MECHANICAL PROPERTIES RESEARCH LABORATORY (MPRL)
http://mprl.me.gatech.edu/

2009-2010 Annual Report

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G.W. Woodruff School of Mechanical Engineering
School of Materials Science and Engineering
(also interfaces with AE, CEE, ECE, GTRI and Emory)

College of Engineering
Georgia Institute of Technology

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MPRL STATUS AND SUMMARY OF 2009-2010 ACCOMPLISHMENTS

The MPRL is an interdisciplinary laboratory that supports research and education programs primarily related to deformation and failure/reliability of structural materials. Principal activities of the MPRL include the measurement and modeling of the mechanical behavior of engineering materials, particularly deformation, fatigue and fracture processes. The MPRL has a direct impact on educational and research programs of the College of Engineering. In its role as an interdisciplinary umbrella organization for research in mechanical properties of materials, the MPRL provides a degree of coordination of equipment usage, training and maintenance that would otherwise be much more costly to the sum of academic units in the conventional university setting of distinctly controlled single investigator equipment. The MPRL has an international reputation for excellence in several areas:

- Fatigue and fracture studies of structural materials, structures and joints.
- Development of constitutive equations for deformation and damage, incorporating these advances into life prediction methodologies.
- Multiscale simulation of materials and microstructure-sensitive fatigue and fracture approaches, making contact with experiments to discern mechanisms and validate models and methodologies, both deterministic and probabilistic (e.g., supporting NSF Center on Computational Materials Design).
- Characterization and quantitative analysis of microstructure and damage in engineering materials such as structural alloys, composites, metal foams, biomaterials and nanostructured materials and alloys.
- Durability and degradation of aging materials and structures.

Participating faculty (16) and students are drawn principally from ME and MSE (Appendix A). The MPRL is administered by the Director, operating in conjunction with an Associate Director and recommendations from a Faculty Governance Board. The External Advisory Board of the School of Materials Science and Engineering also serves as the External Advisory Board of the MPRL. MPRL staff includes Richard C. Brown (Research Equipment Specialist), half-time technician Robert Cooper, and 1/6 time GRA Robert Amaro. Mr. Brown principally serves the MPRL facilities located in Bunger-Henry and Love Buildings, and provides technical oversight and support for systems within the MaRC Hi-Bay, Mr. Amaro, a PhD student in Mechanical Engineering advised by Dr. Rick Neu, schedules machine usage, trains students in test methods and protocol, calibrates extensometers, and sets up testing protocols in the MaRC Hi-Bay MPRL. Mr. Cooper's primary area of responsibility has shifted to maintaining the MaRC Hi-Bay space and associated cluster of MPRL machines, with repairs playing an increasingly common role due to aging systems.

A listing of MPRL facilities can be found at http://mprl.me.gatech.edu/facilities/, summarized by:

- Tensile and Fatigue Test Facilities
- Small-Scale Testing Laboratory
- High-Temperature High-Vacuum Test Facility
- Drop Weight Impact Tester
- Thermal Aging Facility
- Creep Testing Facilities
- Fretting Equipment
- High-Strain-Rate Facility
- Split Hopkinson Bar Intermediate Strain Rate Facility
- Image Analysis Equipment

In addition, TEM and surface analysis facilities are available to MPRL faculty through the GT Center for Nanostructure Characterization and the MiRC. Various MPRL faculty have computing clusters to pursue work at the interface of materials characterization, behavior and modeling.

Participating MPRL faculty offer a wide range of courses in fatigue, fracture, deformation and damage of engineering materials, mechanics of materials, quantitative image analysis and nondestructive evaluation, and mechanical behavior of materials. A graduate certificate in the Mechanical Properties of Solids is also offered through the MPRL. It is estimated that over 25 graduate students were involved during the past year in MPRL-related research.

MPRL accomplishments from July 1, 2009 to June 30, 2010 are summarized in the Table below, with 14 of 16 MPRL faculty responding (A. Antoniou and S. Graham did not report). These numbers pertain to research that is facilitated by the MPRL.

# Faculty Reporting	Published Refereed Papers	# Funded Projects	Students Graduated M.S.	Ph.D.	Faculty & Student Honors /Awards
14	82	57	6	5	5

MPRL faculty reported 98 conference presentations and seminars during this period. Approximately $4.6M was expended in externally sponsored research during the past year on projects somehow related to use of MPRL facilities and research programs, an all-time high for the MPRL, for an average of approximately $329K per reporting MPRL faculty member. The distribution of per capita funding of faculty respondents this past year was as follows: at or above $300K (6), between $200-299K (2), $100-199K (3), $1-99K (2), $0K (1).

Highlights

Administrative highlights of 2009-2010 included the following:

1. Continued to monitor and set priorities for repair and replacement of aging MPRL equipment based on critical path assessment for ongoing research and research opportunities, utilization, and other factors. This past year, $16.2K was received from the Dean's office and used this past year for critical repairs such as seal replacements on leaky servohydraulic actuators. We have had recurring problems with the axial-torsional test systems in the MaRC Hi-Bay. Additional repairs are presently underway; expenditures continue from the regular budget into the next FY on seal replacements and actuator reconditioning for the 20 kip axial-torsional machine in the MaRC Hi-Bay, a piece of equipment in the critical path with regard to our Pratt & Whitney/Georgia Tech Center of Excellence. Moreover, MPRL funds were used as cost-share for Rick Neu to purchase a replacement induction heating unit for thermomechanical fatigue experiments essential to this Center. A major pump failure occurred in late June 2010, explained on the next page; we are in the process of addressing this.
2. Reached out to additional CoE faculty in CEE, ECE, and AE to participate in the MPRL more directly, with Andrew Makeev of AE expressing interest in future MPRL involvement. AE has engaged the services of MPRL research equipment specialist Rick Brown for new test setup this past year. Jenny Michaels of ECE has been using MPRL test equipment this past year to support non-destructive test programs.

