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Microstructure and tensile behavior of multiply needled C/SiC composite fabricated by chemical vapor infiltration

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ABSTRACT

The microstructure and tensile behavior of a multiply needled C/SiC composite fabricated by chemical vapor infiltration were investigated. Results showed that the tensile stress–strain curves exhibited a typical nonlinear behavior and can be divided into three regions: a very small initial linear region followed by a large nonlinear region and finally a quasi-linear region. Needling process caused a crimp around needling fibers and reduced the bearing fibers in plane. Needling process induced damages were the main reasons for the failure of the composite. The fracture mainly occurred at the cross of needling fibers and unidirectional fibers, with the fibers showing multi-step fracture and extensive pullout. The multi-step fracture of clusters and nonlinear curves indicated a typical non-brittle failure behavior of the multiply needled C/SiC composite due to the various damage patterns.

1. Introduction

Carbon fiber reinforced silicon carbide ceramic matrix (C/SiC) composites are widely used as structural materials in aeronautic and space industries (i.e., thermal protection systems (Naslain, 2005; Christin, 2002), advanced propulsion (Schmidt et al., 2004; Bouquet et al., 2003) and braking systems (Krenkel and Berndt, 2005)) due to their high damage tolerance with pseudo-ductility and strain-to-failure compared with monolithic ceramics. Chemical vapor infiltration (CVI) is the most promising process for fabricating composites with advantages of manipulating and modifying the microstructure of the matrix, tailoring the fiber/matrix interface, and fabricating complex net or near-net shaped components at relatively low temperatures (Chiang et al., 1989; Cao et al., 1990).

The mechanical properties and microstructure of 2D, 2.5D and 3D C/SiC composites have been investigated extensively. 2D laminated composites have good in-plane mechanical properties and high fracture toughness (Camus et al., 1996; Wang and Laird, 1995; Wu et al., 2006). However, the 2D composites have some fabrication problems and poor delamination resistance. 2.5D and 3D braided composites have a superior delamination resistance (Ma et al., 2006; Boitier et al., 1997; Xu and Zhang, 1997) but have a high cost. To improve the delamination resistance and save cost, a unique kind of multiply preform was developed by the means of the through-the-thickness needling technique. The multiply needled preforms have 3D architecture in real sense, which are similar to that of Novoltex preforms reported in literatures (Lacoste et al., 2002) but differ significantly from the multiply stitched preforms reported in literatures (Mattheij et al., 2000; Lomov et al., 2002). The multiply needled preforms consisted of unidirectional plies arranged in the desired orientations and short-chopped fiber fabrics. The individual plies and fabrics were kept together by needling yarns. This structure led to an advantageous combination of high material properties and

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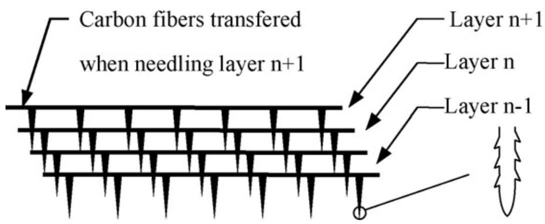

Fig. 1 – Generation of 3D architecture preform with needling process.

low cost processing. The needled preforms have good dimensional stability and good drapeability, making them suitable for fabricating composites with complicated shape (for example, T-shaped and bell-shaped parts).

In order to utilize these novel composites most efficiently, thorough understanding of their mechanical properties is essential. It is well known that the fiber architecture determines the composite microstructures and properties. Therefore, in the present work, the microstructure and tensile behavior of the multiply needled C/SiC composite fabricated by CVI were investigated.

