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Fatigue behavior of an advanced SiC/SiC ceramic composite with a self-healing matrix at 1300 °C in air and in steam☆

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ABSTRACT

The fatigue behavior of a non-oxide ceramic composite with a multilayered matrix was investigated at 1300 °C in laboratory air and in steam environment. The composite was produced via chemical vapor infiltration (CVI). The composite had an oxidation inhibited matrix, which consisted of alternating layers of silicon carbide and boron carbide and was reinforced with laminated woven Hi-Nicalon™ fibers. Fiber preforms had pyrolytic carbon fiber coating with boron carbon overlay applied. Tensile stress-strain behavior and tensile properties were evaluated at 1300 °C. Tension-tension fatigue behavior was studied for fatigue stresses ranging from 70 to 160 MPa in air and in steam. The fatigue limit (based on a run-out condition of 2×10^5 cycles) was between 80 and 100 MPa. Presence of steam had little influence on fatigue performance. The retained properties of all specimens that achieved fatigue run-out were characterized. Composite microstructure, as well as damage and failure mechanisms were investigated.

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1. Introduction

Advanced aeronautics and space applications such as turbine engine components, hypersonic flight vehicles, and spacecraft re-entry thermal protection systems require structural materials that have superior long-term mechanical properties under high temperature, high pressure, and varying environmental factors. Because of their low density, high strength and fracture toughness at high temperatures SiC fiber-reinforced SiC matrix composites are currently being evaluated for aircraft engine hot-section components [1–4]. In these applications the composites will be subjected to cyclic loadings at elevated temperatures. Therefore a thorough understanding of fatigue performance of SiC/SiC composites in service environments is critical to design and life prediction for these materials.

Because their constituents are intrinsically oxidation-prone, the most significant problem hindering SiC/SiC composites is oxidation embrittlement [5]. Typically the embrittlement occurs once oxygen enters through the matrix cracks and reacts with the fibers and the fiber coatings [6–8]. The degradation of fibers and fiber coatings is generally accelerated in the presence of moisture [9]. Composite degradation may be further accelerated by cyclic loading, where the reaction gases are expelled from matrix cracks during unloading and oxidizing atmosphere is drawn into the composite through the matrix cracks during reloading [5]. The issue of improving the oxidation resistance of the SiC/SiC composites has been addressed through the design of innovative multilayered interphases [10–12] and of self-healing multilayered matrices [10,12–16]. The multilayered matrices contain phases that facilitate glass formation at high temperatures thus healing the cracks and preventing oxygen from diffusing further into the composite and reaching the oxidation-prone fibers.

Several recent studies investigated mechanical behavior of high-performance SiC/SiC composites at elevated temperature. Zhu et al. [17,18] evaluated creep and fatigue behavior of CVI derived SiC-matrix composites reinforced with Nicalon™ and Hi-Nicalon™ fibers at temperatures ranging from 1000 °C to 1300 °C in air and in argon. The two woven 2D 0/90 composites were tested with maximum stresses ranging from 30 to 180 MPa and displayed similar creep and fatigue behaviors. At 1300 °C, creep performance of the Hi-Nicalon™-reinforced ceramic matrix composite (CMC) deteriorated in the presence of argon. This was attributed to the instability of the Hi-Nicalon™ fibers at elevated temperature in argon. At 1300 °C in air for applied stresses exceeding 100 MPa, creep or fatigue failures of both CMCs usually occurred after only a few hours, thus limiting the use of these materials to lower temperatures. Chermant et al. [19] studied creep mechanisms in a CVI Hi-Nicalon™/SiC composite at 1400 °C in air. It was found that microcracks initiated in the 90° bundles, which grew and extended into the load-bearing 0° bundles, producing through-thickness matrix cracks. Eventually one dominant crack formed that led to the ultimate composite failure. Ruggles-

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Wrenn et al. [20] investigated fatigue of a CVI Hi-Nicalon™/SiC composite at 1200 °C in air and in steam. The fatigue performance improved with decreasing loading frequency, but was noticeably degraded in the presence of steam. Failures of the composite in air and in steam were due to oxidation embrittlement.

Various authors have studied the high-temperature mechanical behavior of SiC/Si-B-C composites with self-healing matrices. Carrere and Lamon [21] evaluated high-temperature fatigue behavior of a Nicalon™-reinforced CVI composite with a matrix consisting of alternating layers of SiC and SiBC. Crack healing, limited oxidation damage and fiber creep were observed at 1200 °C. Reynaud et al. [22] investigated cyclic fatigue of a CVI 2.5D Hi-Nicalon™/SiBC composite at 600 °C and at 1200 °C in air. At 600 °C the fatigue lifetime was controlled by slow crack growth in the fibers, while at 1200 °C the fatigue lifetime was controlled by fiber creep. Darzens et al. [23] studied creep damage mechanisms of the CVI composites consisting of Nicalon™ fibers and SiC-based self-healing matrices. At or above 1200 °C, the creep deformation of the CMCs was governed by creep of the fibers. Carrere and Lamon [24] examined creep behavior of a CVI Nicalon™/Si-B-C composite with a multilayered self-healing matrix at 1200 °C. The creep rate of the composite was controlled by creep of the fibers and interfacial debonding. No significant creep induced matrix cracking was observed. Ruggles-Wrenn et al. [25,26] studied tension-tension fatigue of a CVI Hi-Nicalon™/SiC-B_4C composite at 1200 °C in air and in steam. It was found that the fatigue performance of the composite was controlled by the creep resistance of the Hi-Nicalon™ fibers.

