

## Track 3:

### Challenges in Mechanics of Time-Dependent Materials and Processes in Conventional and Multifunctional Materials

*Organized by:* Richard B. Hall, Air Force Research Laboratory; H. Jerry Qi, University of Colorado; Peter G. Ifju, University of Florida; Gyaneshar P. Tandon, University of Dayton Research Institute; Bonnie R. Antoun, Sandia National Laboratories; Hongbing Lu, University of Texas-Dallas; Y. Charles Lu, University of Kentucky

#### *Sponsored by the SEM Time-Dependent Materials Technical Division*

Sixty-three papers, including four Keynotes, address constitutive, time (rate)-dependent constitutive and fracture/failure behavior of a broad range of materials systems, including prominent researchers in both applied and experimental mechanics. Solicited papers involve non-negligible time-dependent mechanical response in cases incorporating non-mechanical fields. The sessions are as follows:

- 5**     **Interfaces, Interphases, Inhomogeneities I** (Monday Morning)
- 14**     **Interfaces, Interphases, Inhomogeneities II**  
(Monday Early Afternoon)
- 22**     **Environmental and Reactive Property Changes**  
(Monday Late Afternoon)
- 30**     **Small-scale Properties Evolution I** (Tuesday Morning)
- 38**     **Small-scale Properties Evolution II** (Tuesday Early Afternoon)
- 46**     **Shape Memory Polymers and Composites**  
(Tuesday Late Afternoon)
- 54**     **Dynamic Systems I** (Wednesday Early Morning)
- 62**     **Dynamic Systems II** (Wednesday Late Morning)
- 70**     **Hybrid, Multifunctional and Conformable Systems**  
(Wednesday Early Afternoon)

- 78**     **Composite Structural Systems** (Wednesday Late Afternoon)
- 86**     **High Temperature Systems** (Thursday Early Morning)
- 94**     **Viscoelastoplasticity and Damage I** (Thursday Late Morning)
- 102**    **Viscoelastoplasticity and Damage II** (Thursday Early Afternoon)
- 110**    **Viscous Processes and Biomaterials** (Thursday Late Afternoon)

Papers in the following general technical research areas are included:

- Effects of interfaces and interphases on the time-dependent behaviors of composite, hybrid and multifunctional materials
- Effects of inhomogeneities on the time-dependent behaviors of metallic and polymeric materials
- Environmental and reactive property change effects on thermomechanical and multifunctional behaviors
- Challenges in time-dependent behavior modeling in metallic and polymeric materials at low, moderate and high strain rates
- Challenges in time-dependent behavior modeling in composite, hybrid and multifunctional materials - effects of strain rate and damage
- Modeling and characterization of fabrication processes of conventional and multifunctional materials
- Time dependent behaviors at the nanoscale

The organizers thank the presenters, authors and session chairs for their participation in this symposium.

*Track 3 Keynotes continue on next page*

Keynote Presentation:

**Jeff Baur**

AFRL Materials and Manufacturing  
Directorate

Monday, June 13 • 10:30 AM • Session 5

***Composites and Hybrids: Time-dependent,  
Complex Materials***

Lightweight conventional and multifunctional structural materials are of interest to the Air Force in order to enable current and future aerospace capability. Understanding time and rate dependent processes within materials is critical to accurately designing, processing, predicting and characterizing the needed materials system for rapid transition while also managing risk. This presentation will highlight recent progress and challenges on composite and hybrid material systems being studied within the Composite and Hybrid Materials Branch of the Air Force Research Laboratory. In addition to a top level review of current efforts, specific examples of time-dependent processes will be highlighted. These efforts include the processing of high temperature polymer resins as a function time-dependent chemical reaction and flow; the design of embedded flow sensors based on carbon nanotube arrays as a function of their time-dependent electromechanical response; the prediction of the thermal response of hybrid microvascular panels as a function of time-dependent fluid transport; and the characterization of the thermomechanical response of strain rate and time-dependent shape memory polymers. Additionally, the need for tools which can be brought together through a common Intergrated Computational Materials and Manufacturing Science and Engineering (ICMSE) framework will be discussed.

