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Behavior of two-dimensional C/SiC composites subjected to thermal cycling in controlled environments

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Abstract

Thermal fatigue behavior of two-dimensional carbon fiber reinforced SiC matrix composites fabricated by chemical vapor infiltration technique was investigated using an on-line quench method in controlled environments which simulated an aero-engine gas. A system of damage information acquisition (SDIA) was developed to study changes in electrical resistance of the C/SiC composites during their damage in dynamic testing. Damage to composites was assessed by the ultimate tensile strength (UTS) and SEM characterization. The results showed that: (1) under different atmosphere, the 2D-C/SiC composites subjected to thermal cycling behaved very differently and the most sensitive atmosphere was the wet oxygen; (2) external load could accelerate the degradation of the composites and changed the oxidation regimes of fibers; (3) the electrical resistance of the specimen could be detected on-line, stored in real time and analyzed reliably by the newly-developed SDIA; (4) 2D-C/SiC composites had an excellent thermal fatigue resistance in different environments.

Keywords: Carbon composites; Chemical vapor infiltration; Mechanical properties; Thermal expansion

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. Especially, the mechanical properties of C/SiC composites can be retained at high temperatures and under severe service environments. However, the effects of thermal shock and thermal cycling on the composites have been anticipated to be an important factor and have resulted in degradation of performance in many instances. Consequently, thermal fatigue damage must be understood well before actual use.

Thermal shock resistance of monolithic materials has been extensively studied, and some theoretical analyses have been successfully applied to explain experimental observations [3–5]. Experimental thermal shock studies have been conducted on unidirectional, two-dimensional woven-fiber composites [6,7] and a newly-developed ascending thermal shock test equipment has also been designed to study thermal shock and thermal fatigue of ceramic materials [8]. However, a comprehensive understanding of the thermal fatigue behavior of 2D-carbon-fiber-reinforced ceramic composites (CFCCs) in different environments has not been obtained, despite

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recent advances in the architecture design and processing of these materials.

When evaluating CFCCs for potential use in cyclic temperature structural applications, the basic characterization of materials obtained from mechanical and environmental testing is very important in understanding the fundamental properties of the materials. In the present study, the behavior of a 2D-C/SiC composite (produced by CVI) subjected to thermal cycling in controlled environments was investigated completely and the results of thermal fatigue experiments in different environmental atmosphere are presented. The electrical resistance of 2D-C/SiC composite specimens in testing was acquired in real time by a newly-developed system of damage information acquisition (SDIA).

2. Experimental

2.1. Preparation of 2D-C/SiC composite

T-300™ carbon fiber from Toray (Japan) was employed. The fiber preform was prepared using a layered carbon-cloth braid method, and was supplied by the Nanjing Institute of Glass Fiber, People's Republic of China. The volume fraction of fibers was about 40%. Low pressure I–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 $\alpha = 10$, 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 (about 50 μm) by I–CVI under the same conditions. The dimension of the as-received C/SiC composite specimens is $3\text{ mm} \times 3\text{ mm} \times 185\text{ mm}$. The virgin properties of the 2D-C/SiC composites are listed in Table 1.

2.2. Thermal shock tests

Thermal fatigue tests were conducted with a specific system including a high frequency induction heating furnace and a servo-hydraulic machine (Model INSTRON 8801 from INSTRON Ltd., England). 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 its surfaces. Thermal cycling was carried out between two selected temperatures by a programmable microprocessor and the period was 120 s (holding for 30 s at the lower temperature (less than 700 °C), heating to 1200 °C in 60 s and holding for 30 s, and then cooling back to the lower temperature immediately). The temperature difference ΔT was about 500 °C. Only the middle parts of specimens (about 40 mm long, 3 mm wide and 3 mm thick) were kept in the hot zone and were on-line quenched in environmental atmosphere, which included argon($\geqslant 99.99\%$ and 1.01×10^5 Pa), dry oxygen (8000 Pa), water vapor (15 000 Pa, about 54 °C) and wet oxygen (coupled O_2 with H_2O pressures mentioned above). The flux of gases was accurately controlled by a mass flow controller (5850 i series of BROOKS, Japan) with a precision of 0.1 sccm. In testing, the loading mode was tension–tension fatigue (sine wave, fatigue stress level was about 50% of the as-received strength, frequency 1 Hz and stress ratio $R = 0.5$).

2.3. System of damage information acquisition for C/SiC composites

Changes in resistance can be caused by a wide range of mechanisms such as fiber breakage, delamination, mechanical strain and cyclic temperature. The system of damage information acquisition (SDIA) was designed to real time acquire the electrical resistance of the C/SiC composites subjected to thermal cycling in controlled environments by a sound card of personal computer. It comprised of the following major parts:

(1) Data Acquisition. As we know, the voltage signals changed with the electrical resistance of the vibrating carbon particles in microphones can be transformed into the digital signals by the sound card in the multimedia computer. Similarly, the voltage signals on both ends of the composite specimens in testing collected by the sound card reflect the electrical resistance of the specimens directly. Consequently, the data acquisition was developed

Table 1
Properties of the as-received 2D-C/SiC composites

Property	Density ($\times 10^3$ kg/m^3)	Modulus (GPa)	Strength (MPa)	Poisson's ratio	Porosity (%)	CTE* ($\times 10^{-6}$/°C)			
						600 °C	800 °C	1000 °C	1200 °C
Value	2.0	70	248	0.32	13	4.6	6.1	5.2	5.4

* CTE (the coefficient of thermal expansion) is measured by a dilatometer (Model DIL402C from NETSZCH, Germany).