB exhibits a tough fracture behavior, which is primarily attributed to a weakly bonded fiber/matrix interface and higher strength retention of the fibers.

[Key words] C_f/SiC composites; fiber characteristics; fracture behavior

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1 INTRODUCTION

Fiber-reinforced ceramic composites have attracted great attention for being used in high-temperature structural applications recently[1, 2]. This is mainly due to the assumption that the strong fibers can prevent catastrophic fracture behavior in ceramics by providing various energy-dissipation processes during crack spread, and many reports have demonstrated the potential of this approach[3~5].

Carbon fibers, which are available at much lower cost than other ceramic fibers, possess excellent properties such as low density, high strength and high modulus at high temperature, so carbon fiber-reinforced ceramic matrix composites have been recognized as candidates for advanced structural materials in aerospace applications. There are several methods to fabricate fiber/SiC composites, such as chemical vapor infiltration (CVI)[6, 7], slurry infiltration combined with hot-pressing[8, 9], polymer impregnation and porolysis[10, 11] and reaction sintering, etc.

It is well known that a weak fiber/matrix interface is preferred in order to obtain high-performance fiber-reinforced ceramic composites[12, 13], and the interfacial bonding strength is related to the microstructure of the fibers and matrix as well as fabrication processes. Since there are some types of carbon fibers, which show different structures, it can be expected that these carbon fibers may show different behavior in ceramic matrix composites. In this paper, two types of typical carbon fibers are selected to prepare C_f/SiC composites, and effect of fiber characteristics on the fracture behavior of the composites is investigated.

2 EXPERIMENTAL

The high-strength fibers for this study were M40JB (higher modulus) and T300 (lower modulus). The composites were fabricated by precursor pyrolysis-hot pressing. First, unidirectional fiber-aligned perform tapes were prepared by infiltrating the fibers with a slurry consisting of α-SiC, polycarbosilane (PCS), sintering additives (Y_2O_3 and Al_2O_3) and xylene in a ratio of 48% SiC∶40% PCS∶7% Y_2O_3∶5% Al_2O_3 (mass fraction), and winding slurry-infiltrated fibers onto a mandrel. After drying, the prepared tapes were cut, stacked and prepressed into compacts. The compacts were then hot pressed for 1 h under a pressure of 25 MPa at 1800 ℃ in a flowing argon atmosphere. The fiber volume fraction of the composites is about 0.5.

Bulk densities of the composites were measured by the Archimedes principle. Flexural strength and interlaminar shear strength were determined using a three-point-bending test on bars of 3 mm × 4 mm × 35 mm with a span of 30 mm and 15 mm, respectively. The cross-head speed was 0.5 mm/min. For fracture toughness, a single-edge-notched-beam (SENB) test was applied on notched bars of 2.5 mm × 5 mm × 35 mm with a span of 20 mm and a cross-head speed

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of 0.05 mm/min. The notch was 0.3 mm in width and 2.5 mm in depth. Characterization of the microstructure of the fibers and fractographs of the composites were performed by HRTEM and SEM, respectively.

3 RESULTS AND DISCUSSION

Table 1 lists the densities and mechanical properties of the composites with fiber M40JB (C1) and T300 (C2). It can be seen that the flexural strength and fracture toughness of composite C1 are much higher than those of composite C2, indicating that fiber M40JB is more suitable as reinforcement in C_f/SiC composites than fiber T300. Fig. 1 shows the load—displacement behavior of the composites. Composite C2 fails in an obvious brittle mode. In contrast, the load—displacement behavior of composite C1 is markedly non-linear, indicating that composite C1 fails in a non-brittle mode. Considering that the fiber/matrix interface plays a key role in controlling the properties of the composites[13, 14] and the composites are prepared under the same conditions, it is believed that the great difference in mechanical properties can be rationalized on the basis of the difference in the characteristics of fiber/matrix interfaces, which depends primarily on the microstructure of the fibers.