**Dr. Baur** serves as the Branch Technical Advisor of the Composite and Hybrids Branch within the Materials and Manufacturing Directorate of the Air Force Research Laboratory. His education includes a B.A. in Physics/Chemistry from Illinois Wesleyan University, a B.S. in Materials Engineering from the University of Cincinnati, and a Ph.D. in Materials Engineering from the Massachusetts Institute of Technology (M.I.T.). Dr. Baur has had a diverse professional career in industry, academia, and the government. He has worked in industry (GE Aircraft Engines, Hilton Davis Chemical, Borden Chemical) as both bench level chemist/engineer and as a technical manager. He has worked in academia as the Lab Manager and Staff Scientist in the Institute for Soldier Nanotechnologies at M.I.T.. He began working for the Air Force Research Laboratory through the Palace Knight program and currently has over 14 years of experience in the Materials and Manufacturing Directorate at Wright-Patterson AFB. His past work has focused on the processing and characterization of electrical, optical and mechanical properties of organic or polymer assemblies for advanced applications such as organic-based LED's, photovoltaics, photonic elements, two-photon induced holography, and nano-enhanced polymer composites. His current interest is in the materials systems for adaptive aero vehicles and includes carbon nanotube based sensors, microvascular composites and aircraft skins for reconfigurable air vehicles.

Keynote Presentation:

**Alan Wineman**

University of Michigan

Monday, June 13 • 1:50 PM • Session 14

***Modeling Stress Evolution During Cure of  
Epoxy/Woven Fiber Composites***

A model is presented for the prediction of stress evolution during cure of epoxy/woven fiber composites. The model consists of two main parts. The first is a system of coupled equations for the time dependent spatial distributions of the temperature and extent of cure in a component. The system consists of the heat conduction equation that contains a source term arising from the local heat generated as curing progresses and a phenomenological equation for the evolution of the extent of curing that depends on temperature. The second part of the model is a constitutive theory that imports the temperature and extent of cure results obtained by solving the equations in the first part of the model. The constitutive theory is based on the assumption that a new epoxy network is formed at each instant in a configuration that coincides with the common current configuration of previously formed networks. The configuration is determined by the volumetric contraction that takes place during curing, subsequent thermal expansion and the mechanical strains that occur in previously formed networks during the preceding curing process. Numerical results show the influence of the size of the cylinder and the non-uniformity of fiber distributions on stress development.

**Alan S. Wineman**, Professor of Mechanical Engineering at the University of Michigan, received a B.S. E. in Engineering Mechanics and Mathematics from the University of Michigan in 1959. He received the Ph.D. in Applied Mathematics from Brown University in 1964. Prof. Wineman joined the Department of Engineering Mechanics at the University of Michigan in 1964 as an Assistant Professor. He was promoted to Associate Professor in 1969 and Professor in 1975. He is now Professor in the Department of Mechanical Engineering, Professor of Macromolecular Science and Engineering and Arthur F. Thurnau Professor, the latter in recognition of his excellence in teaching. His research interests include the mechanics of polymeric solid and fluid materials; interaction of deformation with diffusion, electric or magnetic fields in polymeric materials; mechanics of polymers undergoing microstructural change due to high temperature, curing, diffusion of fluids and large deformation; growth and mechanical property evolution in biomaterials

Prof. Wineman was a Guest Scientist in the Polymers Division of NIST in August 1994, and a Visiting Scientist at the Institute for Mechanics and Materials in 1996. He is Associate Editor of Mathematics and Mechanics of Solids and the International Journal of Engineering Science, a Fellow of the ASME, the American Academy of Mechanics and the Society of Engineering Science. His book, the Mechanical Response of Polymers: An Introduction, co-authored with K.R. Rajagopal has been published by Cambridge University Press.

*Track 3 Keynotes continue on next page*

Keynote Presentation:

**Ioannis Chasiotis**

University of Illinois at Urbana-Champaign

Tuesday, June 14 • 10:30 AM • Session 30

***Experiments and Models for the Time Dependent Mechanics of Nanoscale Polymeric Structures and Nanocrystalline Metal Films***

To date, micro and nanoscale experiments have been mostly focused on the length scale dependent mechanical behavior of polymeric and metallic nanostructures and nanostructured thin films but have not been able to address their time and rate dependence. This inefficiency stems from the use of high resolution electron microscopes which are slow imaging tools and often are of detrimental effect to the integrity of soft materials. On the other hand, optical methods have been re-tooled in the recent years and adapted to micro and nanoscale specimens to obtain high resolution deformations and their time evolution in time scales varying from microseconds to days. This presentation will discuss recent developments in methods and instrumentation for nanoscale experimentation with temporal strain resolution to probe the mechanics of polymeric and metallic submicron sized specimens at strain rates varying from  $10^{-6}$  to  $200 \text{ s}^{-1}$ . Nanoscale grain sizes and specimen dimensions have given rise to enhanced ductilities and strengths that are significantly more rate and temperature sensitive than in large grain metals and bulk polymeric specimens. Furthermore, damage processes in nanostructures, such as voiding and microcracking, strongly depend on strain rate, and their evolution is dictated by the competition between creep/stress relaxation and the loading rate, which leads to a variety of failure modes. The rate, temperature and time dependent experimental data presented here are rationalized and discussed in terms of linear viscoelastic modeling and its applicability to ultra-small material volumes.

