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In situ modulus and strength of carbon fibers in C/SiC composites

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ABSTRACT

The in situ elastic modulus and strength distribution of carbon fibers in C/SiC composites were studied. To obtain the in situ property data, fibers were heat treated according to the fabrication process of C/SiC composites. Tensile tests were performed on the single fibers and fiber bundles. The equivalent in situ modulus and strength were proposed considering the loose and unparallel fibers in the composites. The experimental and numerical results showed that the equivalent elastic modulus and average strength of in situ fibers are much lower than that of the original fibers. In addition, the equivalent strength distribution of in situ fibers is more dispersive.

1. Introduction

For the fiber reinforced ceramic matrix composites (CMCs), the properties of fibers have a great influence on that of the composites. Moreover, the property data of fibers are essential for many constitutive models [1–4] that simulate or predict the mechanical behavior of CMCs.

Xu et al. [5] and Zhang et al. [6] used the property data of original fibers (i.e., the property data of fibers before process) to predict the mechanical behavior of CMCs. However, some researchers have found that the modulus and strength of carbon fibers will be degraded by the high-temperature process. Zhou et al. [7] extracted the carbon fibers from the C/Al composites by the NaOH solution and performed the tensile test. They found that the Young's modulus of in situ T300 fibers decreased from 225 GPa to 170 GPa, and that the Young's modulus of in situ M40J fibers decreased from 359.2GPa to 343 GPa. The processing temperature of CMCs is much higher than that of the metal matrix composites. The modulus and strength of fibers in CMCs may be degraded more seriously. Therefore, it is important to obtain the in situ modulus and strength of fibers in CMCs.

However, owing to the indissolvable matrix, the fibers of CMCs cannot be extracted. The in situ modulus and strength cannot be measured directly.

Honjo [8] and Jing et al. [9] determined the in situ strength of a single fiber from its fracture surface. They found that there is a smooth mirror region, a mist region and a hackle region on the fracture surface (see Fig. 1a) of C and SiC fibers. They also presented the following equation that linked the mirror radius r_m to the in situ fiber strength S.

$$S = A_m/\sqrt{r_m} \quad (1)$$

where A_m is an empirical constant. However, the smooth mirror region does not have a distinct boundary which will result in an inaccurate r_m. Moreover, it was found in the experiment that there is not a smooth mirror region on some fracture surfaces (see Fig. 1b) of carbon fibers. Furthermore, the empirical constant A_m cannot be determined exactly.

Nevarez-Rascon et al. [10] and Solá et al. [11] measured the in situ fiber modulus by nanoindentation. However, nanoindentation only probes the local modulus at dimensions in the micron and submicron scales [12–14] instead of the average modulus of a single fiber or a fiber bundle which is really needed in the constitutive models of CMCs.

In the present study, T300 fibers were heat treated according to the fabrication process of C/SiC composites. The heat-treated fibers were counted as the in situ fibers in the composites. Tensile tests on the single fibers and fiber bundles were performed to obtain the in situ elastic modulus and strength distribution. Considering the loose and unparallel fibers in the C/SiC composites, the equivalent in situ modulus and strength of fibers were proposed. The stress-strain response of unidirectional C/SiC composites predicted using the equivalent in situ modulus and strength of carbon fibers is in good agreement with the experimental result.

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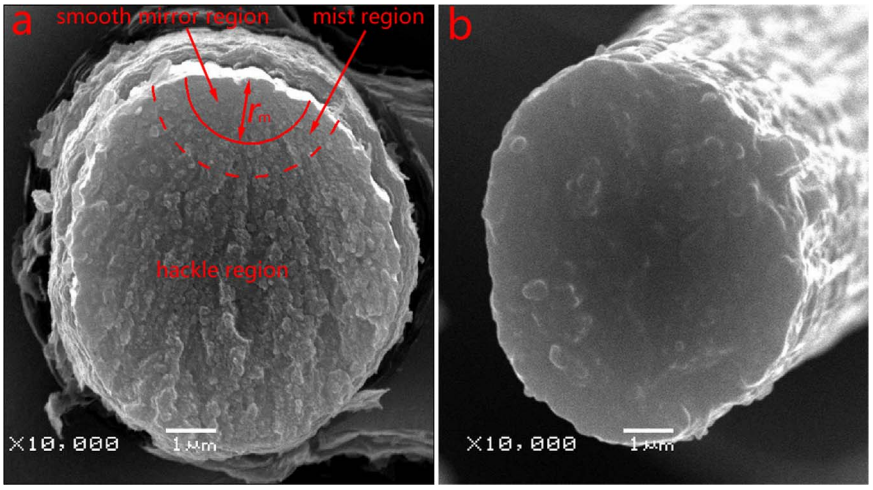

