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by Erin Crawley
AFOSR Public Affairs

2/26/2007 - **ARLINGTON, Va.** -- Leading edge scientific discoveries and breakthroughs funded by the Air Force Office of Scientific Research here were recently presented at an AFOSR ceramics program review.

These latest developments could pave the way for new performance capabilities of materials used in extreme environments, and potentially impact the future of hypersonics.

Dr. Joan Fuller, AFOSR's ceramics and non-metallic materials program manager, spearheaded the event held at the National Science Foundation which featured world-class materials researchers funded by AFOSR.

Fuller stressed the importance of basic research in the area of ceramics and non-metallic materials.

"There are many application areas where a deeper understanding of the fundamental science of structural ceramics could enable revolutionary advancements," Fuller said. "In particular, the Air Force requires strong and light-weight materials that can operate in extreme thermal and chemical environments." As examples, Fuller mentioned the leading-edge of a hypersonic plane, the combustor of a turbine engine, or the optical path of a direct energy weapon.

"In addition to the mechanical requirements of the materials, the components will likely all involve complicated shapes that will require the development of new processing and manufacturing techniques," said Fuller. "It is highly probable that future Air Force mission requirements will simultaneously impose both extreme thermal and chemical operating environments. Therefore, future materials systems must be discovered and developed for these unique operating environments."

AFOSR funded scientists supporting this research area are making great advances. Recent successes include discovery of new, previously unknown compounds; development of a new process called melt texturing; and important micro-structural observations in how materials interact with one another in the operating environment.

A New Compound is Discovered

Dr. Inna Talmy manages the ceramics laboratory at the Naval Surface Warfare Center Carderock Division, Bethesda, Md., and is an internationally recognized expert in ultra-high temperature ceramics and radome materials. In collaboration with AFOSR, her research group is exploring a class of materials called cermets. Cermets are ceramic-metal composites capable of compensating for the intrinsic brittleness of ceramics at room temperature while maintaining the high temperature properties inherent in ceramic materials.

Talmy shared the details of a new compound she and her colleague, Dr. Jim Zaykoski, recently discovered.

According to Talmy, the two researchers discovered the new compound while attempting to prepare a cermet containing tantalum as the metal component and zirconium diboride as the ceramic component. Both materials have very high melting points.

"We anticipated the two elements might not react because they were found to be chemically incompatible," Talmy said. "However, they did react and a new compound formed. There are no data in the literature on this compound So, we actually discovered the new material. Together with Dr. Winnie Wong-Ng at the National Institute of Standards and Technology, we have identified the structure of this new compound," said Talmy.

Talmy said the new compound has a crstal structure with elongated interlocked grains, which results in increased strength. The strength of the new ceramics is significantly higher than that of zirconium diboride, a material that already has great potential for applications at ultyra-high temperatures and has excellent resistance to oxidation and corrosion.

"The new compound has a melting temperature above 2,300 degrees Celsius. For a comparison sapphire (Al2O3) melts at 2,050 degrees Celsius ," said Talmy. Talmy said this suggests the material could potentially be used in re-entry vehicles and nozzle materials because it may be able to withstand the thermal shock.

While Talmy has not given the compound an official name yet, she has applied for a patent and the results of her work will be published in the Acta Crystallographica section of Foundations of Crystallography.

'Melt Texturing' Process is Developed

Dr. Ali Sayir, who has received AFOSR funding for the past seven years, pioneered another recent development in ceramics. Sayir leads a research team from NASA's Glenn Research Center at Case Western Reserve University, and he collaborates with the I. Frantsevich Institute for Problems of Materials Sciences in Kiev, Ukraine. Sayir's team recently developed a new process called "melt texturing" to create highly ordered microstructures in ceramic composites for use in multi-functional aerospace applications. This includes using ceramic actuators for high temperature applications.

In describing melt texturing, Sayir said, "I developed an alternative approach similar to one used with metals and super-alloys. I use lasers to melt the ceramic materials and control their subsequent solidification instead of making them from the traditional powder processing routes. This new processing methodology allows me to precisely control the microstructure and has opened a new area of research for ceramics with very interesting and exceptional properties."

According to Sayir this process has also resulted in the development of a class of new multi-functional ceramic materials that can maintain extreme strength under heavy loads at temperatures above 2,000 degrees Celsius. Most materials are either liquid or vapor at those temperatures. This material was originally discovered by Sayir's colleagues in Kiev. Sayir's team is now optimizing the microstructure to explore both structural and functional uses for this material.

"This is a huge breakthrough because, to my knowledge, there is no material like this. We showed for the first time such a high strength at such high temperatures. It is a giant leap, not only temperature-wise and strength-wise, but also with regard to a material that can support a weight load at high temperature," said Sayir.

Sayir suggested this ultra-high temperature material could be used for a variety of structural applications in propulsion technology, especially for rockets and hypersonic aircraft where extreme thermal environments pose a significant challenge to current materials. Additionally, the material could be used in electron emitter applications for electric propulsion of satellites.

"I could not have done any of this work if AFOSR had not provided the funding to me," Sayir said. "It would not be possible because this is a very niche area where few are being funded. I believe this research is very important to maintaining America's technological aerospace dominance."

New Mathematical Model Devised

Dr. Kevin Hemker of Johns Hopkins University and his colleagues have received funding from AFOSR for the past three years through a Materials and Engineering for Affordable New Systems - MEANS - project. "The unique MEANS program was created by AFOSR to team academics with industrial colleagues in a way that allows them to tackle highly complex problems and derive fundamental physics-based models. Eventually, the goal is to develop detailed design codes that our industrial colleagues can use to efficiently and reliably introduce new materials and systems into aero engines," said Hemker.

Researchers from Johns Hopkins University, the University of California at Santa Barbara, Harvard University, University of Michigan, Princeton University, and the Delphi Research Laboratory have joined Hemker and are teaming with engineers and researchers at Pratt and Whitney and GE Aircraft Engines to conduct research described as Knowledge Oriented Materials Engineering of Layered Thermal Barrier Systems - or NOMELT.

Hemker's MEANS team is developing a mathematical model to describe the complicated mechanisms involved in the catastrophic failure of thermal barrier coatings (TBCs) in turbine engines. The availability of this new model will permit engine designers to identify key material and structural parameters and to probe the design space for improved TBCs.

"This AFOSR supported project has led to important microstructural observations of how the materials are interacting with each other and how they are changing their internal makeup during service. Collaborations between various members of the team have also allowed us to design and conduct experiments that provide the first-ever measures of the mechanical and physical properties of the different TBC layers. Measuring the properties of extremely thin layers - layers thinner than the width of a human hair - is challenging, but an important part of developing the governing models and overall design code," said Hemker.

His team has also developed a new thermo-cycle test that will be a useful diagnostic for industrial colleagues to test the efficacy of future coatings.

The Air Force can benefit from the efforts put forth by this MEANS team. Hemker said, "The designers and creators of advanced jet engines have recognized the tremendous potential of using TBCs for increasing both the durability and the performance of these engines. The use of TBCs has increased dramatically in recent years, and understanding how these systems stay on and how to prolong their life and improve their performance, will allow our industrial colleagues to design more powerful and more efficient aero engines."

By supporting basic research in ceramic and nonmetallic materials AFOSR continues to expand the horizon of scientific knowledge through its leadership and management of the Air Force's basic research program. As a vital component of the Air Force Research Laboratory, AFOSR supports Air Force's mission of control and maximum utilization of air and space. Many of the technological breakthroughs enjoyed by millions today, such as lasers, GPS, and the computer mouse trace their scientific roots to research first funded by AFOSR.