Advanced Repair and Cure Using Nanomaterials and Microwaves

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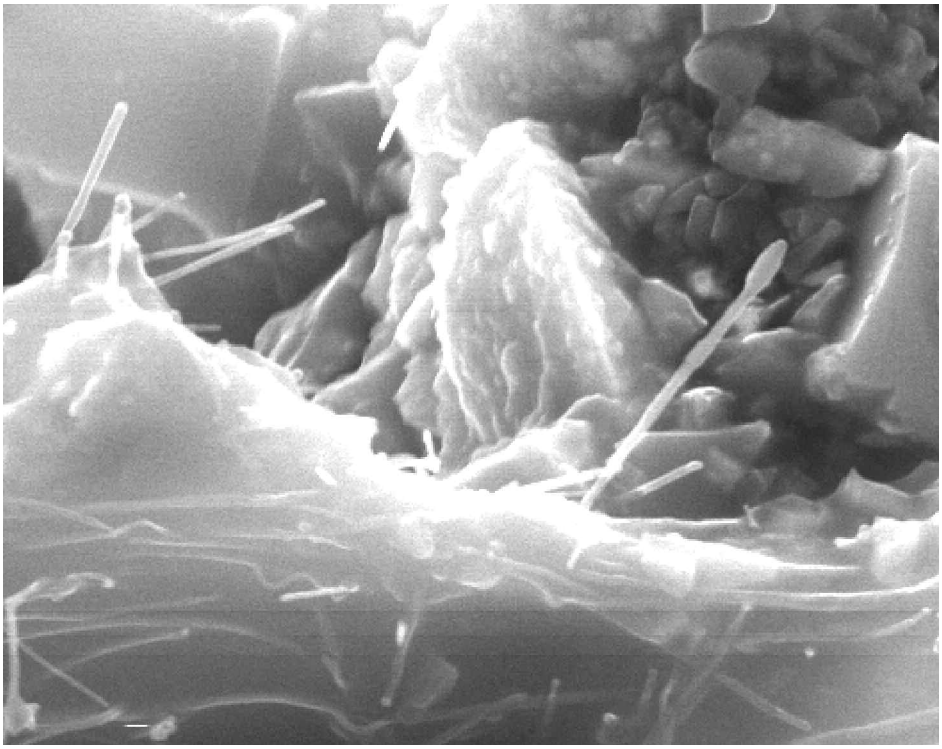
One of the key applications of nanotechnology currently being researched and developed by the Applied Nanotechnology Team is that of Advanced Repair. This project attempts to address aspects of the long-term space exploration need for enhanced repair, curing, and verification technologies for self-reliant systems. This effort focuses on harnessing the unique attributes of small quantities of nanomaterials to enhance the repair and cure capabilities of conventional materials used on shuttle and planned for the Orion vehicle and inflatable/rigidizable lunar structures. The Advanced Repair project is an active collaboration among the Applied Nanotechnology Team and the Space Shuttle Program, Johnson Space Center (JSC) Crew and Thermal Systems Division, JSC Avionics Division, the Astronaut Office, NASA/Marshall Space Flight Center (MSFC), and Rice University.



Scanning electron microscopy of cured shuttle RCC repair material NOAX and carbon nanotube "dopants."

The repair and cure concept centers around the exceptional sensitivity of carbon nanotubes to microwave energy, whose ability to transfer microwaves to thermal energy was previously found to be ~1:1 by collaborator Dr. James Tour of Rice University. This responsiveness allows the team to include small weight percentages of optimized and chemically functionalized carbon nanotubes into conventional space materials that, in turn, provide sensitivity for focused low-power microwaves with resultant localized heating. The initial target material chosen was the temperature-dependent Reinforced Carbon-Carbon (RCC) repair material, or non-oxide adhesive experimental (NOAX), a pre-ceramic polymer sealant impregnated with carbon-silicon carbide power. Current use conditions of NOAX call for the shuttle's heat of entry to provide the majority of thermal energy for a successful cure. It was proposed that incorporation of nanotubes may increase NOAX sensitivity to microwave energy, thereby providing a more reliable and efficient heating and cure procedure.

