1st International Symposium on the Mechanics of Biological Systems and Materials

Organized by: Bart Prorok, Auburn University; Francois Barthelat, McGill University; Chad Korach, State University of New York (SUNY) at Stony Brook; K. Jane Grande-Allen, Rice University; Elizabeth Lipke, Auburn University

Sponsored by the SEM Biological Systems & Materials Technical Division

This symposium is aimed at providing a forum to foster the exchange of ideas and information among scientists and engineers involved in the research and analysis of how mechanical loads interact with the structure, properties and function of living organisms and their tissues. The scope includes experimental, imaging, numerical and mathematical techniques and tools spanning various length and time scales. Establishing this symposium at the Annual Meeting of the Society for Experimental Mechanics provides a venue where state-of-the-art experimental methods can be leveraged in the study of biomechanics. A major goal of the symposium is for participants to collaborate in the asking of fundamental questions and the development new techniques to address bio-inspired problems in society, human health, and the natural world.

The symposium is composed of 12 sessions with a total of 62 papers. The Biological Systems and Materials TD would like to thank the presenters, authors and session chairs for their participation.

Session Title	# of Sessions	# of Papers
Simulation and Modeling in Biomechanics	2	10
Mechanics of Tissue Damage	1	5
Cell Mechanics	2	10
Mechanics of Cardiovascular Tissues	1	6
Advanced Imaging Methods Applied to Biomechanics	1	6
Mechanics of Hydro Gels and Soft Materials	1	6
Mechanics of Hard Tissues	1	5
Mechanics of Biocomposites	1	5
Nanomechanics in Nature	1	4
Indentation Methods for Biological and Soft Materials	1	5
Total	12	62

Keynote Presentation:

Markus J. Buehler

Massachusetts Institute of Technology

Monday, June 13 • 10:30 AM • Session 1

Turning Weakness to Strength

Biology exquisitely creates hierarchical structures, where initiated at nano scales, are exhibited in macro or physiological multifunctional materials to provide structural support, force generation, catalytic properties, or energy conversion. This is exemplified in a broad range of biological materials such as hair, skin, bone, spider silk or cells. For instance, despite its simple building blocks spider silk is one of the strongest, most extensible and toughest biological materials known, exceeding the properties of many engineered materials including steel. This is particularly puzzling since despite its great strength, spider silk is made of some of the weakest chemical bonds known, H-bonds. We have discovered that the great strength and extensibility of spider silk can be explained based on its particular structural makeup, which involves several hierarchical levels from the nano- to the macro-scale. Thereby, the structural confinement of H-bonds into ultra-small beta-sheet nanocrystals with dimensions of only a few nanometers is the key to overcome the intrinsic limitations of H-bonds, creating mechanically strong, tough and resilient cross-linking domains between a semi-amorphous phase composed of 31 protein helices (Buehler et al., Nature Materials, 2010). Our work unveils a material design strategy that enables silks to achieve superior material properties despite its simple and structurally inferior material constituents. Exploiting this concept could lead to a novel materials design paradigm, where enhanced functionality is not achieved using complex building blocks but rather through the utilization of universal repetitive constitutive elements arranged in hierarchical structures. We discuss analogies with other protein materials such as collagen and intermediate filaments, and present approaches towards the design of adaptable, mutable and active materials.

Markus Buehler is an Associate Professor in the Department of Civil and Environmental Engineering at the Massachusetts Institute of Technology, where he directs the Laboratory for Atomistic and Molecular Mechanics, LAMM. Before joining MIT in 2005, he served as the Director of Multiscale Modeling and Software Integration at Caltech's Materials and Process Simulation Center. He received a Ph.D. in Chemistry from the Max Planck Institute for Metals Research after obtaining a M.S. in Engineering Mechanics from Michigan Tech, and undergraduate studies in Chemical and Process Engineering at the University of Stuttgart. Buehler's research focuses on bottom-up simulation of structural and mechanical properties of biological, bioinspired and synthetic materials across multiple scales, with a specific focus on materials failure from a nanoscale and molecular perspective. Buehler's research uses the study of materials failure as a tool to elucidate the design principles of how functional material properties are achieved and how they are lost.

Buehler has published more than 150 articles on computational modeling of materials using various types of simulation techniques, authored one monograph, and given more than 170 invited, keynote and plenary talks. He was cited as one of the top engineers in the United States between the ages of 30-45 through invitation to the *2007 National Academy of Engineering-Frontiers in Engineering Symposium* of the National Academy of Engineering. Buehler received the *2007 National Science Foundation CAREER award*, the *2008 United States Air Force Young Investigator Award*, the *2008 Navy Young Investigator Award*, and the *2008 DARPA Young Faculty Award*. In 2009, his work was recognized by the *Presidential Early Career Award for Scientists and Engineers, PECASE*. He recently received the *2010 Harold E. Edgerton Faculty Achievement Award* for exceptional distinction in teaching and in research or scholarship, the highest honor bestowed on young MIT faculty. Other major awards include the *Thomas J.R. Hughes Young Investigator Award 2011* (for special achievements in Applied Mechanics for researchers under the age of 40, given by ASME's Applied Mechanics Division), the *ASME Sia Nemat-Nasser Medal 2010* (for research excellence in the areas of experimental, computational, and theoretical mechanics and materials), and the *Rossiter W. Raymond Memorial Award 2011* (given by AIME/TMS).