Research program highlights and development activities include:

- MPRL Associate Director Steve Johnson delivered a prestigious plenary lecture at Fatigue 2010 in Prague in early June 2010.
- The Center for Computational Materials Design (CCMD), a NSF I/UCRC joint with Penn State, completed its 5th year in June 2010, and involves a substantial number of MPRL faculty (McDowell, PI/PD, Neu, Zhou, Gokhale, Garmestani, and Zhu). MPRL funding related to integated experimental and computational fatigue and fracture studies is at an all-time high; current funding trends emphasize combining experimental studies with modeling and simulation, a duo for which the MPRL is well-positioned. A renewal for a five year Phase II NSF funding period for the CCMD was submitted in spring 2010 and is pending.
- The MPRL (Johnson, McDowell, Neu) completed its second year as a substantial component of the Pratt & Whitney/Georgia Tech Center of Excellence, serving as a preferred supplier of experiments and modeling related to advanced aircraft gas turbine engine materials (e.g., Ni-base superalloys), and is receiving a substantial related funding increment ($300-400K per year) as a result. Companies such as Pratt & Whitney, GE, Siemens, etc. have high regard for the faculty and facilities of the MPRL and are relying on us to deliver cutting edge research to assist in developing more efficient and durable transportation/propulsion systems.
- Financial support for MPRL activities has been more balanced this year, with W.S. Johnson providing approximately 42% of Rick Brown's MPRL salary support, the remainder split between ME faculty (44%) and 14% from AE and ECE. Rick Brown's support for the Hi-

Bay MPRL supporting more ME-related projects has been increased in 2010 to acknowledge that most support is coming from ME faculty.

APPENDIX A

List of Participating MPRL Faculty

A. Antoniou, G.W. Woodruff School of Mechanical Engineering - Micromechanics of deformation in cellular materials and metallic glasses, using both experimental measurements and numerical modeling; synthesis and mechanical behavior of nanostructured materials.

K. Gall, School of Materials Science and Engineering/ME - Development and characterization of advanced material systems for implementation into emerging technologies; experimental and computational studies emphasizing the mechanical behavior of materials at multiple length scales. Biomaterials and biomimetics.

H. Garmestani, School of Materials Science and Engineering - Quantitative characterization of materials, diffraction methods, statistical continuum mechanics treatments of heterogeneous materials; materials design.

A. Gokhale, School of Materials Science and Engineering - Quantitative fractography and microscopy (stereology), modeling of microstructures, quantitative relationships between microstructure and mechanical behavior of materials.

S. Graham, G.W. Woodruff School of Mechanical Engineering - Thermophysical property measurement at small scales; nanoscale heat transfer in materials and interfaces.

W.S. Johnson, School of Materials Science and Engineering/ME - Experiments and modeling of fatigue and fracture behavior of advanced materials, including nonlinear and temperature dependent behavior; development of life prediction methodologies.

K. Kalaitzidou, G.W. Woodruff School of Mechanical Engineering - Development and characterization of advanced polymer based particles or composites with superior properties for a wide range of applications.

D.L. McDowell, G.W. Woodruff School of Mechanical Engineering/MSE - Cyclic viscoplasticity; microstructure-sensitive fatigue; multiscale modeling from atomistics to continuum; finite strain inelasticity, defect field mechanics; damage and deformation of metallic systems; materials design.

S. Melkote, G.W. Woodruff School of Mechanical Engineering - Characterization of the effects of machined surface integrity on fatigue life of hardened bearing steels; constitutive models for high strain, strain rate and temperature processes such as machining.

R.W. Neu, G.W. Woodruff School of Mechanical Engineering/MSE - Thermomechanical fatigue, environmental effects, composite materials, fracture mechanics, creep, fatigue life prediction methods, mechanics of phase transformations.

O. Pierron, G.W. Woodruff School of Mechanical Engineering - Experimental and analytical characterization of fracture and fatigue of small scale materials (thin films, nanostructures), structural reliability of MEMS/NEMS devices, environmental effects.

P. Singh, School of Materials Science and Engineering - Damage accumulation in metal matrix composites (MMCs), environmental sensitive fracture of Al alloys and MMCs, and high temperature oxidation of composites.

S. Sitaraman, G.W. Woodruff School of Mechanical Engineering - Thermo-mechanical modeling, reliability, and design of electronic packages.

N. Thadhani, School of Materials Science and Engineering/ME - Materials aspects of dynamic deformation, including fracture and flow behavior of solid and porous materials, synthesis of intermetallics and ceramics materials utilizing effects of high-strain-rate loading.

M. Zhou, G.W. Woodruff School of Mechanical Engineering/MSE - High strain rate behavior of materials, experimental and computational studies of shear banding and deformation of heterogeneous materials; atomistic simulations of functional oxides and nanowires.

T. Zhu, G.W. Woodruff School of Mechanical Engineering - Atomistic modeling of defect nucleation in materials; transition states and defect kinetics; coupled multiphysics problems at nanoscales.

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* /ME denotes joint appointment in the Woodruff School of Mechanical Engineering
/MSE " " School of Materials Science and Engineering