Despite their inherent promise, carbon nanotubes are often unsuitable for many host materials without specialized purification and processing. The purification and characterization standards developed and employed by the Applied Nanotechnology Team provided the necessary level of quality assurance to quantify nanotube purity. In collaboration with Dr. Tour's research team at Rice University, carbon nanotubes were successfully functionalized and optimized for inclusion into NOAX. Effective dispersion of the nanotubes is necessary to increase their heating efficiency and reduce the weight percentage necessary for successful microwave heating.

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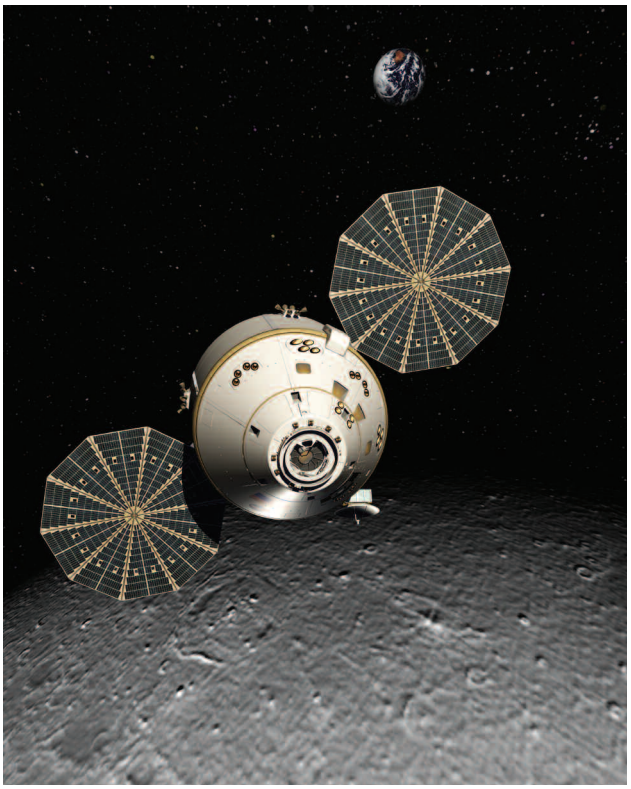
continued

Cure temperatures of over 900°C were achieved in NOAX in approximately 10 minutes in laboratory conditions using microwaves at 100 watts or less. Based on these successful initial experiments, NOAX developers MSFC and Alliant Techsystems (ATK) are exploring scaling up integration and testing of nanotube-doped NOAX with the JSC Applied Nanotechnology Team.

Additional materials tested during the project's first year of development included silicone adhesives and composite epoxies. Silicone adhesives are commonly used by NASA as an adhesive, including thermal protection system (TPS) bonding. Adhesive cure time was reduced by as much as 80% by the localized heating produced by the nanotube and microwave combination.

The continuing development work of this application, in collaboration with MSFC and ATK, is focused on improving NOAX performance while expanding the repair concept to other critical space materials. Efforts to further improve nanotube dispersion techniques and compatibility with host materials are ongoing, while the focused microwave test capabilities used are being improved in collaboration with the JSC Avionics Division. Initial success with an additional class of host materials has been shown with phenolic resins, the principal component proposed for the Orion vehicle ablator TPS. This effort is highly complementary to the ongoing collaboration between JSC and Ames Research Center for the multifunctional Orion Thermal Radiation and Impact System, which includes development of phenolic reinforcement using carbon nanotubes.

Along the vein of providing technologies for sustainable long-duration missions, the cure and repair concept is currently being expanded to the proposed composite materials for the Orion vehicle.



An artist's rendering of the Orion crew exploration vehicle.