UNITED STATES AIR FORCE MATERIALS TECHNOLOGY HIGHLIGHTS

Air Force Research Laboratory

Materials & Manufacturing Directorate

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Focused Ion Beam Microscope Improves Aerospace Materials Characterization

The Air Force Research Laboratory Materials and Manufacturing Directorate has acquired an advanced microscope that will greatly enhance the facility's capability to develop new materials for current and future aerospace systems.

Designed around the basic functions of a focused ion beam (FIB) and a scanning electron microscope (SEM), the new instrument significantly improves materials characterization by combining nano-machining, micro-deposition and micromanipulation capabilities with simultaneous imaging using both ion and electronic optics. Researchers at the directorate's Microstructural Characterization Facility (MCF), collaborating with faculty at Ohio State University, the Air Force Office of Scientific Research (AFOSR) and FEI, Inc. (formerly Phillips Electron Instruments), helped develop the critical concepts required to build this next generation laboratory instrument.

ML research scientists and engineers study an extensive variety of materials and systems in order to enhance understanding, assist in discovery, and advance technologies that help strengthen the Air Force and national security. This effort includes timely and accurate characterization of microstructure, crystallography and chemistry, which have become increasingly diversified and have grown tremendously in the past few years. This growth has placed several demands on ML personnel and resources, particularly in research-critical microstructural characterization instrumentation.

Scientists and engineers in the directorate's MCF surmised that due to the intrinsically diverse nature of materials discovery and expanding levels of microstructural control and manipulation, new analytical tools were needed that are more sensitive, user-friendly, computer controlled and efficient. The MCF team also knew these tools must be able to address large numbers of materials classes and systems, and that the amount of time needed to prepare samples must be drastically reduced. Improved characterization capability was clearly the best solution.

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Dr. Mike Uchic points out an item to Dr. Larry Matson on Dual-Beam FIB-SEM instrumentation in ML's Microstructural Characterization Facility.

Software-Based Modeling Tool Aids Materials Qualification of Textile and Three-Dimensional Preform Composites

Engineers from the Materials and Manufacturing (ML) Directorate's Structural Materials Branch have developed a software-based analytical tool that will supply engineers and composite manufacturers with important materials qualification information on traditional textile composites, and on three-dimensional perform composites, which contain three-dimensional (3-D) fiber architectures.

Traditional textile and 3-D preform composites are the key material forms used to produce the complex shapes and structures that exist in Air Force aviation, space and munitions applications. The tool is expected to save manufacturers time and costs related to materials qualification by supplying reliable data about the strength, stress and complex 3-D failure modes. This information will allow manufacturers to quickly produce and incorporate the emerging lightweight, low-cost, load-bearing structural materials needed to sustain present and future Air Force applications.

Working with composite materials, engineers have discovered that traditional composite laminates, containing no fiber reinforcement in the thickness direction, are not as delamination resistant as a textile and 3-D preform composite where fibers are woven or braided. By weaving fibers in three dimensions, the damage tolerance, impact resistance, through-the-thickness strength and stiffness of the composite are increased.

Textile and preform composites enable low cost manufacturing processes (such as Vacuum-Assisted Resin Transfer Molding) for fabricating structural components of complex shapes. So textile composites have become a widely used and affordable medium in advanced composite manufacturing. But because the fiber yarns are curved to create the complex shapes and structures that exist in Air Force aviation, space and munitions applications, there are challenges related to analyzing their structural performance.

To produce composites with optimum structural characteristics, engineers have to develop a basic understanding of the deformation/damage mechanics and failure mechanisms of the textile that they are working with. Observation of damage initiation in textile composites reveals that damage, in the form of interface cracks, initiates at the location where the yarn is curved (crimped), which is strongly influenced by stresses at a location of high strain gradients.

