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Damage mechanisms of C/SiC composites subjected to constant load and thermal cycling in oxidizing atmosphere

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Abstract

Properties of a carbon fiber reinforced silicon carbide matrix composite were investigated in controlled environments including constant load, thermal cycling and wet oxygen atmosphere. Damage was assessed by residual mechanical properties and scanning electron microscopy characterization. Thermal strain was shown to change with cyclic temperatures over the same period (120 s). Strain varies approximately from the initial linear elastic strain of 0.63% to the final nonreversible damage strain of 1.6% during the short time of the test. The experimental strain difference between two selected temperatures is about 0.16% and the theoretical calculation value is 0.1566%. After 50 thermal cycles, the Young's modulus of the composites is reduced by a factor of 0.5 while the residual strength still retains 82% of the initial strength. It is observed that matrix cracks transversely and wave-shaped cracks are arranged on the coating surface at relatively regular spacing. A typical superficial oxidation can be found along the opening and propagating cracks beneath the coating.

Keywords: Fiber; Ceramic matrix composites; Thermal cycling; Creep; Residual properties

1. Introduction

Carbon fiber reinforced SiC-matrix composites (C/SiC) fabricated by the chemical vapor infiltration process (CVI) have been proposed as advanced materials suitable for aerospace and gas turbine engine parts [1,2]. In particular, in recent years many efforts have been devoted to the high-temperature applications of C/SiC composites. These composites show some attractive properties and advantages over traditional ceramics: higher tensile and flexural strength, enhanced fracture toughness and impact resistance, lower density and no cooling requirement. In particular, the mechanical properties of C/SiC composites can be retained at high-temperatures and under severe service environments. In many of the instances under consideration, the composites will be also subjected to both thermal cycling and some rigid constraint conditions in an oxidizing atmosphere during its service. Consequently, thermal cycling damage to the composites under such conditions must be well understood before actual use in these environments.

The effects of temperature cycling on the structural integrity of polyester matrix composites have been investigated using a large scale model composite [3] and a computational model of delamination of a two-layer composite laminate subjected to the cyclic loads, both mechanical and thermal, was obtained [4]. On the other hand, experimental thermal shock studies have also been conducted on unidirectional, two-dimensional and three-dimensional (3D) woven-fiber composites [5–7] and newly-developed ascending thermal shock test equipment has also been applied to study thermal shock and thermal fatigue of ceramic materials [8]. However, the mechanical response and damage features of C/SiC composites subjected to thermal

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cycling under a constant load in oxidizing atmosphere have not been reported in a detailed manner, despite recent advances in the architecture design and processing of these materials.

When evaluating C/SiC composites for potential use in structural applications where periodically changing temperatures occur, the basic characterization of the materials obtained from mechanical and environmental testing is very important in understanding the fundamental properties of the materials. In this paper, thermal cycling testing results of 3D braided C/SiC composites under a constant load of 60 MPa in a wet oxygen atmosphere are presented. Corresponding thermal stress or thermal strain during testing will be measured, calculated and analyzed by theoretical and experimental methods. Effects of thermal cycling on mechanical properties of composites will be discussed and the morphologies of fracture sections and coating surfaces will be observed.

2. Experimental

2.1. Preparation of C/SiC composite

T-300™ carbon fiber from Toray (Japan) was employed. The fiber preform was prepared using a 3D braid method. The volume fraction of fibers was about 40% and the braiding angle was about 20°. Low pressure CVI was employed to deposit a pyrolytic carbon layer and the silicon carbide matrix. A thin pyrolytic carbon layer was deposited on the surface of the carbon fiber as the interfacial layer with C_3H_8 at 800 °C. Methyltrichlorosilane (MTS, CH_3 $SiCl_3$) was used for the deposition of the SiC-matrix. MTS vapor was carried by bubbling hydrogen. Typical conditions for deposition were 1000 °C, a hydrogen:MTS ratio of 10:1, and a pressure of 5 kPa. Argon was employed as the diluent gas to slow down the chemical reaction rate of deposition. Finally, the test specimens were machined from the fabricated composites and further coated with SiC by isothermal CVI under the same conditions. The morphology and dimensions of the as-received specimens are shown in Figs. 1 and 2. The properties of the composite are listed in Table 1.

