Thermal Radiation Impacts Protection System

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All returning vehicles that enter the Earth's atmosphere have high heating rates that challenge designers. These high heating rates require vehicle heat shields that remain intact after long transit outside of the Earth's atmosphere. One of the Thermal Protection System materials under consideration for vehicle heat shields is phenolic impregnated carbon ablator (PICA), which was developed at the NASA Ames Research Center (ARC) in the mid-1990s for Discovery-class missions. Among these Discovery-class missions was Stardust – a capsule that completed a 7-year, 3-billion-mile journey to collect comet samples. This capsule's heat shield, composed of PICA, successfully executed the highest speed Earth entry to date on January 15, 2006.

PICA is a porous fibrous carbon insulation infiltrated with phenolic resin. While PICA is an excellent ablator, its desired thermal properties come at the expense of its mechanical strength. From an application standpoint, it is necessary to improve the mechanical properties of virgin PICA and, hence, its tolerance against micrometeoroid/orbital debris (MMOD) impact damage in space. Additionally, one of the protective mechanisms for PICA during entry heating is the formation of a char layer that both radiates heat away from the vehicle and insulates the vehicle, thereby preventing heat penetration. It is desirable to increase the yield and the strength of the char to ensure better performance. Lower-strength char can spall (chunks pop off, from internal pressure, deteriorating heat shield performance), so increasing the char strength will allow PICA to operate at higher pressures than those of the currently qualified ablator.

The Johnson Space Center (JSC) is collaborating with ARC scientists on the Thermal Radiation Impact Protection System (TRIPS) Team. The TRIPS Team is using carbon nanotubes as a reinforcement additive that will improve PICA properties by adding a supportive nanoscale fibrous structure that permeates the otherwise randomly oriented polymer. Successful incorporation of carbon nanotubes into PICA requires chemical modification of the nanotube surface to achieve desired chemical compatibility and dispersion of nanotubes. These are critical points, as only well-dispersed and compatible nanotubes can potentially create a supportive network of nanofibers within the PICA. Several types of nanotubes and several synthetic approaches were developed at JSC and ARC, followed by development of the corresponding processing techniques to manufacture nano-PICA. In addition, JSC scientists studied the properties of the nanotube – i.e., polymer interface and its influence on the load transfer mechanisms – as well as the mechanical properties of the composite.

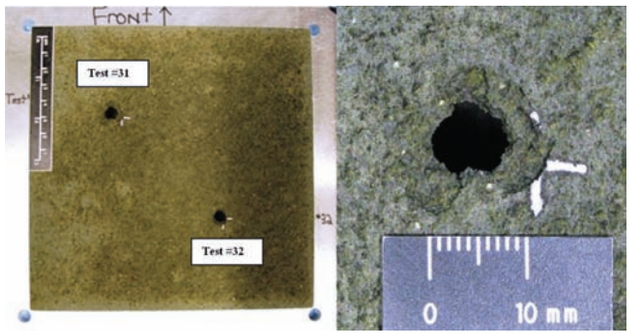

Fig. 1. *Nano-PICA following arc-jet testing to simulate atmospheric entry conditions. Thick char layer has formed outside.*

As a result of these studies, chemical functionalization and processing techniques were successfully scaled up to manufacture test articles for tensile testing, to perform arc-jet testing that simulates atmospheric entry conditions, and to complete MMOD testing that simulates hypervelocity micrometeoroid impact. Specifically, tensile tests demonstrated that a 46% increase in strength and a 76% increase in modulus can be achieved with certain combinations of nanotube type, concentration, and functionalization. Arc-jet tests demonstrated reduced

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continued

recession rates, reflecting on the higher char strength. Hypervelocity impact testing of nano-PICA is under way at the White Sands Test Facility (figures 1 and 2).

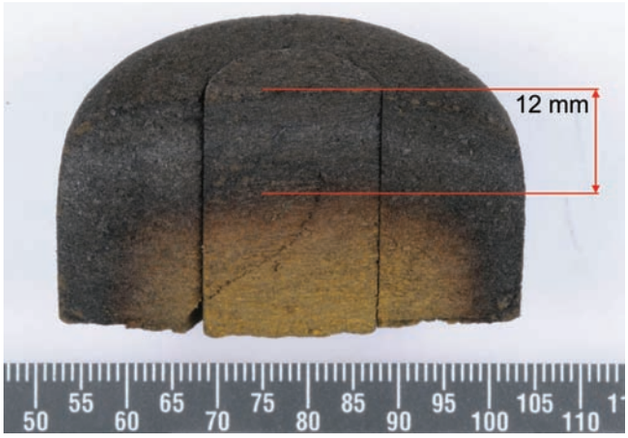

Fig. 2. *Nano-PICA following hypervelocity impact testing at the WSTF. The entry hole size is comparable to that in standard PICA. The internal damage dimensions will be determined by x-ray imaging.*

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