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Mechanical and thermal properties of chemical vapor infiltration engineered 2D-woven and 3D-braided carbon silicate composites

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Abstract

SiC_f/SiC composites reinforced with either two-dimensional woven or three-dimensional braided preforms were fabricated by the chemical vapor infiltration (CVI) process. The microstructure, mechanical and thermal properties of the composites were studied. In comparison, the 3D-braided out-performed 2D-woven composites based on the mechanical and thermal properties. The geometry and microstructure determinants of the properties of the composites were investigated. Additionally, we tested how resilient the SiC_f/SiC composites were in contact with eutectic molten salt of LiF, NaF and KF to determine whether such materials could function in a molten salt reactor. The molten salt had minimal influence on mechanical properties of SiC_f/SiC composites due to the SiC coating blocking the infiltration of molten salt. Our data demonstrated the feasibility of CVI produced SiC_f/SiC composites with potential applications in molten salt reactor.

Keywords: A. SiC_f/SiC composite; B. Mechanical properties; C. Thermal properties; D. Fracture; E. Woven and braided

1. Introduction

SiC_f/SiC composites are carbon silicate fiber reinforced carbon silicate ceramic matrix materials which have desirable properties for applications in nuclear fusion and advanced fission reactors, such as chemical stability to withstand high temperatures, pseudo-ductile fracture behavior and low induced radioactivity [1–3]. SiC_f/SiC composites have been considered in the design of nuclear reactors in the USA, Japan and EU, such as the ARIES-AT [4], DREAM [5] and TAURO [6]. SiC_f/SiC composites were also considered for "first wall" structure in PROMETHEUS IFE reactor [7] and, in China, SiC_f/SiC composites are planned for use as control rod shroud tubes in Thorium Molten Salt Reactors (TMSR). Primary processing of SiC_f/SiC composites includes chemical vapor infiltration (CVI), hot press, reaction sintering, liquid phase sintering, polymer impregnation and pyrolysis (for details see Ref. [3]). Among the fabrication processes of SiC_f/SiC composites, CVI has shown the most promise as it results in less damage to the preform; is performed at lower temperatures; is amenable to fiber/matrix interphase tailoring and yields a material which is stable to neutron irradiation.

The fabrication of SiC_f/SiC composites has been widely developed since the 90's and a variety of preformed materials with different tertiary structures have been assessed. For textile structural SiC_f/SiC composites, Yang et al. [8] studied thermo-mechanical durability of CVI-processed two dimensionally woven and three dimensionally braided SiC_f/SiC composites and indicated the fiber geometry, matrix porosity, interlaminar shear strength and testing conditions affect the thermomechanical durability of SiC_f/SiC composites. Pluvinage et al. [9] examined the mechanical properties of two-dimensional (2D)-woven and three-dimensional (3D)-braided SiC_f/SiC composites with Nicalon fiber (1st Generation). Yamada et al. [10] investigated thermo-mechanical properties of 3D satin-weaved and

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2D non-woven SiC_f/SiC composite and reported that the thermal conductivity increased when the ratio of fiber configured to Z-direction increased. Xu et al. [11] reported high performance 3D textile SiC_f/SiC composites by chemical vapor infiltration. Similarly, Yamada et al. [12] reported highly thermal conductive, sintered SiC fiber-reinforced 3D-SiC_f/SiC composites: experiments and finite-element analysis of the thermal diffusivity/conductivity. Araki et al. [13] examined the flexural properties of several high-density SiC_f/SiC composites using Weibull distribution analysis. There have been a number of recent studies report continued developing of SiC_f/SiC composites with 2D and 3D preforms [14–16]. We investigated 2D-woven and 3D-braided composites using CVI had improved properties for use in molten salt reactors.

Our objective is to lay the groundwork for a feasible manufacturing processes and assess the properties and ability to engineer 2D-woven and 3D-braided SiC_f/SiC composites. We test the resilience and integrity of SiC_f/SiC composites for compatibility in a molten salt environment similar to what might be expected in a molten salt reactor. We aimed at a multilayered interface with total thickness of approximately 400 nm and investigated determinants of mechanical and thermal properties with regard to fiber geometry and microstructure.

2. Materials and methods

2.1. Preparation of preforms and chemical vapor deposition (CVD) and molten salt infiltrated SiC_f/SiC composites

2D-woven and 3D-braided preforms were made of SiC fiber bundles (2nd Generation fiber) by researchers at Xiamen University. The characteristics of the SiC fiber used in preparation of 2D-woven and 3D-braided preforms are described in Table 1. The 2D-woven preform consists of two sets of fiber interwoven orthogonally in the same plane with many layers of weave built vertically upon each other (Fig. 1a). 3D-braided preform material was braided at an angle of 30°; the orientation can be seen in Fig. 1b. The 3D-braided fabrics had multiple layers and no delamination due to the integration of a network of fibers.

