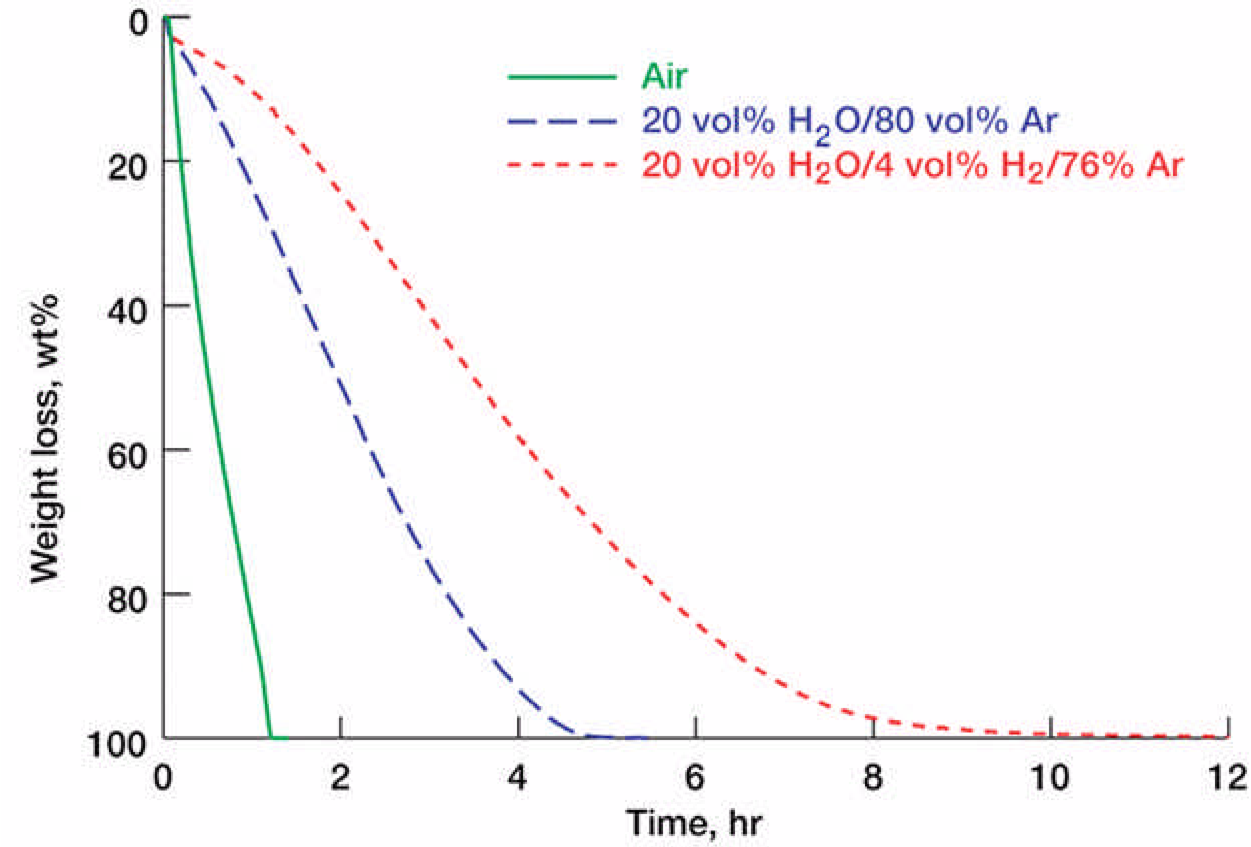
Oxidation of Carbon Fibers in Water Vapor Studied

T-300 carbon fibers (BP Amoco Chemicals, Greenville, SC) are a common reinforcement for silicon carbide composite materials, and carbon-fiber-reinforced silicon carbide composites (C/SiC) are proposed for use in space propulsion applications. It has been shown that the time to failure for C/SiC in stressed oxidation tests is directly correlated with the fiber oxidation rate (ref. 1). To date, most of the testing of these fibers and composites has been conducted in oxygen or air environments; however, many components for space propulsion, such as turbopumps, combustors, and thrusters, are expected to operate in hydrogen and water vapor (H_2/H_2O) environments with very low oxygen contents. The oxidation rate of carbon fibers in conditions representative of space propulsion environments is, therefore, critical for predicting component lifetimes for real applications. This report describes experimental results that demonstrate that, under some conditions, lower oxidation rates of carbon fibers are observed in water vapor and H_2/H_2O environments than are found in oxygen or air. At the NASA Glenn Research Center, the weight loss of the fibers was studied as a function of water pressure, temperature, and gas velocity. The rate of carbon fiber oxidation was determined, and the reaction mechanism was identified.

At temperatures of 1100 °C and above, the fiber oxidation rate is controlled by the transport of oxidant in the gas phase to the fiber surface. The oxidation rate depends on the gas velocity, is directly proportional to the oxidant partial pressure, and is nearly independent of temperature. The oxidation rate in this regime is the same in oxygen and water vapor for the same amount of oxidant. At temperatures below 1100 °C, the fiber oxidation rate is controlled by the chemical reaction of the oxidant with the fiber surface. The fiber oxidation rate in this regime is independent of the gas velocity, has a complex fractional dependence on the oxidant partial pressure, and is strongly dependent on the oxidation temperature. In this regime, the oxidation rate varies strongly with the oxidant species. Oxidation in water vapor is much slower than oxidation in oxygen for the same amount of oxidant. Oxidation rates in H_2/H_2O mixtures are slower still. A comparison of fiber oxidation rates in different environments in the chemical-reaction-controlled regime is shown in the graph. The temperature at which the regime change occurs depends on the gas velocity. Higher gas velocities drive the transition temperature higher.



Comparison of the oxidation rate of T-300 carbon fibers in different gas environments. All exposures were conducted at 900 °C with a gas velocity of 4.4 cm/sec.

The conclusion of this study is that C/SiC composites used in high-gas-velocity H_2/H_2O environments in the chemical-reaction-controlled regime will have lifetimes much longer than those that would be expected on the basis of testing in air or oxygen. These relatively low-temperature, high-gas-velocity H_2/H_2O environments may be ideal conditions for the application of these materials. Future work will examine in more detail the oxidation rates of carbon fibers in high-hydrogen-content environments.

Find out more about the research of Glenn's Environmental Durability Branch http://www.grc.nasa.gov/WWW/EDB/.

Reference

1. Verrilli, M.J., et al.: Effect of Environment on Stress-Rupture Behavior of a Carbon Fiber-Reinforced Silicon Carbide (C/SiC) Ceramic Matrix Composite. In preparation for J. Amer. Ceram. Soc.

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