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Tensile creep behavior of three-dimensional four-step braided SiC/SiC composite at elevated temperature

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ABSTRACT

This article presents experimental results for tensile creep deformation and rupture behavior of three-dimensional four-step braided SiC/SiC composites at 1100 °C and 1300 °C in air. The creep behavior at 1300 °C exhibited a long transient creep regime and the creep rate decreased continuously with time. The creep behavior at 1100 °C exhibited an apparent steady-rate regime and the creep deformation was smaller than that at 1300 °C. However, the creep rupture time at both temperatures showed little difference. The mechanisms controlling creep deformation and rupture behavior were analyzed.

1. Introduction

Ceramic matrix composites (CMCs), particularly those containing braided or woven fiber preforms, are under development for high temperature applications as e.g. in aero engines, rocket nozzles, and re-entry heat shields. The SiC/SiC composites exhibited good tensile strength (~350 MPa) at room temperature [1,2]. However, a significant decrease to approximate 200 MPa in tensile strength was observed at 1100 °C and 1300 °C in air, which was due to oxidation embrittlement initiated from the surfaces. Moreover, composites with environmental barrier coating (EBC) maintained good mechanical properties for short-term at 1300°C [2].

The creep behavior of SiC/SiC (C/SiC, SiC/C) composites has been widely investigated [3–19] because long-time mechanical properties at high temperatures are important for the application of CMCs. The creep behaviors are different in a combination of different fiber and matrix. Generally, stress redistribution occurs during creep and the rule of mixture is violated. Therefore the creep mismatch ratio (CMR) is proposed which is defined as a ratio of the creep rate of the fiber to that of the matrix [20]. When CMR < 1, stress transferred from matrix to fiber. The embedded fiber control the deformation and rupture behavior of CMCs. When CMR > 1, stress transferred from fiber to matrix at first, so the creep behavior is dominated by matrix properties. Once greater matrix stress results in matrix cracking, the stress transferred to bridging fiber once again. Zhu investigates creep and fatigue behavior of SiC fibers (Nicalon and Hi-Nicalon) reinforced CVI derived SiC matrix composites in air and argon at temperatures ranging from 1000 °C to 1300 °C [3–6]. Both creep and fatigue resistance of Hi-Nicalon/SiC is similar to that of enhanced SiC/SiC, but much better than standard SiC/SiC. For these SiC/SiC of which the creep is controlled by matrix, better performance of the matrix can effectively improve the CMCs creep resistance. Recently research of Morscher demonstrates that the porous matrix, for example the SiC matrix derived by PIP process, does not carry significant load, which leads to higher creep strain rate of composites compared to that contains CVI or MI matrix [7] . Moreover, the creep behavior of the CMCs composites is not only depended on the constituent creep properties, but also influenced by their textile structures. The creep damage and failure of CMC is relevant to matrix cracking behavior, which is influenced by fiber preform. The creep behavior of the CMCs composites which has different type of fiber preform was not widely investigated. Previous research was mainly focused on woven CMCs. For woven CMCs, transverse matrix cracking initiated in transverse tows or inter-tow matrix, penetrating the longitudinal tows, leading to ultimate failure [9,10,12,18].

In general, the first generation Si-C-O fibers and carbon-rich interface in SiC/SiC-based composites possessed relative low oxidation resistance at elevated temperature in air, limiting the long-term performance of SiC-based CMCs [21–23]. The oxidation embrittlement propagates through matrix cracking, and the oxygen reacts with fiber,

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interface and matrix. In order to overcome this drawback, besides the application of second or third generation more creep resistant SiC fiber [24], glass phase in the matrix [4,5], SiBC [18], glass sealant [25] and coatings [26] were applied on the composites to act as an oxygen diffusion barrier and make the composites exhibited good mechanical properties in air.

The present work investigated the tensile creep behavior of three-dimensional four-step braided KD-1 fiber/PyC interface/SiC matrix composites at 1100 °C and 1300 °C in air. Composites with and without coatings were crept at 1300°C, and composites with coatings were crept at 1100 °C. Rupture behaviors and failure mechanisms of composites after creep testing was also evaluated by scanning electron microscopy (SEM) and computed tomography (CT). Based on the experimental results, the creep controlling mechanism and the coating effect will be discussed with the experimental results.

2. Material and experimental procedures

The CMC [1], are based on the SiC/SiC system with SiC fibers as reinforcement. The yarns consisting 1.2K fibers were braided into a 3D four directional preform. The fiber volume fraction was approximately 46.5%. The preform was surrendered to a chemical vapor deposition (CVD) process to prepare a ~200 nm thick pyrolysed carbon (PyC) layer. Polymer impregnation and pyrolysis (PIP) process with a polymer precursor of liquid polyvinycarbosilane (LPVCS) was adopted to dense the matrix. 14 cycles of impregnation and pyrolysis were repeated to reduce the composites porosity. The original densified preform was a flat plate of which the size is 130 mm×60 mm×4 mm. The tensile test specimens shown in Fig. 1 were cut by water-jet cutting machine. The overall specimen dimensions were roughly 127 mm ×14 mm×4 mm and the central reduced section were 30 mm× 6 mm×4 mm. For some specimens to be tested in elevated temperature, after machining to the geometry suitable for mechanical testing, a two-layer EBC was applied on the specimen surfaces to protect the composite against oxidation. The inner layer was mullite and the outer layer was erbium silicate. Both of the layer thickness was 0.1 mm.

