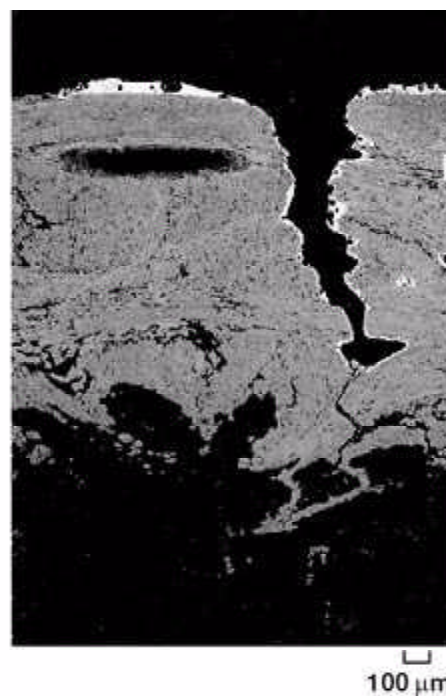
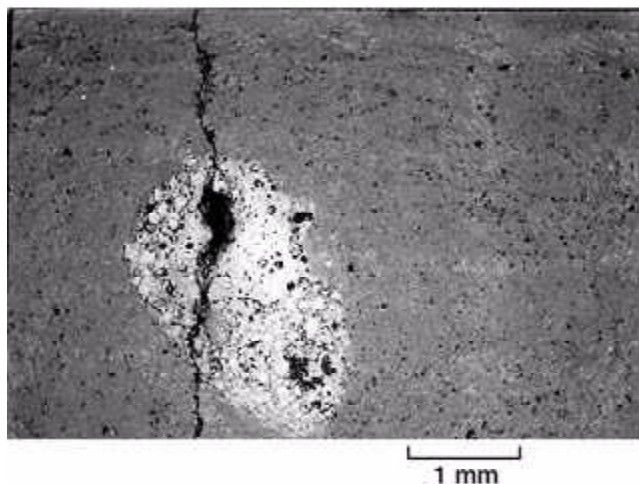


Formation of Leading-Edge Pinholes in the Space Shuttle Wings Investigated

The space shuttle wing leading edge and nose cap are composed of a carbon/carbon composite that is protected by silicon carbide. The coefficient of thermal expansion mismatch leads to cracks in the silicon carbide. The outer coating of the silicon carbide is a sodium-silicate-based glass that becomes fluid at the shuttles' high reentry temperatures and fills these cracks.

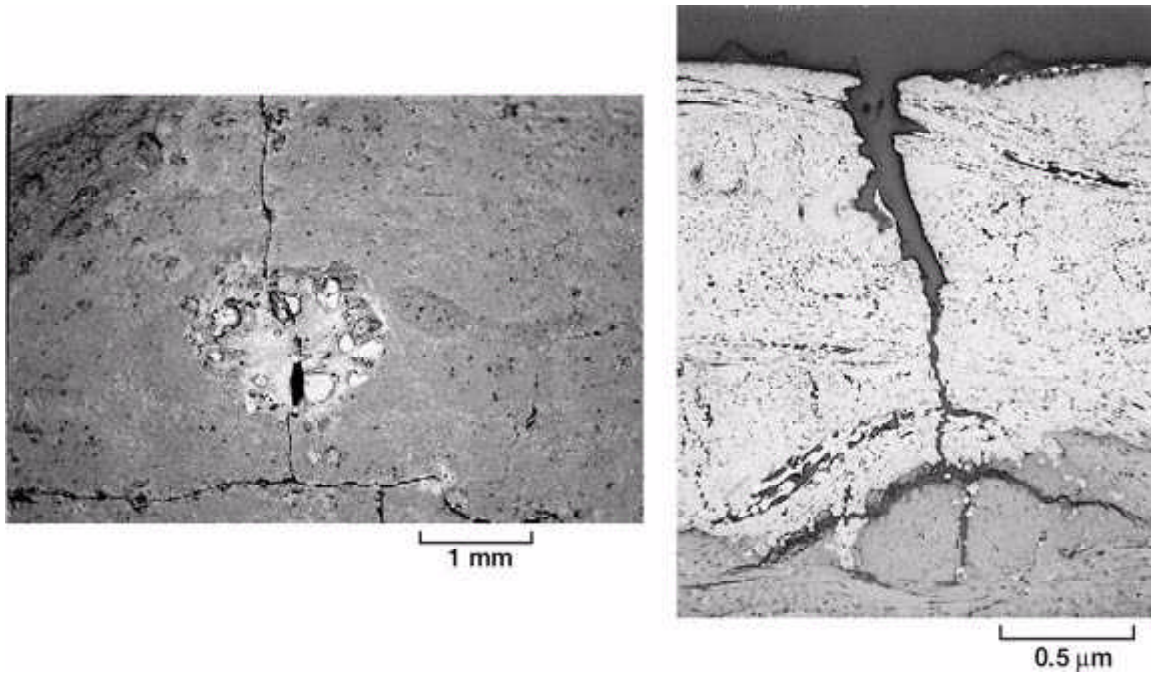
Small pinholes roughly 0.1 mm in diameter have been observed on these materials after 12 or more flights. These pinholes have been investigated by researchers at the NASA Johnson Space Center, Rockwell International, the Boeing Company, Lockheed Martin Corporation, and the NASA Glenn Research Center at Lewis Field to determine the possible sources and the extent of damage.