**Ioannis Chasiotis** is a Willett Faculty Scholar of Engineering at the University of Illinois at Urbana Champaign and an Associate Professor of Aerospace Engineering and the Beckman Institute for Advanced Science and Technology. He received his Ph.D. and M.S. degrees in Aeronautics from the California Institute of Technology in 2002 and 1998, respectively, and a Diploma in Chemical Engineering in 1996. His research focuses in experimental deformation and fracture mechanics of thin films for MEMS/NEMS and nanoscale structures. He is a recipient of the Presidential Early Career Award for Scientists and Engineers (PECASE), the SES Young Investigator Medal, the NSF-CAREER Award, the ONR Young Investigator Award and the Founder's Prize from the American Academy of Mechanics. Since 2006 he serves as an Associate editor of the journal *Experimental Mechanics*.

Keynote Presentation:

**Peter G. Ifju**

University of Florida

Wednesday, June 15 • 2:30 PM • Session 70

***Hybrid Materials for Micro Air Vehicles***

The University of Florida (UF) has developed a series of flexible wing micro air vehicles that have distinct advantages over traditional rigid wing counterparts, including; delayed stall, better efficiency, gust rejection and enhanced longitudinal stability. They also are more suited for morphing and for implementation of embedded control mechanisms since less energy is required to deform them. The use of hybrid and multifunctional materials can also lead to significant weight savings. By utilizing such materials the airframe can serve to carry flight loads as well as act as antenna, energy storage, energy harvesting mechanisms and distributed sensors. The implementation of these materials can be done by applying a material to a specific airframe or by designing the airframe around the material. The latter is more likely to be optimal, but requires the combined knowledge of both the material capabilities/limitations as well as the ability to design the aircraft. Since the aircraft design is a fluid/structure interaction problem it is very challenging. Experimental methods such as flight testing, and wind tunnel testing is required for validation of the design. Full-field methods such as digital image correlation in the wind tunnel environment combined with traditional methods such as loads measurements and flow visualization are utilized regularly at UF.

**Peter Geza Ifju** is a Professor in the Mechanical and Aerospace Engineering Department at the University of Florida. He received a Ph.D. in Materials Engineering Science (1992), a M.S. in Engineering Science and Mechanics (1989), and a B.S. in Civil Engineering (1986) all from Virginia Tech. He also performed a Post-Doc at NASA Langley Research Center (1992-1993) in the Mechanics of Materials Branch. His research activities include experimental stress analysis, optical methods for stress analysis (moiré interferometry, luminescent photoelastic coatings), and composite materials stress analysis and fabrication. He has also gained notoriety in micro air vehicle (MAV) design, fabrication, system integration, applications, and experimental characterization. Dr. Ifju has gained considerable international recognition in experimental mechanics including being selected as the first recipient of the A.J. Durelli Award from the Society for Experimental Mechanics in 2004. AIAA granted Dr. Ifju the Abe M. Zarem Award in 2005. He also received the NSF Career award in 1995. His publications have been recognized by paper of the year awards in three separate journals, including the Journal of *Experimental Techniques* (Harting Award), the Journal of *Experimental Mechanics* (Peterson Award) and the *Journal of the Society for the Advancement of Materials and Process Engineering* (SAMPE). He has received teacher of the year awards on the department and college level at the University of Florida. The University of Florida MAV Team, lead by Dr. Ifju, won first place overall in the International MAV Competition in 1999, 2000, 2001, 2002, 2003, 2004, 2005, and 2006. In 2000 Discovery magazine granted Dr. Ifju a Top Ten Technology Innovation Award for Micro Air Vehicle Development. Dr. Ifju has coauthored or authored 2 books (one on experimental stress analysis and one on micro air vehicles), more than 10 book chapters, more than 55 journal papers, and more than 100 conference papers.