Table 1 Properties of composites with fiber M40JB or T300

Composite	Fiber type	Density /(g·cm^{-3})	Shear strength /MPa	Flexural strength /MPa	Fracture toughness /(MPa·m$^{1/2}$)
C1	M40JB	2.39	31.5 ± 3.4	421.6 ± 30.8	14.9 ± 1.7
C2	T300	2.32	38.9 ± 4.1	285.7 ± 28.3	8.4 ± 2.3

It is well known that carbon fibers are of turbostratic structure[15], which is mainly related to the heat treatment temperatures. Because the heat treatment temperature of M40JB (over 2000 ℃) is much higher than that of T300 (below 1500 ℃), M40JB has a higher degree of graphitization compared with T300, which is indicated by XRD patterns of the carbon fibers as shown in Fig. 2. In general, carbon fibers with lower degree of graphitization exhibit higher chemical activity, such as chemical reactions. Fig. 3 shows the HRTEM micrographs of the fibers, which also confirmed that fiber M40JB has a much higher degree of graphitization than T300. It is also known that fibers treated at lower temperatures consist of more impurities (such as N, O, H), which are left during the pyrolysis of the precursors, than those treated at higher temperatures. So it is reasonable that the impurities in the fibers will affect the microstructure and properties of the fibers during the preparation of the composites.

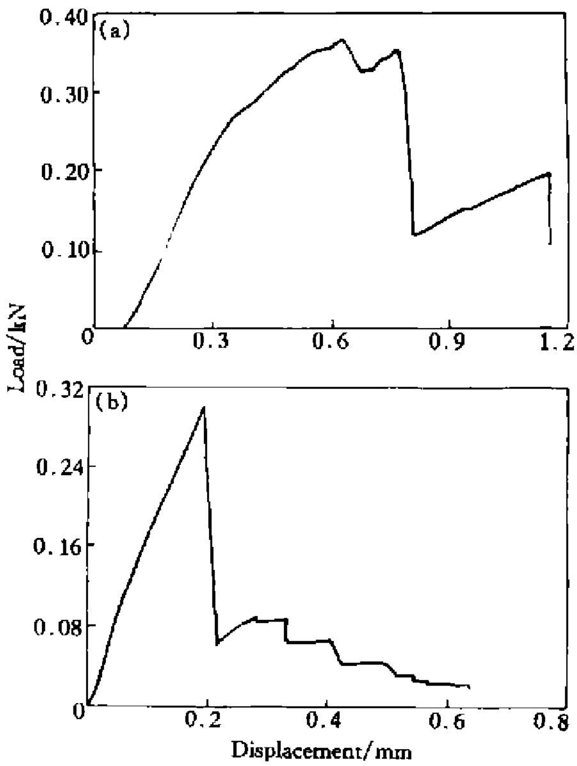

Fig. 1 Load—displacement curves of composite C1 (a) and C2 (b)

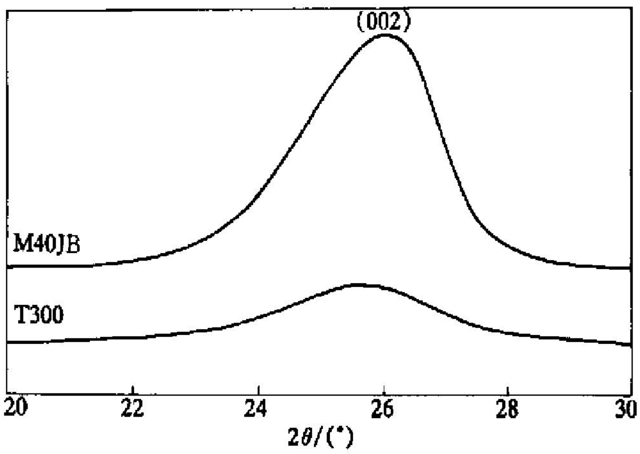

Fig. 2 (002) Peak in XRD patterns of as-received carbon fibers

The relationship between the heat treatment temperature and tensile strength of the fibers treated in argon atmosphere is given in Fig. 4. It is found that M40JB treated at 1800 ℃ for 1 h has a higher strength retention ratio (over 85%) compared with T300 which only has a strength retention of ratio 56%. Since the decrease of tensile strength in the fibers is mainly ascribed to the graphitization of amorphous carbon in fibers, it is reasonable that the higher retention of strength in the case of M40JB is primarily attributed to the higher degree of graphitization. However, in the case of T300, both the lower degree of graphitization and reactions of impurities with car-