This study investigates the tension-tension fatigue behavior at 1300 °C of a CVI ceramic composite comprised of Hi-Nicalon™ fibers, pyrolytic carbon fiber coating with boron carbide overlay and a SiC-based multilayered matrix. The oxidation inhibited

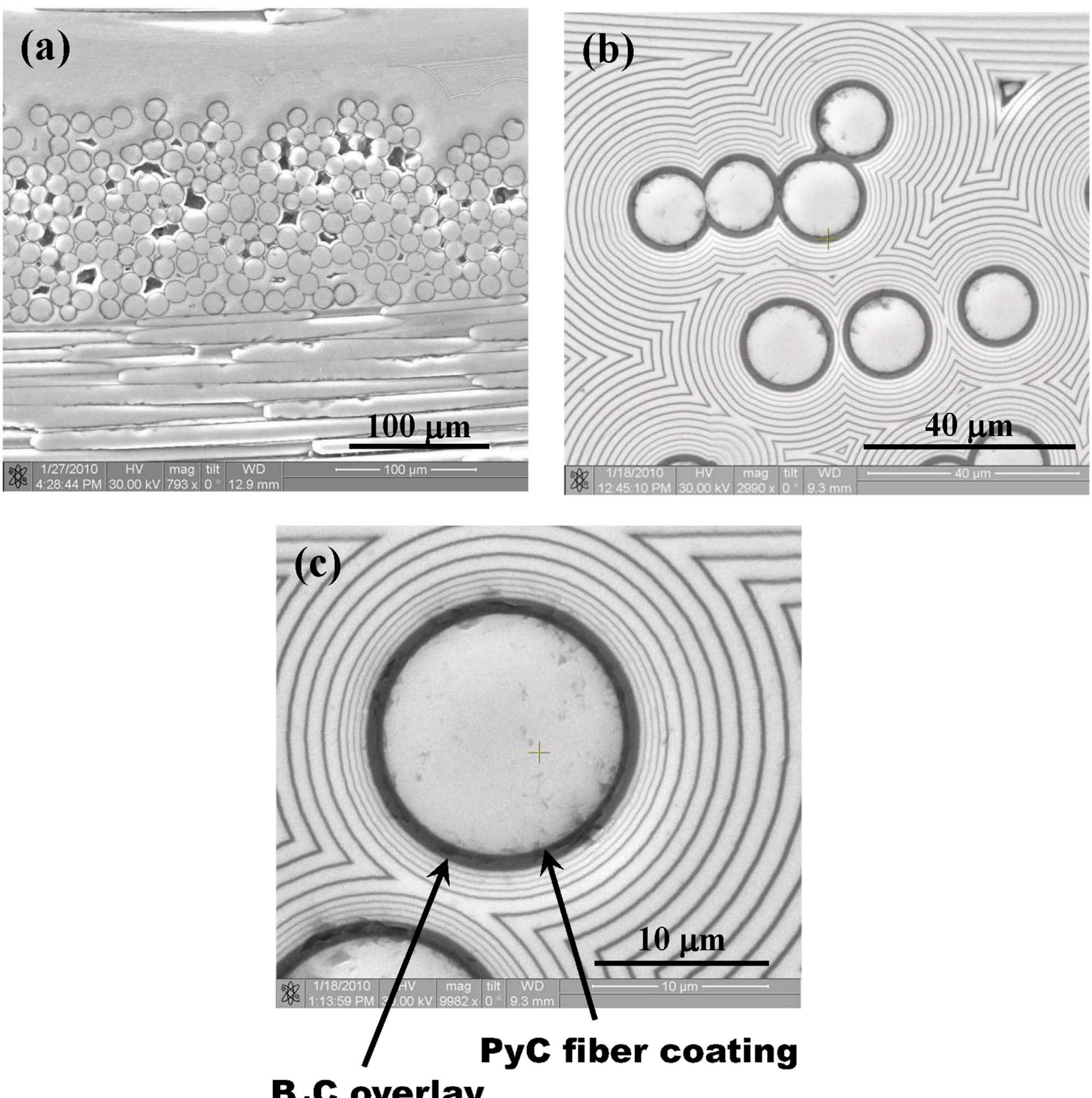

Fig. 1. SEM images: (a) typical microstructure of Hi-Nicalon™/SiC-B_4C, (b) oxidation inhibited matrix consisting of alternating layers of SiC and B_4C, (c) fibers and PyC fiber coating with B_4C overlay.