Monotonic tension and creep tests were conducted under stress control in a servo-hydraulic SHIMADZU test machine, following the general guidelines of ASTM standard C1337 [27]. The specimens were griped by edge load, passive grip interface and the alignment of the testing system was verified at the beginning of the test series. The high temperature furnace and contact-type Epsilon-3548 high temperature extensometer used for these experiments have also been shown in Fig. 1. Details about the experiment system were in ref [2]. The loading rate at the beginning of the creep test was 3 MPa/s and creep stress range was 40–120 MPa. Creep tests for coated specimens were conducted at 1100 °C and 1300 °C, while for uncoated specimens the tests were only conducted at 1300 °C.

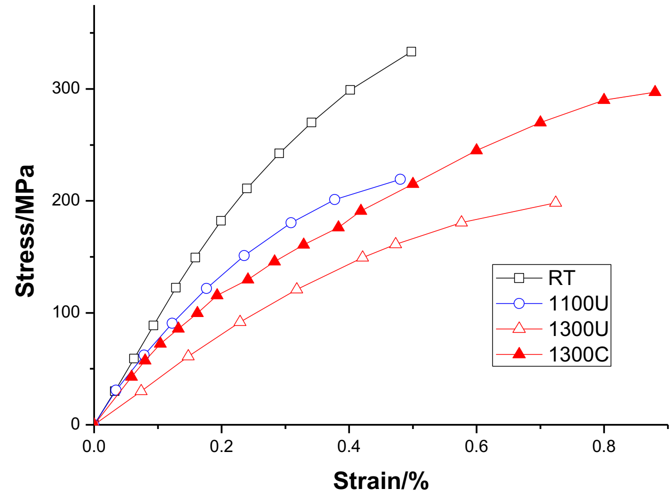

Fig. 2. Typical monotonic tensile stress-strain curve for coated and uncoated composites (U means uncoated and C means coated).

After the creep test, fracture surface, cross-section and side surface of the specimens were observed using by scanning electron microscopy (SEM). The inner micro structure evolution was evaluated by computed tomography (CT). X-ray diffraction (XRD) analysis was conducted in order to investigate crystallization of SiC/SiC during creep tests.

3. Results and discussion

3.1. Monotonic tensile behavior

Monotonic tensile stress–strain curves of the SiC/SiC composites at room temperature(RT),1100 °C and1300 °C are shown in Fig. 2. All the curves were similar, starting with a linear response, and being followed by a non-linear pseudo-ductile fracture behavior. The ultimate tensile stress(UTS) of composites with coating was considerably higher than

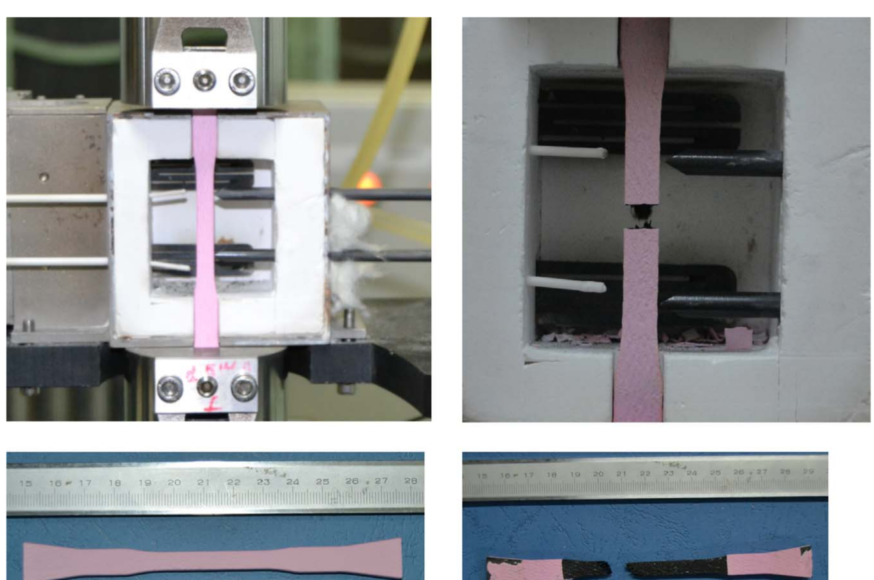

Fig. 1. Test configuration and specimens used for monotonic loading and creep testing at elevated temperatures.