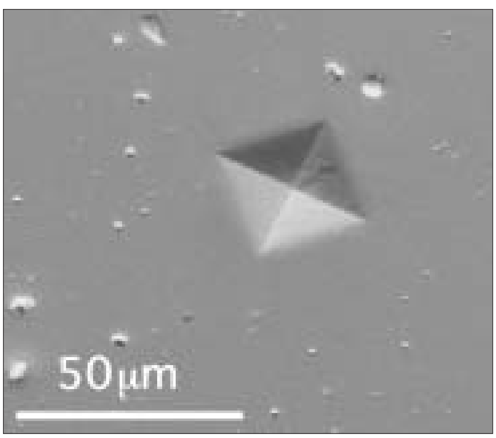
Materials

Improvements in materials for both space and aeronautical vehicles may heighten safety and ease repair.

Space shuttle advances

NASA Langley has successfully developed an on-orbit repair capability for the shuttle orbiter's carbon-carbon wing-leading-edge (WLE) panels that will be flown on future missions. The repair consists of a 7-in.-diam carbon-silicon carbide (C/SiC) coverplate that can be attached to a damaged panel using a titanium/zirconium/molybdenum (TZM) refractory metal toggle mechanism and sealed using an experimental high-temperature sealant (NOAX) developed by Alliant Techsystems (ATK).



Researchers conducted a Vickers indentation test (1,000-g load) of a 1.5-mm-thick yttria stabilized zirconia/gold nanocomposite film on steel.

NOAX, or nonoxide adhesive experimental, is a formulation of preceramic sealant mixed with SiC powder and other manmade fillers. The adhesive remains malleable enough for astronauts to spread it onto a damaged surface in the vacuum of space. NOAX partially cures after exposure to several hundred degrees of heat, but will not harden completely until it experiences the extreme temperatures of reentry into Earth's atmosphere. The chemical vapor infiltration C/SiC coverplate for the repair is produced by General Electric Ceramic Composites.

There were significant materials breakthroughs achieved during this accelerated development activity—two new materials (C/SiC and TZM) will be certified for use on the shuttle, and a new high-temperature oxidation barrier coating (MCM-700) was invented by engineers at General Electric.

NASA Langley has also developed and verified new testing methods to measure full-field displacements and strains of sprayed-on foam insulation (SOFI) material used on the shuttle external tank. The SOFI is an anisotropic material that exhibits a significant amount of nonuniformity in its microstructure, which can lead to localization in the material response when subjected to thermal and mechanical loads. To date, material properties such as modulus and fracture toughness have been determined by using relatively low-fidelity bulk engineering measurements and generally exhibit a substantial amount of scatter in the test data.

The testing uses a commercially available video image correlation system that tracks the deformations of a high-contrast speckle pattern applied to the specimen and then calculates displacements and strains of the viewing surface. Specimen preparation procedures and guidelines were developed for testing and processing the image data. In addition, methods for taking measurements at elevated and at cryogenic temperatures have been developed and verified.

Recent efforts have focused on assessing the response of standard material characterization tests such as those used to measure material stiffness and strength. The foam testing is an important leap forward in the ability to characterize and measure behavior of foam materials subjected to relevant combined mechanical and thermal loads. These data ultimately will be used to verify current testing techniques, help develop and refine new test methods, and provide data for analysis tool validation activities.

Repairing reusables

Reusable launch technology to meet the Air Force's target of seven-day maintenance turnaround times for relaunch, with an ultimate goal of a turnaround time of 12 hr or less, will require field repair capability for critical components to meet operational readiness objectives. The Air Force Research Lab (AFRL) continues to address the operability requirements of these future systems with the development of an innovative repair concept that uses a "snap-together" tool.

The tool can be easily assembled in a field environment to create a hard surface for the fabrication of a large area overwrap repair. It is packaged in a flat arrangement with all necessary repair materials and, when assembled, results in a three-dimensional tooling surface that emulates the outer mold line of a leading-edge panel. The repair material is then laid up onto the surface and cured at low temperatures, creating a rigid leading-edge overwrap that can be attached to the vehicle.

This repair concept utilizes overwrap materials that can be processed at relatively low temperatures (250 F) yet provide adequate protection during reentry. One material is Glenn Refractory Adhesive for Bonding and Exterior Repair (GRABER), developed at NASA Glenn. A version of the adhesive, GRABER 5, a phenolic based resin loaded with carbon and SiC powder, was used. Preliminary tests by ATK on a SiC/GRABER laminate indicate that this material is capable of surviving reentry conditions.

by **Gregory A. Schoeppner**
Edward H. Glaessgen

Nanotube composites

Composites formed from carbon nanotubes in a polymer matrix are being studied at NASA Langley with multiple-length scale models that combine quantum chemistry, molecular dynamics simulation, micromechanics, and continuum mechanics molecular simulation techniques. The properties of the nanotube-matrix interface are being studied in detail in order to determine the effect of functionalization on mechanical and thermal properties. The intrinsic atomistic structure and properties of novel nanostructured materials are explicitly used in the determination of the behavior of the complete macroscale material system.