2D-woven and 3D-braided SiC_f/SiC composites were fabricated by isothermal CVI at the Center for Composite Materials at the Shanghai Institute of Ceramics, Chinese Academy of Sciences, China. A multilayered interphase was deposited in a similar way onto the surface of both preforms prior to CVI, which consists of alternating layers of ~250 nm-thick pyrolytic carbon (PyC), ~100 nm-thick SiC and ~50 nm-thick PyC as illustrated in Fig. 2. The 2D-woven composite density ranged from 2.52 to 2.58 g/cm^3. The fiber volume fraction was approximately 50% and the residual porosity ranged from 10% to 11%. The 3D-braided composite densities were about

Table 1
Characteristic of SiC fiber.

Diameter (μm)	Bulk density (g/cm3)	Tensile strength (GPa)	Fracture elongation
14	2.6	1.9	1.2%

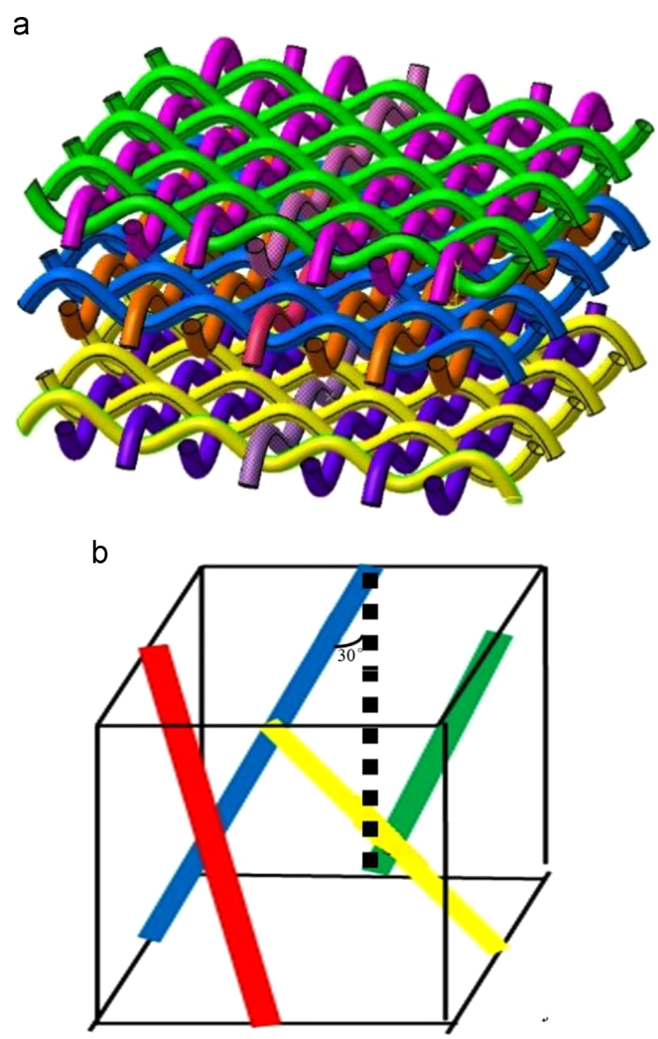

Fig. 1. Schematic diagrams of 2D woven and 3D braided preforms. 1(a) 2D woven preform; 1(b) 3D braided perform.

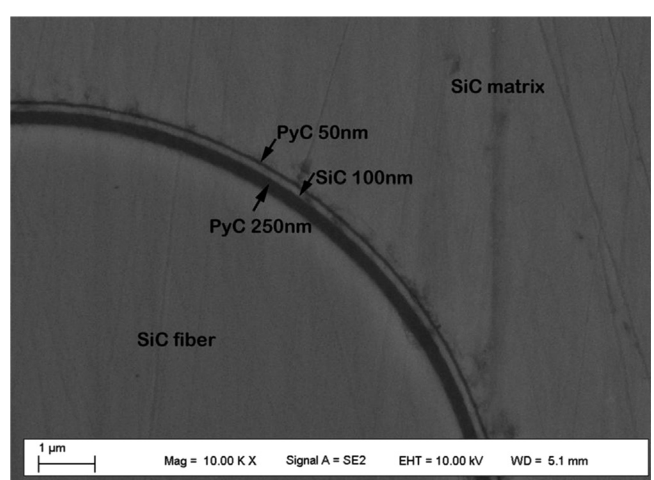

Fig. 2. Interface thickness between SiC fiber and matrix.