Engineers from ML have developed a numerical modeling tool, which runs on a software application, to address these challenges. The tool combines the stress analysis of three-dimensionally curved fiber reinforcements (yarns) in conjunction with finite element analysis. Manufacturers provide the fiber reinforcing direction (fiber yarn direction), its dimensions, and properties of the fiber and matrices. When the modeling tool is provided with this information, it calculates the stresses that a fiber yarn and the matrix materials are experiencing when a load is applied. When the strengths of the composite constituents (fiber and matrix materials) are defined, researchers can conduct trend prediction to determine how cracks or failure will initiate and propagate in textile and preform composites.

Until now, most of the research in textile composites has been based on two-dimensional stress analysis, which does not reliably predict yarn interface stresses. In addition, computational modeling of flat composite structures has lacked consideration for curvature, or interface stress continuity around the area where the

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Focused Ion Beam Microscope

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Unfortunately, the cost of upgrading and maintaining a world class materials research facility with state-of-the art surface and bulk characterization instrumentation has grown at an alarming rate, and has subsequently limited the growth of the characterization market. This in turn has constrained the level of characterization effort in many research programs and slowed technological advancement.

Characterization equipment developers are trying to reverse this trend by making their laboratory instruments more versatile. Research institutions, on the other hand, have been compelled to consider joining forces and forming what are known as "centers of excellence" at each institution. In essence, when a technology is needed that one institution does not have, the work is accomplished in a cooperative center and visa versa.

Researchers at the MCF, collaborating with Ohio State University faculty and AFOSR, assisted FEI in the development of the Dual-Beam FIB-SEM. The new FIB-SEM incorporates many of the versatility qualities eagerly sought by characterization equipment developers, while offering outstanding potential as a shared resource among partnering centers of excellence. Numerous analytical sensors for chemistry and crystallography can be incorporated into the new microscope, as well as process controls and digital data acquisition via user-friendly computer interfaces.

Of particular importance to ML and the MCF, the new instrument has proven highly effective in characterizing a large number of solid material classes and systems such polymers, metals, ceramics, and mixtures of each. It has also been used to characterize microelectromechanical systems (MEMs), micro-lithography, oxidation and corrosion scales, and has proven to be very effective for studying biological samples such as arthropods, human hair, brain cells, and pollen. The new Dual-Beam FIB-SEM reduces sample preparation times from weeks to hours, saving time and money.

For more information, contact the Materials and Manufacturing Directorate's Technology Information Center at techinfo@afrl.af.mil or (937) 255-6469. Refer to item 01-256.

Nonstructural Materials Experts Evaluate Lubrication, Extend Operation of Aircraft Between Maintenance Intervals

Discoveries from research and analysis conducted by experts from Air Force Research Laboratory's Materials and Manufacturing Directorate (ML) of a grease lubricant used in the B-2 aircraft has led to longer intervals between grease lubricant maintenance, which will result in significant cost-savings for the Air Force.

By inspecting the operational life of the lubricant, ML researchers made recommendations to the B-2 Systems Program Office (SPO) that allowed them to extend the lubrication maintenance interval for flight controls and flight control actuators from every 600 hours to every 1,000 hours, a 67 percent extension. The application of the new intervals provides cost savings of $7.2 million over 20 years of aircraft operation, including costs associated with 60,000 hours worth of unnecessary maintenance and aircraft down time.

Lubricants are used to minimize corrosion, wear and failure in areas where moving metal components perform or interact with each other. During the operational life of a lubricant, oil evaporation and exposure to oxygen and water can change the physical and chemical properties of a grease, and make it less effective. In addition, grease sometimes becomes contaminated with wear or elastomeric seal debris, which changes the consistency of the lubricant and negatively affects the performance of the system where it is applied. These catalysts make regular maintenance of grease lubricants necessary.

"When working properly, a grease enables the long-term performance of Air Force technologies," said Lois Gschwender, a lubricant specialist working in the directorate. "Grease keeps parts moving and keeps wear down, which often results in improved system performance, minimized failures, and, in this case, cost-saving benefits."

Researchers from ML's Nonstructural Materials Branch, who conduct research and development on nonmetallic, nonstructural materials such as fluids, oils, greases and solvents, received a request from the B-2 SPO to compare and analyze the effectiveness of the lubricant grease, MIL-PRF-23927, during regular and extended maintenance intervals.

