Thermal Radiation Impact Protection System

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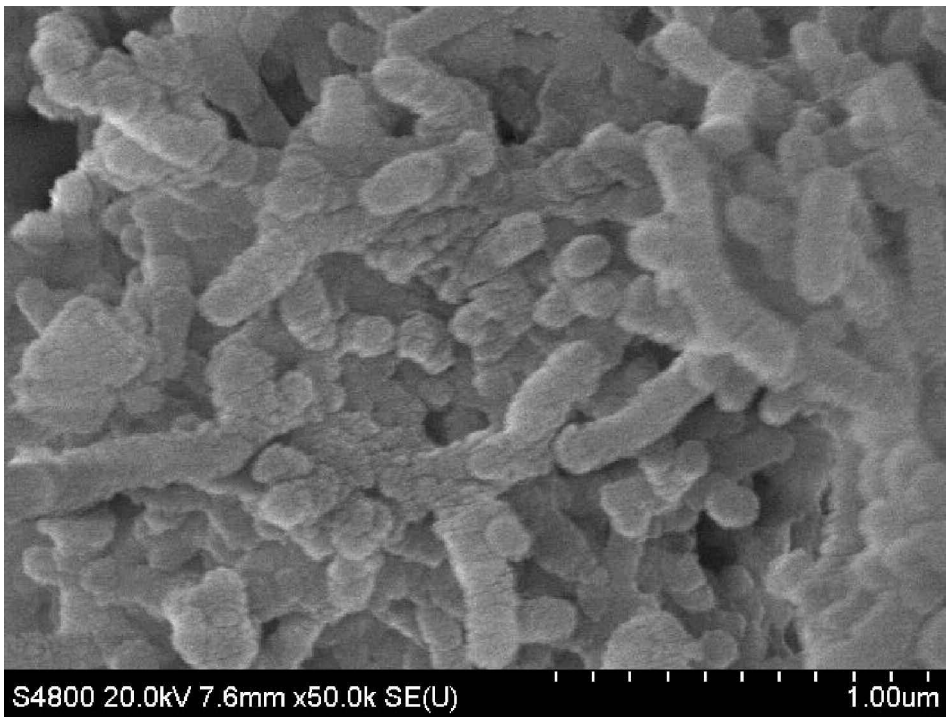
The Johnson Space Center (JSC) Applied Nanotechnology Team is collaborating with the Thermal Design Branch (ES3) and Ames Research Center (ARC) on the Thermal Radiation Impact Protection System (TRIPS) project to improve the Orion (new launch vehicle) vehicle's thermal protection system (TPS) properties. Orion vehicle is the crew exploration vehicle for the space station and the Moon. Phenolic Impregnated Carbon Ablator (PICA) has been selected as the block II heat shield, but improvements are sought for PICA's char and micrometeoroid strength. The TRIPS team is attempting to use small amounts of carbon nanotubes to meet Orion vehicle's TPS challenges.



Nanotubes coated with phenolic polymer.

Small additions of carbon nanotubes to the phenolic polymer have potential to greatly improve char strength. Char is formed as a thin layer as heat from entry pyrolizes PICA's leading surface. Aerodynamic heat and pressure from lunar and martian returns will push the ablator to its limits. If the char is too weak, pressure from hot internal gases can cause the char to spall or break off, thus exposing virgin PICA. This causes uneven heating and disturbances to the boundary layer. Carbon nanotubes increase char strength by adding an additional fibrous structure to the otherwise randomly orientated pyroloisis region.

Nanotube inclusion has the potential to also improve PICA's micrometeoroid impact resilience. While docked on the International Space Station, sections of the heat shield are exposed to micrometeoroid orbital debris (MMOD). Should MMOD damage the TPS, hot gases could penetrate into the PICA on entry and damage the integrity of the TPS and vehicle.

Successfully incorporating carbon nanotubes into PICA requires close integration of the growth, processing, characterization, and applications efforts within the Applied Nanotechnology Team. These fundamental areas span the

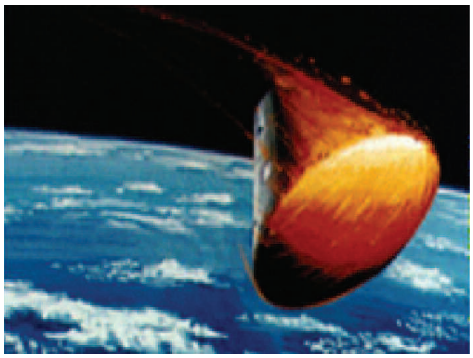
synthesis of the starting nanomaterial, purification, and functionalization of the nanotubes to optimize compatibility, dispersion, and anchoring of the nanotubes in the phenolic matrix, and analysis of nanotube purity and compatibility with the host material to ensure quality control. The applications effort centers on the integration of nanotubes into PICA, definition of the material requirements, and testing of bulk test articles.

Selection of the proper nano-constituent is vital for achieving desired performance, so the TRIPS project is studying three distinct forms of carbon for the task. Single-wall carbon nanotubes have the best mechanical properties, but they are the hardest to produce and process. Multi-wall carbon nanotubes have larger diameters and are not as strong, but they are cheaper to produce and easier to process. Graphene sheets are another low-cost nano-additive being evaluated. For the TRIPS project, single-wall nanotubes have the highest long-term potential, but multi-wall nanotubes are more feasible in the near term.

Processing of the nanotubes represents a key challenge for the project. After production, nanotubes contain impurities, mostly amorphous carbon and metal catalyst. The TRIPS team uses a JSC-developed purification procedure to produce pristine nanotubes. However, pristine nanotubes alone are unusable since they bundle or aggregate and, without additional processing, will cause a decrease in material system performance. To solve this problem, chemical groups are added to the nanotube sidewalls (functionalization) causing the nanotubes to separate and interact with the phenolic matrix. Ideally, the functionalization results in a strong bond between the nanotube and the phenolic, anchoring the nanotubes in the matrix. A major challenge is scaling this process in the lab environment to produce enough optimized nanotubes for bulk test articles.

The characterization team studies the nanotubes through all growth, processing, and testing phases. Analytical techniques include Raman spectroscopy, scanning electron microscopy, optical microscopy, and transmission electron microscopy. A new technique – a four-point bending stage combined with a Raman spectrometer – allows for simultaneous measurement of the strain in the bulk material with strain transferred to the individual nanotubes.

Bulk performance is characterized by standard TPS test methods to compare against standard PICA. These include hypervelocity impact, arc jet, thermal, tensile, and char strength. Initial tensile testing results show a 35% increase in the strength with 0.4 wt % functionalized nanotubes. Thermal testing showed that the carbon nanotubes do not significantly change the thermal conductivity.



Artist's rendering of the new Crew Exploration Vehicle entry into Earth atmosphere showing thermal effects – Courtesy of NASA ARC.