OXIDATION OF C/SiC COMPOSITES IN REDUCED OXYGEN PARTIAL PRESSURES

Elizabeth J. Opila*, Jessica Serra^
NASA Glenn Research Center, Cleveland, OH 44135
^The Pennsylvania State University, University Park, PA, 16802

Carbon-fiber reinforced SiC (C/SiC) composites are proposed for leading edge applications of hypersonic vehicles due to the superior strength of carbon fibers at high temperatures (>1500°C). However, the vulnerability of the carbon fibers in C/SiC to oxidation over a wide range of temperatures remains a problem. Previous oxidation studies of C/SiC have mainly been conducted in air or oxygen[1-3], so that the oxidation behavior of C/SiC at reduced oxygen partial pressures of the hypersonic flight regime are less well understood. In this study, both carbon fibers and C/SiC composites were oxidized over a wide range of temperatures and oxygen partial pressures to facilitate the understanding and modeling of C/SiC oxidation kinetics for hypersonic flight conditions.

T-300 carbon fiber and C/SiC coupons were oxidized at temperatures of 816°, 1149°, 1343°, and 1538°C (1500°, 2100°, 2450°, and 2800°F) and in gas mixtures containing 50% O_2/Ar, 5% O_2/Ar, 0.5% O_2/Ar, and 0.1% O_2/Ar at one atmosphere total pressure. The T-300 fibers were held in slotted alumina crucibles for the oxidation testing. Oxidation kinetics were monitored using thermogravimetric analysis. Post test characterization of selected coupons included optical microscopy, x-ray diffraction, scanning electron microscopy, and energy dispersive spectroscopy.

Results of the T-300 carbon fiber oxidation are shown in Figure 1. The oxidation rates reported are instantaneous rates when 50% of the fibers are consumed. It can be seen from Figure 1 that the oxidation kinetics are only weakly dependent on temperature, but strongly dependent on oxygen partial pressure. The weak temperature dependence and oxygen pressure dependence shown in Figure 2 are both consistent with oxidation limited by gaseous transport.

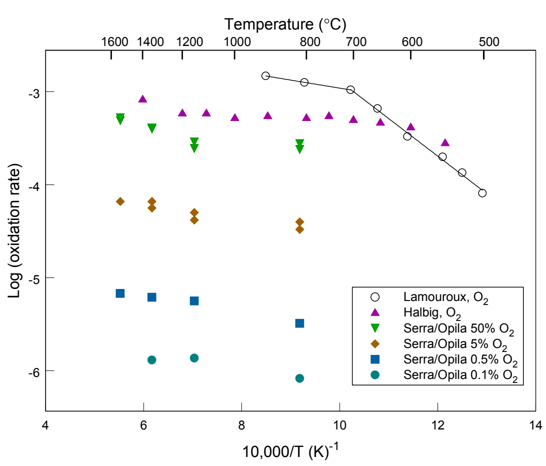

Figure 1. Oxidation rates of T-300 carbon fibers as a function of temperature and oxygen partial pressure.

The results in Figure 1 include oxidation rates for T-300 fibers in 100% oxygen that are found in the literature[1,4]. The results of Halbig et al.[4] were obtained in the same laboratory and show consistent pressure dependence with the new results as shown in Figure 2.

Kinetic results for C/SiC coupon oxidation are shown for all temperatures in 50% O_2/Ar in Figure 3. Weight loss is typically observed indicating that oxidation of carbon fibers rather than oxidation of SiC dominates the kinetics even at the highest oxygen partial pressure studied. Weight loss is largest at 816°C where cracks in the SiC coating and matrix are open allowing ingress of oxygen and complete consumption of the C fibers. As the temperature is increased thermal expansion and oxidation of the SiC both contribute to crack closure. The variation in the observed weight change is explained by variation in the number and size of cracks in the SiC seal coat as well as varying extents of crack closure. At lower oxygen partial pressures and higher temperatures crack closure is attributed exclusively to thermal expansion rather than formation of silica in the cracks.

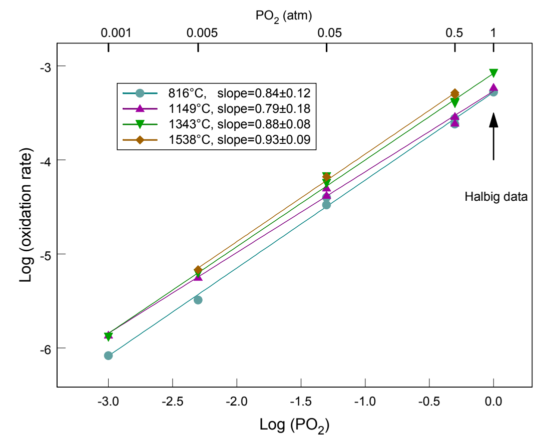

Figure 2. Oxygen partial pressure dependence of T-300 fiber oxidation rates obtained at all temperatures.

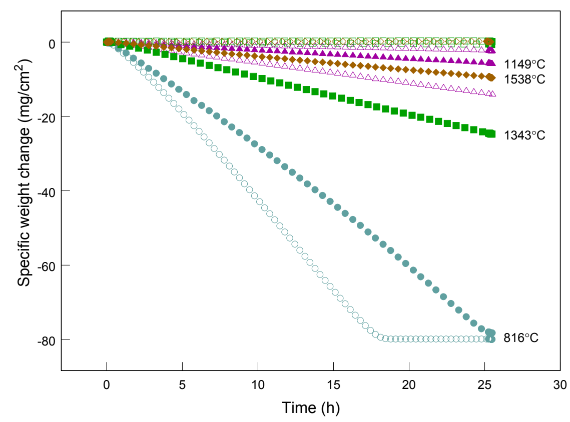

Figure 3. Oxidation weight loss of C/SiC composites in 0.4 cm/sec flowing 50% O_2/Ar as a function of temperature.

At the highest temperature (1538°C) and lowest oxygen partial pressure (0.1% O_2/Ar) the C/SiC coupon was rapidly consumed due to active oxidation of the SiC and oxidation of the C fibers as they were exposed.

Acknowledgment
This work was funded by the NASA Aeronautics Research Mission Directorate/Fundamental Aeronautics Program in Hypersonics.

References
[1] F. Lamouroux, X. Bourrat, and R. Naslain, "Structure/Oxidation Behavior Relationship in the Carbonaceous Constituents of 2D-C/PyC/SiC Composites," Carbon 31 [8] 1273-1288 (1993).

[2]F. Lamouroux, G. Camus, J. Thebault, "Kinetics and Mechanism of 2D Woven C/SiC Composites: I, Experimental Approach," J. Am. Ceram. Soc. 77 [8]2049-57 (1994).

[3]F. Lamouroux, R. Naslain, J.-M. Jouin, "Kinetics and Mechanism of 2D Woven C/SiC Composites: II, Theoretical Approach," J. Am. Ceram. Soc. 77 [8]2058-68 (1994).

[4]M.C. Halbig, D.N. Brewer, and A.J. Eckel, "Degradation of Continuous Fiber Ceramic Matrix Composites Under Constant Load Conditions," NASA TM-2000-209681.