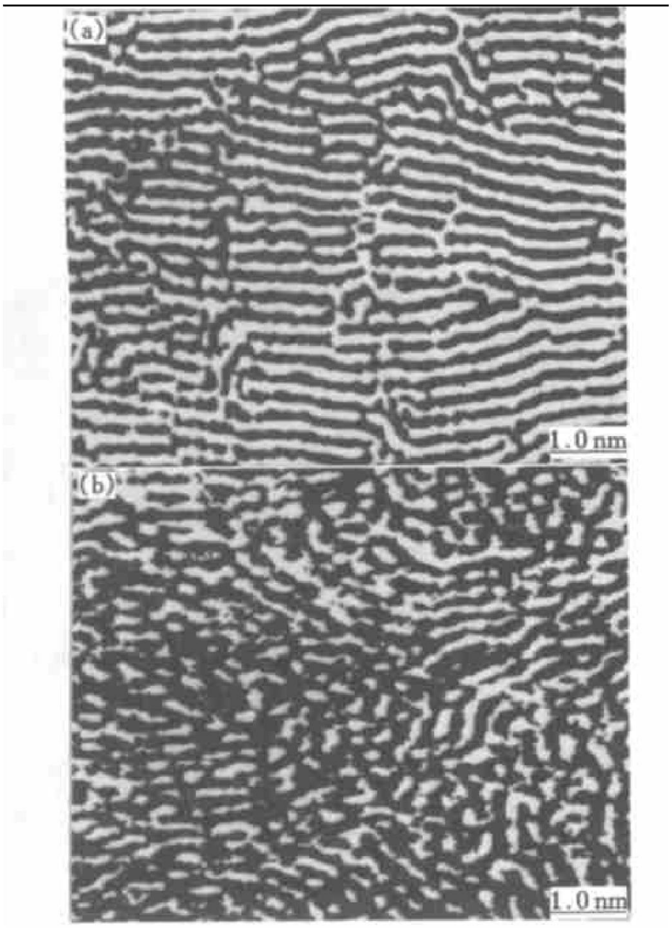

Fig. 3 HRTEM images of fibers
(a) —M40JB; (b) —T300

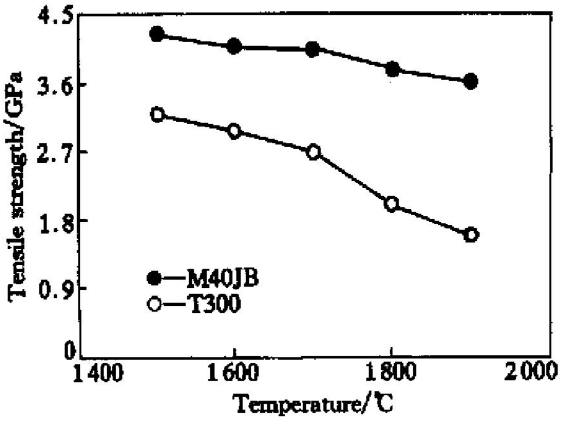

Fig. 4 Tensile strength of fibers as function of heat treatment temperature

bon at high temperature led to the lower retention ratio of strength. Based on the results above-mentioned, it can be concuded that T300 exhibits a higher chemical activity than M40JB. In other words, fiber M40JB is stabler than T300 at elevated temperature.

From the fact that T300 possesses a higher chemical activity than M40JB, it can be proposed that fiber T300 was strongly bonded to the matrix and fiber M40JB was weakly bonded to the matrix in the composites. This can be confirmed by the differences in fracture behavior (Fig. 1 and Fig. 5) and the differences in interlaminar shear strength (Table 1). The two different models for bonding of the matrix to the fiber yarns are given in Fig. 6, which illustrates the weakly bonded fiber/matrix interface in composite