Fig. 1. Fracture surfaces of carbon fibers.

2. Material and experimental procedure

2.1. Heat treatment of fibers

The fiber examined in the present study was polyacrylonitrile (PAN) based carbon fiber with a trade name of T300. Each fiber bundle was constituted by 3000 single fibers. The fiber was heat treated in the tube furnace and in Ar. The heating process was the same as the fabrication process of C/SiC composites. The maximum temperature was 1100 °C, and the total heating time was 500 h.

2.2. Tensile test of single fibers

The tensile test of single fibers was performed by the electronic tensile tester (see Fig. 2a). The specimen of a single fiber was glued to the mounting tab (see Fig. 2b) which was made of a cardboard. 250 heat-treated and 250 original single fibers were tested.

2.3. Tensile test of fiber bundles

The tensile test was performed on three fiber bundles (bundles A, B and C) of which features are listed in Table 1. The experimental system and method proposed in the literature [4] were used in the present study. Note that two pyrocondensation pipes (5 mm long) were attached to the specimen (see Fig. 3) in order to prevent the fibers being cut by the knife edge of the extensometer.

2.4. Tensile test of unidirectional C/SiC composites

The unidirectional C/SiC composites were manufactured using the chemical vapor infiltration process by the Institute of Metal Research, Chinese Academy of Sciences. Note that fibers in the C/SiC composites were the same as that in Sections 2.1–2.3. As shown in Fig. 4, the tensile test of unidirectional C/SiC was performed on a servohydraulic load-frame (Model 793, MTS Systems Corp., Eden Prairie, MN USA) at

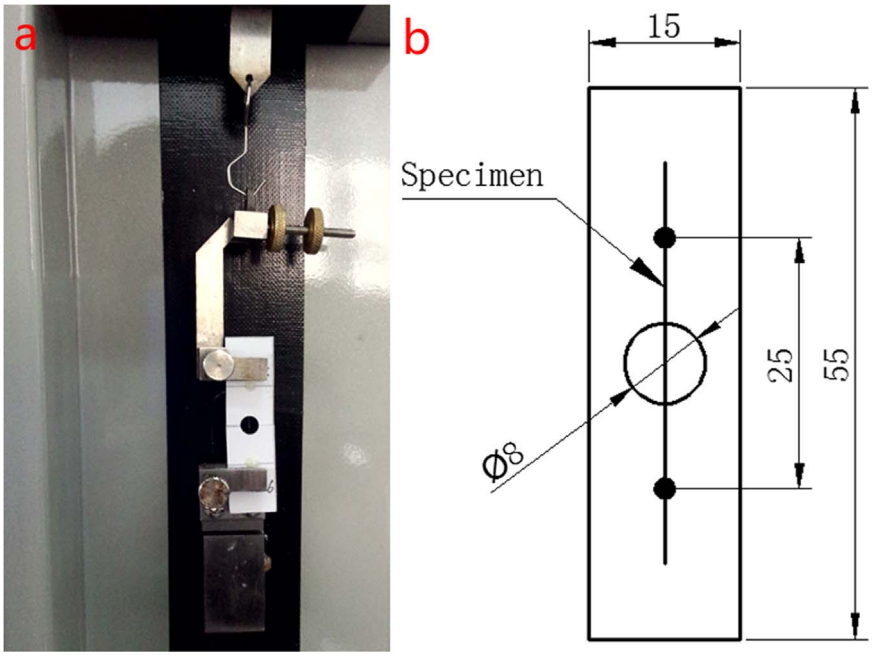

Fig. 2. Tensile test and specimen of a single fiber.