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The yarn size dependence of tensile and in-plane shear properties of three-dimensional needled textile reinforced ceramic matrix composites

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ABSTRACT

The yarn size scaling of tensile and in-plane shear properties is examined for three-dimensional needled textile reinforced ceramic matrix composites (3DN CMC) fabricated by chemical vapor infiltration. The results showed that large yarn size would cause the nonwoven yarn of 3DN CMC crimp and lower composite density, resulting in decrease of tensile and in-plane shear properties. The "modified lamina modeling" was presented to predict the tensile and shear elastic moduli of 3DN CMC with different yarn size. Other two methods were also proposed to evaluate the tensile and in-plane shear strengths of 3DN CMC with different yarn size, respectively. All predicted results showed consistent well with the experimental results.

1. Introduction

Textile composites are attracting growing interest from both the academic community and industry [1–3]. This family of materials, at the center of the cost and performance spectra, offers significant opportunities for new applications of fiber reinforced composites. Structural design of textiles is a major direction to tailor the properties of these composites [4,5]. Recently, in order to improve through-thickness properties of laminate composites, the sandwich structure, three-dimensional needled textile, has been proposed.

The three-dimensional needled textile has three-dimensional architecture in the real sense, which is similar to that of Novoltex textile reported in literature [6], but differs significantly from the multiply stitched textile reported in literatures [7,8]. The three-dimensional needled textile consists of unidirectional plies arranged in the desired orientations (0/90°) and short-cut fiber webs. The individual plies and webs are kept together by needling yarns. This structure leads to an advantageous combination of high material properties and low cost processing.

Three-dimensional needled carbon fiber textile reinforced silicon carbide composites (3DN C/SiC) is a representative of three-dimensional needled textile reinforced ceramic matrix composites (3DN CMC). The basic mechanical properties of 3DN C/SiC have been investigated by many researchers [9–11]. Those studies showed that it improved the disadvantage of through-thickness mechanical properties of the traditional 2D laminar C/SiC and would be widely applied in the high temperature and hard wearing components. In order to fully understand the relationship between the structure of 3DN textile and the properties of CMC, the effect of the structural parameters for 3DN carbon preform on properties of C/SiC would give an effective illustration to it. Yarn size is an important structural parameter for 3DN textile. However, so far, there is no study on the effect of carbon yarn size on the mechanical properties of 3DN CMC. In this work, the tensile and in-plane shear properties of two 3DN C/SiC with different yarn size fabricated by chemical vapor infiltration (CVI) are compared, and furthermore general predictive methods are presented to evaluate yarn size effect on these two properties of 3DN CMC based on them.

2. Experimental details

2.1. Materials

The structure of 3DN textile is illustrated in Fig. 1, which has been described in detail elsewhere [9]. In this work, two 3DN carbon fiber textile preforms were supplied by Jiangsu Tianniao Institute of Carbon Fiber, China. Nonwoven fiber cloths of two 3DN preforms were made of 1 and 6 K T300 carbon fibers (Toray, Tokyo, Japan), respectively. All short-cut fiber webs were made of T700 12 K carbon fibers (Toray, Tokyo, Japan). Two 3DN preforms had

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the same carbon fiber diameter (7 μm), short-cut fiber length (40 mm), fiber volume fraction (30%), weight ratio of nonwoven fiber to short-cut fiber (85/15), and needling density (30–35 cm^{-2}).

CVI was employed to densify these two 3DN carbon preforms. To protect carbon fibers from damage in CVI process and to weaken the interfacial bonding between the carbon fibers and the SiC matrix [12], a pyrolytic carbon layer with 200 nm thickness was deposited on the surface of carbon fibers as fiber/matrix interphase prior to the densification of SiC matrix. The conditions for CVI process were as same as that described in [5,7,8].

2.2. Measurements and observations

Tests of the tensile and in-plane shear properties were performed subject to tensile and compressive loading using the servo-hydraulic mechanical tester (Instron1850, Instron Corp., MA, USA) at room temperature. The shape and dimensions of specimens for two mechanical tests are shown in Fig. 2. All specimens were machined in parallel to the nonwoven lamina and the longitudinal axis of specimens was parallel to the direction of nonwoven yarn. Ten specimens were tested for each type of 3DN C/SiC.

