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

2014-2015 Annual Report

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School of Materials Science and Engineering
(also interfaces with AE, CEE, ECE, GTRI, IMat, GTMI)

College of Engineering
Georgia Institute of Technology

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MPRL STATUS AND SUMMARY OF 2014-2015 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/attachments, particularly in extreme environments including high temperature applications.
- Development of constitutive equations for deformation and damage, incorporating these advances into life prediction methodologies.
- Multiscale modeling and 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 the NSF Center for Computational Materials Design, Integrated Computational Materials Engineering (ICME), and Materials Genome Initiative (MGI)).
- Characterization and quantitative analysis of microstructure and damage in engineering materials such as structural alloys, composites, metal foams, thin films, biomaterials and nanostructured materials and alloys.
- Durability and degradation of aging materials and structures.

Participating faculty (22) and students are drawn principally from ME and MSE (Appendix A). The MPRL is administered by the Director. MPRL staff during the past year included 50% time Research Engineer J.D. Huggins assisted by part-time ME graduate student Kyle Brindley. The plan is for J.D. Huggins to increase his time commitment to MPRL as his other appointment with Professor Emeritus Wayne J. Book winds down. Until J.D. Huggins is full-time with MPRL, additional support of graduate students, post-docs, or other part-time support will be used.

A listing of MPRL facilities can be found at http://mprl.gatech.edu/facilites. Major equipment includes:

- Servohydraulic test systems (14)
- Electromechanical test systems (7)
- Drop weight impact tester
- Fretting and reciprocating sliding tester
- Charpy impact tester
- Thermal aging and creep facilities

Major accessories and expertise include:

- Gripping / adapters for tension, compression, bending, fracture, etc.
- Various extensometers for axial, diametral, axial-torsion, high temperature, crack opening, etc.
- Digital image correction (DIC) accessories for full field strain measurements
- Environmental chambers, ovens, and furnaces
- Induction heaters
- Temperature measuring devices (thermocouples, pyrometers)
- In-situ x-ray monitoring of damage
- Long-focal length optical microscopes for in-situ observations
- Specimen preparation, microstructure characterization prep, and image analysis
- Portable hardness tester

In addition, SEM, TEM and surface analysis facilities are available to MPRL faculty through the GT Institute for Electronics and Nanotechnology (IEN), the Center for Nanostructure Characterization and Fabrication (CNCF), and a scanning electron microscope with EBSD in the Mesoscale Material Characterization Lab (MMCL). Various MPRL faculty members have access to computing clusters to pursue work at the interface of materials characterization, behavior and modeling.

Participating MPRL faculty members contribute to a wide range of courses in fatigue, fracture, deformation and damage of engineering materials, mechanics of materials, quantitative image analysis and nondestructive evaluation, materials selection and design, and mechanical behavior of materials. A graduate multidisciplinary certificate in the Mechanical Properties of Materials is also offered through the MPRL. It is estimated that over 25 graduate students were involved during the past year in MPRL-related research. In addition, it is estimated that over 20 undergraduate students used the lab during the past year for either undergraduate research or a capstone design project. This is in addition to the instructional use of MPRL for both undergraduate and graduate courses.

MPRL accomplishments from July 1, 2014 to June 30, 2015 are summarized in the Table below, with 17 of 22 MPRL faculty responding, 14 of whom stated that they had some level of research activity within the MPRL during the past year.

# Faculty Reporting Funded Activity	Published Refereed Papers	# Funded Projects	Students Graduated M.S.	Students Graduated Ph.D.	Faculty & Student Honors /Awards
17	62	38	5	6	8

Active MPRL faculty reported 87 conference presentations and seminars during this period. Approximately $3.19M was expended in externally sponsored research during the past year on projects related to MPRL facilities or thrusts, reported by MPRL faculty members. The distribution of per capita funding of the 16 faculty respondents this past year who were actively involved in MPRL research was as follows: at or above $300K (4), between $200-299K (1), $100-199K (4), $1-99K (5). Several non-MPRL-affiliated faculty also utilized MPRL or its

research engineer during this period including Billyde Brown (GTMI), Dimitri Mavris (AE), Richard Salant (ME), and Suman Das (ME/MSE). Those projects are not reported in these numbers.

Highlights

Administrative highlights of 2014-2015 included the following:

- Our Research Engineer J.D. Huggins has successfully completed four years of part-time service to the lab. He is now well entrenched in its operation and can agilely handle requests of faculty, students, post-docs, and external organizations.
- Extensively revamped and updated the MPRL website using the GT-themed DRUPAL platform. The updated website now better publicizes the capabilities of the lab aimed at potential users and sponsors, provides links to the capabilities of the affiliated labs, and provides clearer instructions on how to obtain access to the facility.
- Implemented a test proposal submission and lab management system, transitioning from a paper submission process to electronic. Approvals from student's advisor (when applicable), MPRL research engineer, and MPRL director are electronically obtained via email link. This new system facilitates a quicker turn around on test plans to make sure everyone (advisor, student, research engineer) is on the same page so that experimental programs conducted in MPRL are successful. The lab management system helps us maintain compliance with EHS requirements by documenting all required Institute safety and equipment training for each user of the lab.
- A new instrumented Charpy impact tester was installed in the MPRL Instructional Lab.
- Increased the readiness of the lab to rapidly handle requests through systematic equipment maintenance, repair, and upgrades. Some highlights include (a) acquired an additional high temperature axial extensometer, (b) replaced seals on two hydraulic actuators, (c) refurbished a Cycle-Dyne Induction heater (replaced SSR controller), (d) updated several temperature controllers in the creep lab, (e) ordered a second split-tube furnace with 1100°C capability filling a gap in temperature capability, and (f) replaced seals on several accumulators and ordered one new one.
- Annual force transducer calibrations were performed by outside vendor to maintain compliance required by DOD and other sponsors.
- Continued to work with the Director of the Institute for Materials, D.L. McDowell, to make MPRL a strategic user facility in the Institute for Materials (IMat) and participate in both large center proposals and cooperative partnerships with industry where MPRL will have a significant role.

Research program highlights and development activities include:

- The MPRL (Johnson, Neu, McDowell, Antolovich) completed its 8th 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 for the hot components (e.g., Ni-base superalloys, TiAl, MoSiB).
- MPRL (Neu) completed its 9th year working with Siemens Energy Inc. on industrial gas

turbine structural integrity.

- S.D. Antolovich was one of four invited speakers at the Ecole des Mines de Paris special celebration (Aspects cristallographiques de la déformation et de la rupture des métaux, May 21, 2014.) which was held to honour Profs. André Pineau and Samuel Forest on their achievements. Title of his presentation was "Concentrations de Déformation: Enjeux, Succès et Défis-L'Accent sur la Fatigue" (Translation: "Concentration of Deformation with an Accent of Fatigue: What's in Play, Successes and Challenges").
- S.D. Antolovich was a Guest Editor (with R.W. Armstrong, J.F. Knott, and J.R. Griffiths) of invited special issue "Fracturing across the Multi-scales of Diverse Materials" for Philosophical Transactions of the Royal Society A. Issue to appear in 2015.

Plans for 2015-2016

- J.D. Huggins will continue at 50% with the remaining 50% time covered by Professor Wayne Book's program. This is still not the level of support needed to fully support the lab. Therefore, we plan to continue to employ additional part-time staff, usually a senior graduate student.
- Work with the Director of the Institute for Materials, D.L. McDowell, to make MPRL a strategic user facility in IMat.
- Enhance cooperative laboratory relationships among affiliated labs housed on the first floor of the Bunger-Henry building (i.e., Muhlstein, Xia, and Kalidindi).
- Organize an internal workshop on Digital Image Correlation (DIC) in collaboration with IMat.
- Hold a users meeting to get feedback and publicize the capabilities of the lab.
- Engage new ME, MSE, and AE faculty that may be potential users.
- Market the Mechanical Properties of Materials Certificate Program.

- **APPENDIX A**

List of Participating MPRL Faculty

S.D. Antolovich, School of Materials Science and Engineering/ME – Fatigue, deformation and degradation of materials, high-temperature behavior of materials, application of mechanics and materials to structural failures, and fracture mechanics.

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.

C.S. Deo, G.W. Woodruff School of Mechanical Engineering - Atomistic and mesoscale modeling; defects in materials; materials behavior in extreme environments including deformation and particle irradiation.

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 microscopy, modeling of microstructures, quantitative relationships between microstructure and mechanical behavior of materials.

W.S. Johnson, School of Materials Science and Engineering/ME - 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/MSE - Development and characterization of advanced polymer based particles or composites with superior properties for a wide range of applications.

S. Kalidindi, G.W. Woodruff School of Mechanical Engineering/MSE – Designing material internal structure for optimal properties and performance and identifying hybrid processing routes for its manufacture.

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; constitutive models for high strain, strain rate and temperature processes.

C. Muhlstein, School of Materials Science and Engineering - Deformation, fatigue, fracture mechanics, degradation mechanisms, structural materials, composite materials, nanomaterials, thin films.

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

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.

C.J. Saldana, G.W. Woodruff School of Mechanical Engineering - Ultrafine-grained and nanocrystalline materials, and surface modification and micro-scale texturing methods.

P. Singh, School of Materials Science and Engineering – Environmental-induced damage and failure in structural alloys and composites, corrosion kinetics, stress corrosion cracking, high temperature oxidation.

S. Sitaraman, G.W. Woodruff School of Mechanical Engineering - Fabrication, characterization, thermo-mechanical predictive modeling and reliable design of micro-scale and nano-scale structures.

L.K. Stewart, School of Civil and Environmental Engineering - Characterization of material and structural response to high strain rates; explosive and shock effects on materials; computational mechanics for shock and vibrations.

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.

S. Xia, G.W. Woodruff School of Mechanical Engineering - Experimental solid mechanics, nano and micromechanics, mechanics of energy storage and conversion materials, mechanics of heterogeneous media, fracture and fatigue of active materials.

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/MSE - 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 denotes joint appointment in the School of Materials Science and Engineering