Biological Systems & Materials Keynotes continue on next page

Keynote Presentation:

Krystyn Van Vliet

Massachusetts Institute of Technology

Wednesday, June 15 • 10:50 AM • Session 58

Chemomechanics of Cell Deformation in the Attached and Suspended States

In vitro and in vivo, cell reversibly adhere to adjacent materials via molecular binding. Cells that explore the limits of such states, and that respond significantly to changes in local mechanical or chemical stimuli, provide systems to explore how and why these molecular-level cues lead to changes in experimentally measured cell behavior. Human mesenchymal stem cells (hMSCs) are therapeutically useful cells that are typically expanded in vitro before re-implantation. Here we explore MSC mechanical and structural changes via atomic force microscopy and optical stretching during extended passaging, and we demonstrate that cytoskeletal organization and mechanical stiffness of attached MSC populations are strongly modulated over more than 15 population doublings in vitro. Cytoskeletal actin networks exhibit significant coarsening, attendant with decreasing average mechanical compliance and differentiation potential of these cells, although expression of molecular surface markers does not significantly decline. These mechanical changes are not observed in the suspended state, indicating that the changes manifest themselves as alterations in stress fiber arrangement rather than cortical cytoskeleton arrangement. We relate these experimental findings at the whole-cell level to our experiments and models of intermolecular binding kinetics.

Van Vliet received her Bachelor's and Ph.D. in Materials Science and Engineering at Brown University and MIT, respectively. Her thesis research focused on nanomechanics of crystalline materials, particularly experimental measurements and computational predictions of dislocation nucleation. She then completed a postdoctoral fellowship at Children's Hospital Boston in the Vascular Biology Program, and characterized the effects of cell-level strain on angiogenesis. Van Vliet is currently the Paul M. Cook Associate Professor of Materials Science & Engineering at MIT, with joint appointment in the MIT Department of Biological Engineering. Van Vliet's laboratory studies material chemomechanics: the dynamic coupling between mechanical & chemical states at material interfaces. To identify the fundamental mechanisms of such interactions at the atomistic scale, her group develops experiments and computational simulations that span material mechanics, chemistry, physics, and biology. Van Vliet seeks to predict how mechanical stiffness and force can alter molecular interactions, and how chemical stimuli can alter the forces required to rupture adhered interfaces. The motivating example of this research is the interface between biological cells and their microenvironments. Van Vliet has thus developed both experiments and computations to quantify how intermolecular binding kinetics depend on mechanical or biochemical changes at cell-material interfaces. These studies have shown that the stiffness of materials tethered to molecular ligands directly affects ligand-receptor kinetics at cell surfaces; and how this coupling affects the adhesion, force generation, and function of cells. This mechanistic approach requires new tools and models validated in nonbiological material interfaces and extreme environments, achieved via her group's parallel analysis of engineered nanostructures and nanocomposites with diverse functional applications. Van Vliet also serves as the faculty director of the DMSE Nanomechanical Technology Laboratory, has co-developed new undergraduate and graduate laboratory classes, and has implemented new programs to retain underrepresented minority students. Her research and teaching efforts have been recognized most recently by the MIT Edgerton Faculty, Junior Bose Teaching, and Human Frontiers Science Program (2009) awards.

Keynote Presentation:

Nejat Olgac

University of Connecticut

Wednesday, June 15 • 4:20 PM • Session 74

Adaptive Hybrid Control for Low Resolution Feedback Systems: Ros-drill©, An Application

A novel hybrid control system is deployed on a novel cellular microinjector called the Ros-Drill© (Rotationally Oscillating Drill). It is primarily developed for ICSI (IntraCytoplasmic Sperm Injection) operations. This control structure is an inexpensive set-up, which performs a precise control over an actuator (DC motor), to create very precise and high-frequency rotational oscillations at the tip of an injecting pipette to drill cells. Angular motion control presents no particular difficulties when the application counts on precise sensing mechanisms with high fidelity measurements of the motion being controlled. However, size, costs and accessibility of the needed technology relevant to the hardware components influence the design of the control settings. In this paper we present an adaptive-hybrid control structure which is developed around a commonly available micro-controller. We consider the limiting factors of bounded sampling speed of the controller, extremely low-resolution of position measuring sensor, as well as the limited capabilities of generating the desired rotational trajectory. We present a novel methodology to overcome these specific problems. Here, an adaptive, robust and optimal PID control strategy is performed. We demonstrate that the required fine rotational motion for the cellular injections is obtained with desirable fidelity, despite the stated shortfalls in the components.

Nejat Olgac, Dr. Eng. Sci. Columbia University 1976, M.Sc. Technical University of Istanbul, Turkey 1972, both in Mechanical Engineering. He is a professor with the Mechanical Engineering Department of the University of Connecticut since 1981. His research interests are in robust nonlinear controls, active vibration absorption, time-delayed systems, micromanipulation in bio-engineering. Dr. Olgac holds three patents (1995-1996-1999) on the Delayed Resonator active vibration suppression technique. He is the director of Advanced Laboratory for Robotics, Automation and Manufacturing (ALARM) at UConn. Dr. Olgac was Visiting Professor at INRIA (Sophia Antipolis, France) 1988-89, SEW Eurodrive Fellow- Guest Professor at Technical University of Munich, Germany in 1995-96 and Visiting Professor at Harvard University 2002-03). He was on the editorial board of the ASME *Trans. of Dynamic Systems, Measurement and Control* (1996-2004), and the guest editor of the Special Issue of JDSMC on Time Delayed Systems (June, 2003), is presently on the Editorial Boards of *J. Vibration and Control*, *Int. J. of Mechatronics and Manufacturing Systems*. He was a member and the Chairman of the Executive Committee of the ASME Dynamic Systems and Control Division (2001-6). Prof. Olgac is a member of the Connecticut Academy of Science and Engineering (CASE), Fellow of ASME and Senior Member of IEEE.