Left: Pinhole from OV-102 wing leading-edge panel 12 RH; 15 flights. Right: Cross-sectional view (backscattered electron image).

A typical pinhole is illustrated in the preceding photomicrographs. These pinholes are found primarily on the wing leading edges and not on the nose cap, which is covered when the orbiter is on the launch pad. The pinholes are generally associated with a bead of zinc-rich glass. Examination of the orbiter and launch structure indicates that weathering paint on the launch structure leads to deposits of zinc-containing paint flakes on the wing leading edge. These may become embedded in the crevices of the wing leading edge and form the observed zinc-rich glass.

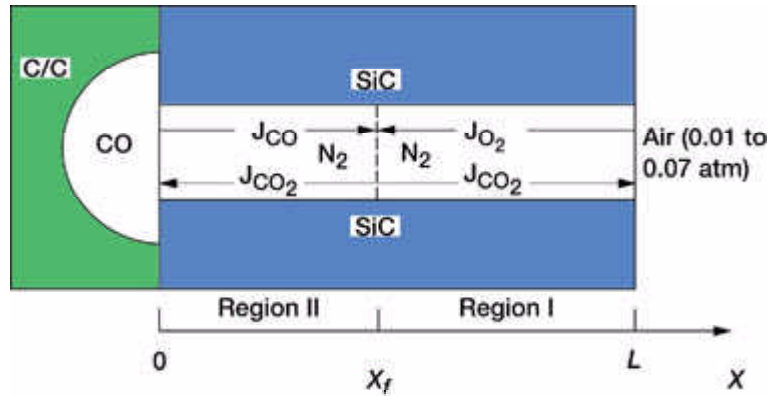
Laboratory experiments indicate that zinc oxide reacts vigorously with the glass coating on the silicon carbide. Thus, it is likely that this is the reaction that leads to pinhole formation (Christensen, S.V.: Reinforced Carbon/Carbon Pin Hole Formation Through Zinc Oxide Attack. Rockwell International Internal Letter, RDW-96-057, May 1996). Cross-sectional examination of pinholes suggests that they are enlarged thermal expansion mismatch cracks. This is illustrated in the following photomicrographs. A careful microstructural analysis indicates that the pinhole walls consist of layers of zinc-containing glass. Thus, pinholes are likely formed by zinc oxide particles lodging in crevices and forming a corrosive zinc-rich glass that enlarges existing cracks (ref. 1).



Left: Pinhole from OV-102 wing leading-edge panel; 12 RH, 15 flights. Right: Cross-sectional view with optical microscope.

Having established the likely source of the pinholes, we next needed to model the damage (ref. 2). Our concern was that if a pinhole went through the silicon carbide to the carbon/carbon substrate, oxygen would have a clear path to oxidize the carbon at high temperatures. This possibility was examined with studies in a laboratory furnace. An ultrasonic drill was used to make artificial pinholes in a sample of protected carbon/carbon. After exposure, the specimens were weighed and cross-sectioned to quantify the extent of oxidation below the pinhole.

The results at higher temperatures showed good agreement with a simple diffusion-control model. This model is based on the two-step oxidation of carbon to carbon monoxide and carbon dioxide. The fluxes are illustrated in the final figure. The model indicates a strong dependence on pinhole diameter. For smaller diameters and short times, the oxidation of carbon is very limited.



Model for the oxidation of a carbon/carbon composite at the bottom of a pinhole in a SiC coating.

References

1. Jacobson, N.S.: Space Shuttle Pinhole Formation Mechanism Studies. NASA/TM—1998-208659.
2. Jacobson, N.S., et al.: Oxidative Attack of Carbon/Carbon Substrates Through Coating Pinholes. Carbon vol. 37, no. 3, 1999, pp. 411–419.

Glenn contact: Dr. Nathan S. Jacobson, (216) 433–5498,
Nathan.S.Jacobson@grc.nasa.gov

NASA Johnson contact: Dr. Donald M. Curry, (281) 483–8865,
donald.m.curry1@jsc.nasa.gov

Author: Dr. Nathan S. Jacobson

Headquarters program office: OSF

Programs/Projects: Space Shuttle Leading Edge Structural Subsystem