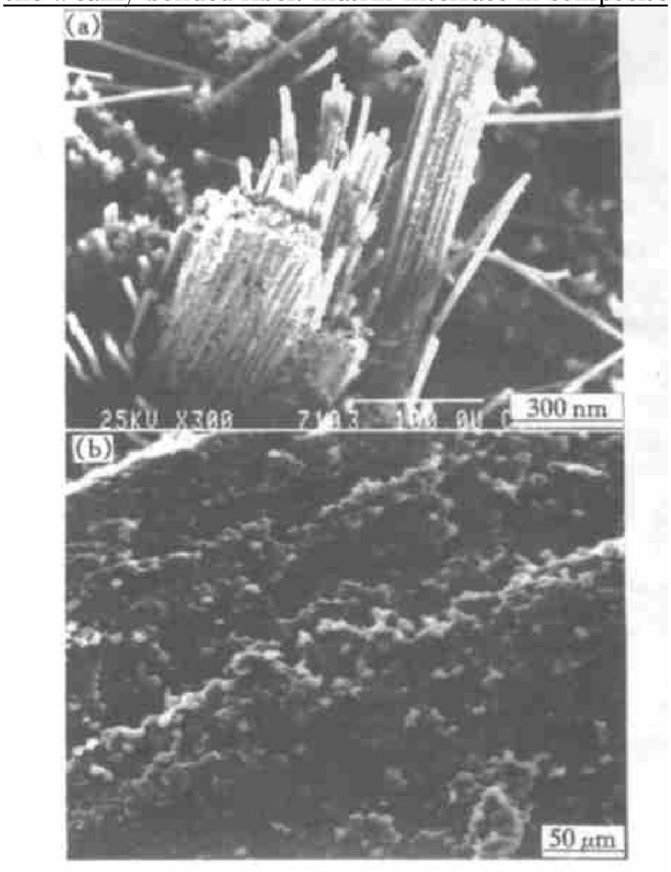

Fig. 5 Fractographs of composite C1 (a) and C2 (b)

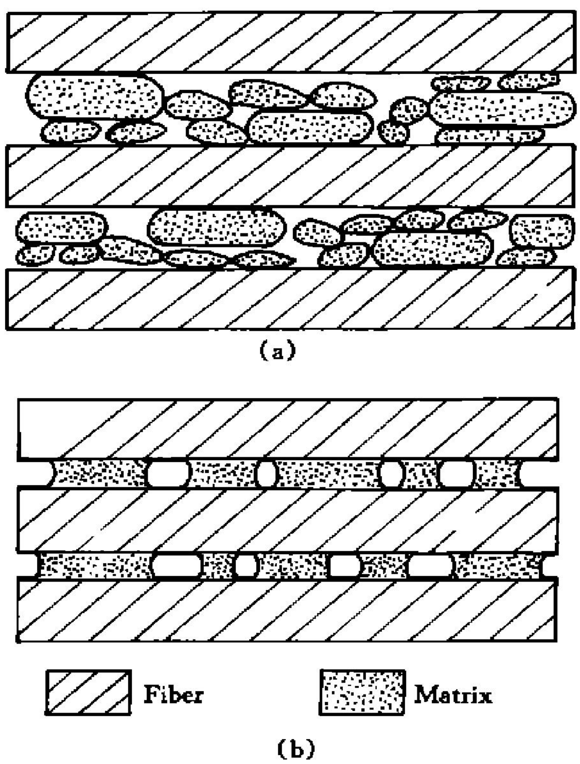

Fig. 6 Models for bonding of matrix to fiber yarns
(a) —M40JB; (b) —T300

C1 and the strongly bonded fiber/ matrix interface in composite C2. As a result, the composite with M40JB exhibites tough fracture behavior (Fig. 5 (a)), suggesting better mechanical properties. On the contrary, the composites with T300 exhibits a brittle fracture behavior (Fig. 5(b)), indicating poor mechanical properties. It is also shown that highly-graphitized carbon fibers are more suitable to be used as reinforcement in C_f/ SiC composites.

4 CONCLUSIONS

1) T300, compared with M40JB, has lower degree of graphitization and consists of more impurities, which can be explains by the lower heat treatment temperature. So, T300 exhibits a much higher chemical activity than M40JB.

2) The composite with M40JB exhibits a tough fracture behavior, which is mainly attributed to the weakly bonded fiber/ matrix interface and the higher strength retention ratio of the fibers. However, the composite with T300 shows a brittle fracture behavior, which is mainly ascribed to the strongly bonded fiber/ matrix interface as well as the degradation of the fibers.

3) Difference in fracture behavior of the composites is primarily attributed to the fiber characteristics, which are strongly dependent on the heat treatment temperature.

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