Tensile tests were conducted in accordance with ASTM: C1275–10. The gauge length of specimens was 50 mm. Aluminum tabs were bonded to the ends to ensure uniform load transfer and to avoid crushing of the specimen. A 25 mm gauge length extensometer was used to check the longitudinal strain. The loading rate was 10 MPa/min. Some tests were continuous with monotonically loading to failure. Other tests were interrupted to perform hysteresis measurements with 10 MPa progressive speed. Typically, at least five hysteresis loops were obtained in each test.

The iosipescu method was applied to measure the in-plane property according to ASTM: C1292–10. Two millimeters thick aluminum end tabs were used to strengthen and stabilize the specimens, which helped to prevent compression failure. Shear strain was measured by bonding two biaxial strain gauges, one on each opposite face of the specimen, to the center of the specimen, in the area between notches. The strain gauges had a gauge length of 3 mm, to keep within the region of uniform stress, and were aligned at ± 45° to the longitudinal axis of the specimen. The crosshead speed was set at 0.5 mm/min.

In addition, the interlaminar shear property was attained according to ASTM: C1292–10. The dimensions of specimens for

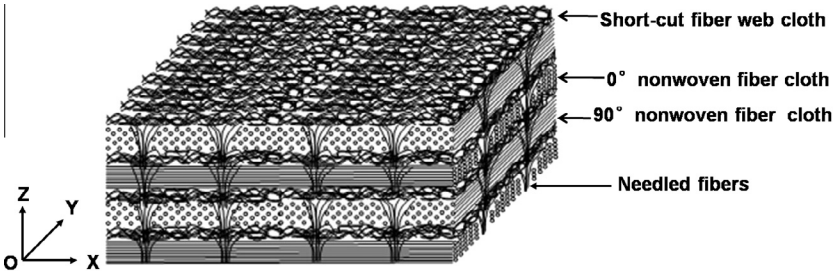

Fig. 1. Schematic of 3DN textile.

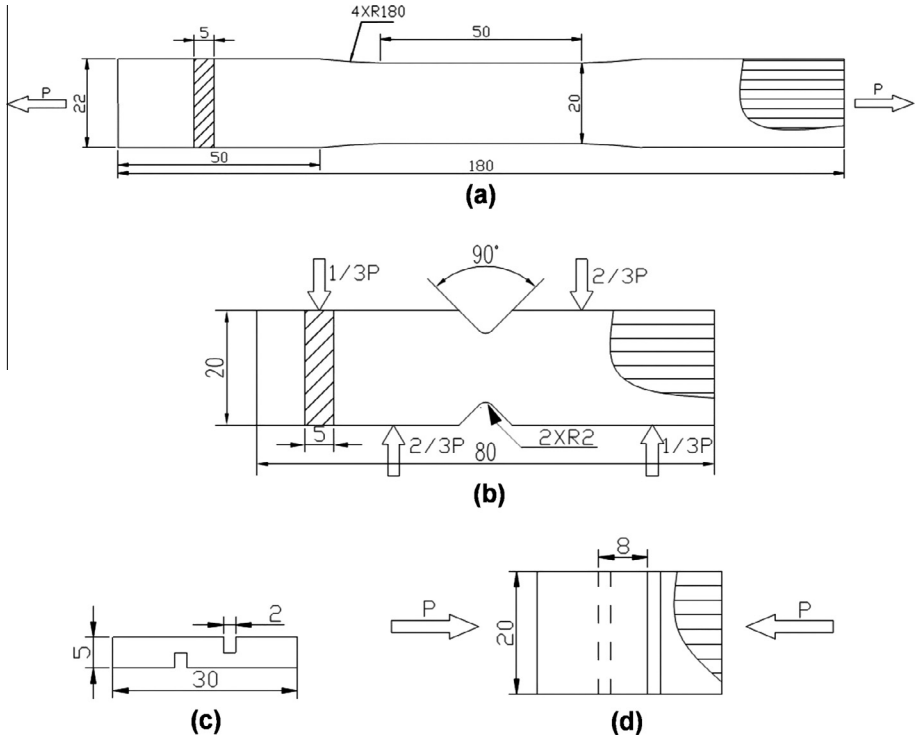

Fig. 2. Shape and dimensions of (a) tensile specimen, (b) iosipescu shear specimen, (c) front view of double notch specimen and (d) vertical view of double notch specimen (dimensions in mm).