"The SPO wanted to safely extend the amount of time the aircraft could operate between maintenance down time," Gschwender said. "So we examined, compared and analyzed new, unused grease with grease that had 600 and 1,200 hours of operation life."

Grease samples from four aircraft, which were in maintenance inspections, were analyzed by researchers using microscopic and infrared spectroscopic techniques. ML researchers discovered that while "used" greases had a slightly harder consistency and darker color than new grease, they were not contaminated with wear or seal debris. In addition, the consistency of the grease indicated that several of the major failure modes of grease, including thermal and oxidation degradation, reaction of the base oil with water, and evaporation of base oil, had not occurred.

"We concluded that the grease was suitable for continued use, had significant life remaining, and didn't need to be checked or replaced every 600 hours," Gschwender said. She added that researchers from ML reported their results during discussions with the SPO and Northrop Grumman, the aircraft's manufacturer.

Representatives from Northrop Grumman, Rexnord Shafer (a bearing manufacturer), and ML also conducted an analysis of bearings from flight control actuators that had operated for 38 and 40 months using the grease. With more than 800 hours since their last maintenance the bearings appeared to be "shiny" and showed no signs of damage. Though some insignificant corrosion and wear marks were observed when examined under magnification, researchers concluded that the bearings were suitable for continued use in the aircraft.

"(We) Researchers from all the involved organizations were in agreement that the grease and bearings were performing beyond the current lubrication maintenance schedules," Gschwender said. "This allowed the SPO to make a positive change to their day-to-day responsibilities, and to save the Air Force a substantial amount of money."

Top: Lois Gschwender analyzes grease samples using microscopy. Bottom: Dr. Shashi Sharma, a researcher from the ML's Nonstructural Materials Branch inspects a bearing to evaluate the performance of lubricants and their impact on real world systems.

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yarn is crimped. Because satisfying the interface stress continuity at the crimped location is essential for prediction of damage initiation and propagation in textile and preform composites, the yarn interface stresses near the crimp region must be accurately predicted.

Most other models have "smeared" the properties of the reinforcing yarns, such as yarns woven or braided in different directions and matrix (resin) regions, and modeled them as a homogeneous medium (material). These models do not produce an accurate stress field for reliably predicting failure initiation locations. In the directorate's model, each yarn is modeled separately as a homogeneous medium to accurately represent the yarn interface region. The matrix regions that exist around the yarns are represented as separate regions. In order to predict the characteristics of damage, where crack initiation and propagation could occur, the equilibrium of stresses is satisfied point wise everywhere in the model, and the yarn interface stress compatibility is enforced.

Materials manufacturers have already experienced success using the model to determine the structural characteristics of three-dimensionally woven textile composites. Researchers expect that continued use and implementation of the model will yield future aircraft and munitions that are stronger, more reliable, lower cost, and contribute to the overall mission readiness of the Air Force.

For more information, contact the Materials and Manufacturing Directorate's Technology Information Center at techinfo@afrl.af.mil or (937) 255-6469. Refer to item 01-386.

NEW sTART Contracts

- Integrated High Performance Rocket Propulsion Technology Exit Cones - F33615-02-C-5016
- Liquid Crystal Polymer Lined Graphite Fiber Reinforced Composites - F33615-02-C-5017
- Processing Of Tough, Fracture And Puncture Resistant Thin Film - F33615-02-C-5011
- Advanced Turbine Life Prediction System - F33615-02-2-5201
- Rotating Turbomachinery For Cryogenic Rocket Engines - F33615-02-C-5206
- Free-Form Optics Polishing By Magnet Or Heological Approach - F33615-02-M-5222
- Improved Titanium Machining Process - F33615-02-C-5320
- Development Of Optical Host Materials With High Laser Damage Thresholds - F33615-02-C-5418
- Heteroepitaxial Growth On Nanostructured Silicon Surfaces - F33615-02-C-5401

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