# Oxidation of Carbon Fibers in a Cracked Ceramic Matrix Composite Modeled as a Function of Temperature
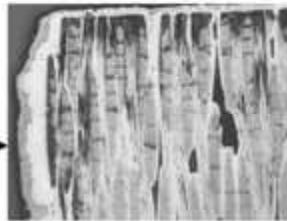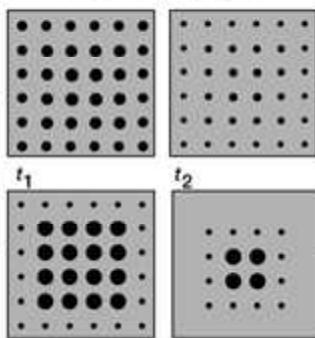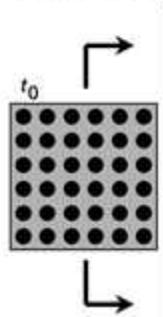
Oxidation model for carbon fibers in a CMC as a function of temperature.
Long description. Illustrations of the reaction- and diffusion-controlled regimes studied with the oxidation model. A cross-section of a composite with a 6-by-6 array of reinforcing fibers is shown from left to center for time equal to t_0, t_1, and t_2 for the reaction-controlled regime (top) and the diffusion-controlled regime (bottom). Photomicrographs showing oxidation patterns for the kinetic regimes are shown to the right. Reaction-controlled kinetics occur at low temperatures. The kinetics depend on the rate at which carbon and oxygen reactions occur. The entire material can become saturated in oxygen so that a somewhat uniform consumption of carbon is obtained. Diffusion-controlled kinetics occur at high temperatures. The kinetics depend on the rate at which oxygen is supplied. A large gradient in oxygen concentration is obtained so that the interior is starved of oxygen and oxidation occurs from the outer perimeter inward.

Carbon-fiber-reinforced ceramic matrix composites (CMCs) offer great potential for use in advanced space transportation applications. The composite system is currently being considered for many components such as nozzles, cooled panels, bladed disks, and leading edges. However, the susceptibility of carbon fiber to oxidation can inhibit its use in certain reusable and long-term applications. To better determine the potential applications for these materials, researchers need a greater understanding of the oxidation kinetics and the resultant material degradation. To address this issue, NASA, U.S. Army, and Case Western Reserve University researchers at the NASA Glenn Research Center developed a finite-difference oxidation model as part of the CMC Life Prediction Methods Program.

The oxidation model simulates the oxidation of the reinforcing carbon fibers within a ceramic matrix composite material containing as-fabricated microcracks. The physics-based oxidation model uses theoretically and experimentally determined variables as input for the model.

The model simulates the ingress of oxygen through microcracks into a two-dimensional plane within the composite material. Model input includes temperature, oxygen concentration, the reaction rate constant, the diffusion coefficient, and the crack opening width as a function of the mechanical and thermal loads. The model is run in an iterative process for a two-dimensional grid system in which oxygen diffuses through the porous and cracked regions of the material and reacts with carbon in short time steps. The model allows the local oxygen concentrations and carbon volumes from the edge to the interior of the composite to be determined over time. Oxidation damage predicted by the model was compared with that observed from microstructural analysis of experimentally tested composite material to validate the model for two temperatures of interest.

When the model is run for low-temperature conditions, the kinetics are reaction controlled. Carbon and oxygen reactions occur relatively slowly. Therefore, oxygen can bypass the carbon near the outer edge and diffuse into the interior so that it saturates the entire composite at relatively high concentrations. The kinetics are limited by the reaction rate between carbon and oxygen. This results in an interior that has high local concentrations of oxygen and a similar amount of consumed carbon throughout the cross section.

When the model is run for high-temperature conditions, the kinetics are diffusion controlled. Carbon and oxygen reactions occur very quickly. The carbon consumes oxygen as soon as it is supplied. The kinetics are limited by the relatively slow rate at which oxygen is supplied in comparison to the relatively fast rate at which carbon and oxygen reactions occur. This results in a sharp gradient in oxygen concentration from the edge where it is supplied to the nearest source of carbon, which is where the oxygen is quickly consumed. A moving reaction front is seen in which the outlaying carbon is consumed before the next inner layer of carbon begins to react.

The model allows for the oxidation of reinforcing carbon fibers within a CMC to be studied with input parameters that relate to application conditions (environment, temperature, and stress). With correlation to failure models, the oxidation model can be used to determine strength reduction and/or failure of CMCs due to oxidation of the reinforcing carbon fibers.

Find out more about the research of Glenn's Materials Divisivion http://www.grc.nasa.gov/WWW/MDWeb/.

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