Examples include a nonlinear constitutive model developed and applied to the calculation of nonlinear stress/strain curves of cross-linked nanotube materials, calculations of thermal conductivity of carbon nanotube-based polymers, and the calculation of the macroscopic effect of local chemical functionalization of carbon nanotubes on the critical buckling loads of polymer nanotube composites.

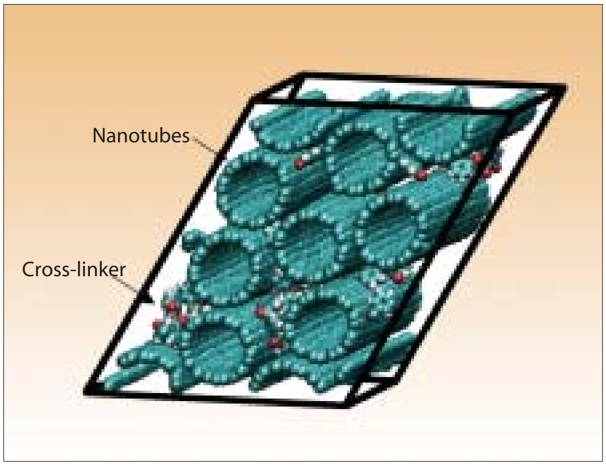
AFRL advances

AFRL scientists and engineers have developed a new class of wear-resistant materials, comprised of very hard 3-5-nm grains of carbides or oxides embedded in an amorphous matrix of either diamond-like carbon or a metal/ceramic mixture, that could improve the performance and durability of aircraft engines. During the material characterization stage, the materials exhibited an unusual combination of high hardness (exceeding that of ceramics) and fracture strength (similar to that of tough metal alloys).

AFRL teamed with Frederick Seitz Materials Research Laboratory at the University of Illinois to conduct a series of in-situ transmission electron microscope tests to identify, with nanometer-level resolution, the mechanisms responsible for the unexpected combination of hardness and strength. As a result, they discovered a new mechanism of macroscopic ductility—one not based on dislocation mobility or diffusion-related boundary reconstructions.

The new mechanism is a unique feature of nanocrystalline/amorphous composite design, resulting from a large number of 1-2-nm shifts of nanograins inside the amorphous matrix. The experimental research results explain the high fracture toughness of the nanocrystalline/amorphous composites when exposed to large contact deformations with high loading rates.

There have also been significant advances in the development of bulk metallic glasses that can be used to improve the durability and performance of aerospace components. AFRL scientists have created working scientific models capable of predicting the composition of new metallic glasses, which help researchers determine in advance whether the glasses can be manufactured in bulk. As a result of the research, several new bulk metallic glasses have been discovered. Their work has also led to the successful development of a new technique for illustrating the topology of amorphous (noncrystalline) metal alloys. These advances will enable the development of metallic glasses with the exceptional functional properties (magnetic and structural) required to meet the demands of tomorrow's crucial technologies.



An atomistic model of a bundle of single-wall carbon nanotubes shows the inclusion of cross-linker material used as a tether between individual tubes.

Scientists at AFRL have developed a super-high-strength aluminum alloy that can improve the performance and capability of aerospace components, specifically for cryogenic rocket engine applications. In the past, metallurgists have tried to produce high-strength aluminum alloys through an expensive nanophase aluminum process. Unfortunately, the alloys that result from this process do not possess required combinations of strength and ductility properties to make them appropriate for use in the cryogenic rocket engine applications.

Together with scientists from Universal Energy Systems and with technical support from Boeing-Rocketdyne, AFRL researchers used an alternative approach to produce alloys using conventional casting technology, which is less expensive than powder metallurgy. The strength of the alloys results from thermomechanical treatment, which leads to precipitation of very fine, nonsoluble dispersoids and grain refinement. An alloy with specific strength and ductility characteristics that surpass those of the alpha titanium alloy currently used in rocket engine turbopump impellers was achieved. The aluminum alloy is significantly less expensive, more resistant to hydrogen embrittlement, and 38% lighter than the conventional titanium alloys currently used in propulsion systems. Currently, it has been made in castings that are 76 mm in diameter and 6 m long.