2. Experimental procedure

2.1. *Preform preparation*

The fibrous preforms fabricated by the through-the-thickness needling technique were supplied by Jiangsu Tianniao Institute of Carbon Fiber, China. The preforms were composed of unidirectional fibrous plies (also named as nonwoven web) and short-chopped-fiber fabrics. In the present work, HTA carbon fibers from Toho (Japan) were used for unidirectional fibrous plies and T-700 12 K carbon fibers from Toray (Japan) were used for short-chopped-fiber fabrics. The ratio of unidirectional fibrous plies to short-chopped-fiber fabrics was 3:1. One unidirectional fibrous ply and one short-chopped-fiber fabric were named as one unit layer. After each unit layer laminated in desired orientations (0°/90°) and sequences, needling process was carried out to keep adjacent units together with carbon fibers carried, as shown in Fig. 1. Hooks were designed on needle so that fibers stayed where they have been carried when needles left preform. As a result, each part of the preform has received the same amount of transferred fibers through the thickness, and this provides the preform with good through-the-thickness homogeneity. The fiber volume fraction of the preform is about 30–32%.

2.2. *Densification processing*

To protect the carbon fibers from damage in the CVI process and to weaken the interfacial bonding between the carbon fibers and the SiC matrix (Naslain, 1998, 2004), a pyrolytic carbon (PyC) layer was deposited on the surface of carbon fibers as fiber/matrix interphase prior to the densification of SiC matrix. CVI was employed to deposit PyC interphase and SiC matrix. The conditions for CVI process were the same as that described in reference (Xu et al., 1998). The density and open porosity of the composite were 2.0–2.1 g/cm^3 and 14–17%, respectively, determined by the Archimedes' method.

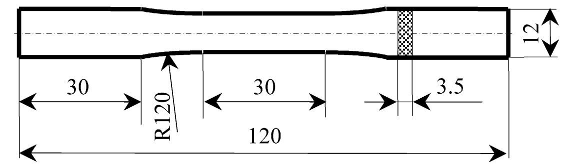

Fig. 2 – Schematic of tension specimens (dimensions in millimeter).

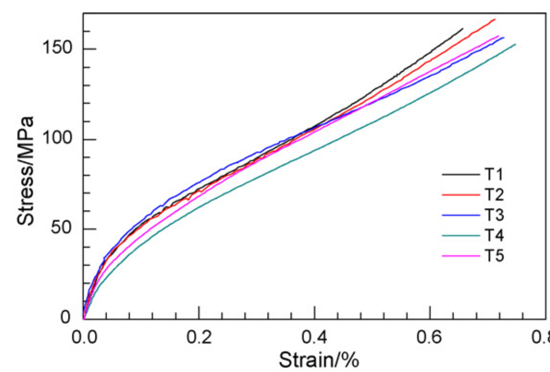

Fig. 3 – Tensile stress–strain curves of the multiply needled C/SiC composite at room temperature.

2.3. *Tension tests and microstructure observation*

Five specimens for tensile tests were prepared in the same furnace runs. The shape and dimensions of the specimens are shown in Fig. 2. To avoid local fracture at loading points, aluminum end tabs were bonded to the specimens using an epoxy resin adhesive. The tensile tests were conducted on an Instron 1196 test machine with a crosshead speed of 0.05 mm/min. Strains were recorded using an extensometer with a gauge length of 25 mm. Microstructure of the composite and the fracture surfaces of the tested specimens were observed by scanning electron microscopy (SEM, S4700).

3. Results and discussion

3.1. *Tensile behavior*

The tensile stress–strain curves are shown in Fig. 3. From Fig. 3, the tensile stress–strain curves can be divided into three regions: a very small initial linear region with a low limitation stress followed by a large nonlinear region and finally a quasi-linear region. The large nonlinear region was accompanied by a significant decrease in the modulus. In the quasi-linear region, the modulus recovered very little and gradually tended to be stable up to the failure of the composite. As listed in Table 1, the average tensile strength and failure strain for the composite are 158.9 MPa and 0.71%, respectively. The average initiation modulus obtained by linear fitting of the stress–strain curves from 0 to 40 MPa is 75 GPa for the needled C/SiC composite.