2.2. Thermal cycling test

Thermal cycling experiments under load constraints were conducted with a newly-developed integrated system including an induction heating furnace (with a controlled atmosphere chamber providing various kinds and concentrations of oxidizing gas) monitored by a programmable microprocessor and a servo-hydraulic machine (Model Instron 8801, Instron Ltd., England). Many experimental conditions/parameters must be taken into consideration, especially regarding (1) the load alignment, (2) the configuration of the specimen, (3) the heater, (4) the cooling water, (5) the measurement for temperature, (6) the induction coil for cyclic temperature, (7) the grip holder and (8) the pressure and flow of the controlled atmosphere (as shown in Fig. 3). The temperature was measured by an infrared pyrometer through a small window in the wall of the furnace and the wall was internally cut out to enable the circulating cold water to reach all over the surfaces. Thermal cycling was carried out between two selected temperatures and the period was 120 s: holding for 30 s at 900 °C, heating to 1200 °C in 60 s and holding for 30 s, then cooling back to 900 °C immediately (temperature difference $\Delta T \approx 300$ °C). Only the middle parts of the specimens (40 mm long, 3 mm wide and 3 mm thick) were kept in the hot zone and oxidizing atmosphere. In testing, a constant load of 60 MPa was applied to both the longitu-

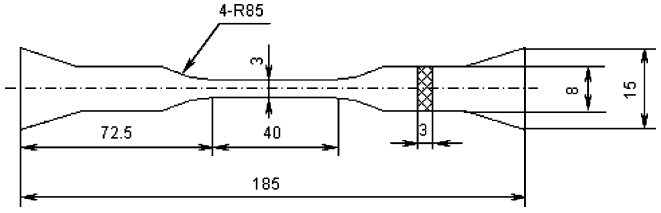

Fig. 2. Drawing of as-prepared C/SiC specimen (all dimensions in mm).

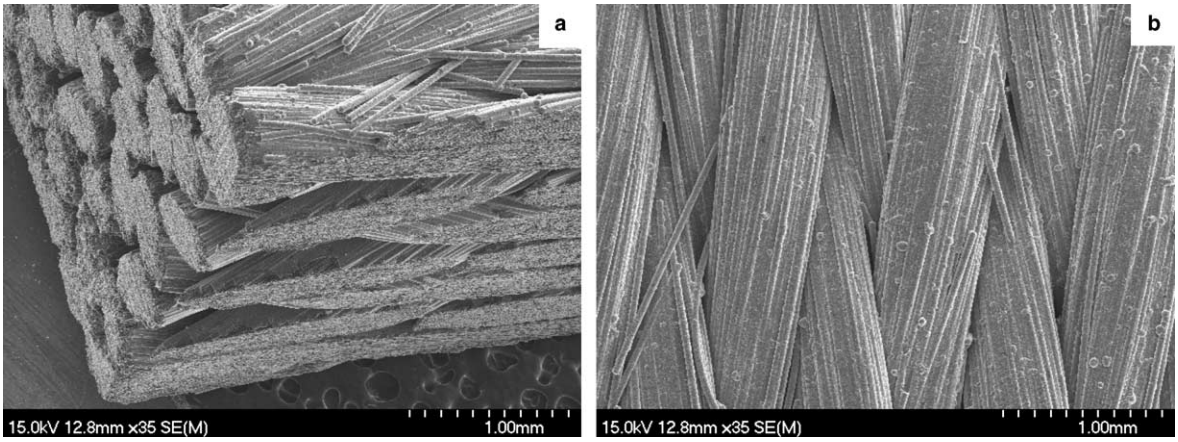

Fig. 1. (a) Substrate of the 3D-C/SiC composite and (b) its top surface.