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

2015-2016 Annual Report

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

College of Engineering
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MPRL STATUS AND SUMMARY OF 2015-2016 ACCOMPLISHMENTS

The Mechanical Properties Research Laboratory (MPRL) is an interdisciplinary laboratory that supports research and education programs primarily related to mechanical properties, deformation and failure/reliability of structural materials. The mission, vision, and research thrusts are fully described on our website, mprl.gatech.edu. The MPRL is a research center that has a direct impact on instructional and research programs of the College of Engineering. MPRL currently falls under the classification of a "Center (CTR)" based on the new EVPR strategic mapping.

In its role as an interdisciplinary "Center" for research in the 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 supports new faculty so that they better utilize their startup funds to develop new facilities and not duplicate existing ones. Our Center is especially focused on helping younger faculty get established by removing some of the burden of acquiring equipment and getting their students trained on the use of equipment so they can achieve early success in their research programs. The COE support enables us to provide this service to our young faculty. MPRL also supports exploratory studies to generate data to make external proposals more competitive, a return on investment of the COE support.

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 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.

We see the use of the Center growing with the push of the Materials Genome Initiative (MGI) and the growth of structural materials fabricated by additive manufacturing. This facility gives GT a competitive edge.

Participating faculty (22) and students are drawn principally from ME and MSE (Appendix A). The MPRL is administered by the Director. MPRL provides training on the use of a variety of mechanical test systems, including servohydraulic systems that can cause serious injury if used incorrectly. MPRL staff support both instructional and sponsored research projects in setting up test programs, designing accessories and adapters, developing new protocols, integrating new sensors and transducers, developing control algorithms, etc. MPRL staff also

perform routine maintenance and repairs to keep systems in a state of readiness. MPRL staff also ensure all users comply with EH&S requirements. We have implemented a test proposal submission and lab management system to facilitate a quick response to users and 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 EH&S requirements by documenting all required Institute safety and equipment training for each user of the lab. MPRL staff during the past year included 50% time Research Engineer J.D. Huggins assisted by part-time ME graduate students Kyle Brindley, Ashley Goulding, and Sanam Gorgannejad. The plan is for J.D. Huggins to increase his time commitment to MPRL as his other appointment with Professor Emeritus Wayne J. Book ends in Summer 2016.

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, MPRL supports a wet lab with specific expertise on metallography and failure analysis. Additional SEM, TEM and surface analysis facilities are available to MPRL faculty through the new Materials Characterization Facility (MCF) administered through the Institute for Materials (IMat). Various MPRL faculty members have access to high performance computing through PACE (pace.gatech.edu) 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 in both ME and MSE. MPRL staff provide support for these instructional services covered through the COE support.

MPRL accomplishments from July 1, 2015 to June 30, 2016 are summarized in the Table below, with 15 of 22 MPRL faculty responding, 13 of whom stated that they had some level of sponsored funded 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
15	61	34	5	5	14

Active MPRL faculty reported 79 conference presentations and seminars during this period. Approximately $3.0M 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 13 faculty respondents this past year who were actively involved in sponsored MPRL research was as follows: at or above $300K (4), between $200-299K (1), $100-199K (4), $1-99K (4). Non-MPRL-affiliated faculty also utilized MPRL or its research engineer during this period including Dr. Boris Prilutsky (Applied Physiology). This project is not reported in these numbers.

Highlights

Administrative highlights of 2015-2016 included the following:

- Continued to work with the Director of the Institute for Materials (IMat), D.L. McDowell, to make MPRL a strategic user facility in IMat and participated in both large center proposals and cooperative partnerships with industry where MPRL will have a significant role.
- We initiated the process of incorporating MPRL into the Materials Characterization Facility (MCF) and the user facility component of MPRL will be re-branded as the Mechanical Properties Characterization Facility (MPCF) when the incorporation takes place. A cost center study is currently underway. In preparation for the cost center study, 31 distinct pieces of equipment or sub-facilities were identified to be part of the MPCF. Plans are to incorporate MPCF equipment in the Shared User Management System (SUMS) in FY17.
- The non-equipment activities of MPRL (multidisciplinary certificate admin, proposal collaborations, leadership) will be placed under a new umbrella tentatively titled, Mechanical Properties Research Center (MPRC), using the new terminology defined by

the Office of the EVPR.

- Our Research Engineer J.D. Huggins has successfully completed five 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.
- Increased the readiness of the lab to rapidly handle requests through systematic equipment maintenance, repair, and upgrades. Some highlights include (a) added a permanent "kidney-loop" style external filter unit to the hydraulic power system that supplies eight of our servohydraulic test systems in MaRC Hibay, (b) retuned and calibrated displacement on several servohydraulic systems, (c) refurbished two hydraulic cylinder systems by re-chrome plating the cylinder and replacing seals, (d) installed a three zone high-temperature heater controller, (e) replaced heating elements on the tube furnace, (f) repaired metallurgical sample polisher in the wet lab (new air valves), (g) upgraded the temperature controllers on two test frames, (h) added new USB based DAQs to the creep frames and the 5 kip servohydraulic system in the MaRC Hibay lab, (i) purchased USB based strain gage amplifiers for student use, and (j) repaired the DN55 fretting and reciprocating sliding machine.
- Annual force transducer calibrations were performed by outside vendor to maintain compliance required by DOD and other sponsors.
- All water-cooled equipment in the Bunger-Henry building, including hydraulic power supplies, high temperature grips and accessories, and induction heaters, were connected to the campus chilled water system.
- MPRL staff worked with instructors of lab classes in both ME and MSE to ensure equipment needed by students in these classes were ready and train several student groups working on capstone design projects, both in ME and MSE.
- MPRL staff assisted GT Motorsports in evaluating the strength of carbon fiber composite components.
- We recorded new demonstrations of ASTM standard fracture toughness tests in collaboration with Dr. Olivier Pierron and GT Professional Education.

Research program highlights and distinctions of our MPRL participating members include:

- MPRL (Neu) completed its 10th year working with Siemens Energy Inc. on industrial gas turbine structural integrity. Siemens Energy Inc. is considering designating Georgia Tech as one of their preferred universities for collaborations and the only one in the USA. The MPRL is key motivating factor giving Georgia Tech an edge in being selected.
- The MPRL (Johnson, Neu, McDowell, Antolovich) completed its 9th 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).
- S.D. Antolovich was the organizing Guest Editor (with Esteban Busso, Peter Skelton, and Jack Telesman) of the invited special issue on "High Temperature Materials for Aerospace Applications," for *Materials at High Temperatures*. Issue to appear in 2016.
- S.D. Antolovich was the Managing Guest Editor (with Hael Mughrabi) of invited special issue "Gigacycle Fatigue – Theory and Applications," dedicated to the memory of Professor Claude Bathias for *International Journal of Fatigue*. Issue to appear in 2016.
- MPRL Participating Member Dr. Shuman Xia (ME) received an NSF CAREER Award

in 2016.

- MPRL Participating Member Dr. Ting Zhu (ME/MSE) was awarded ASME Fellow.
- MPRL Participating Members are currently editors of several of the leading international journals on mechanical behavior of materials:
    - D.L. McDowell, Editor, *International Journal of Fatigue*
    - R.W. Neu, Editor, *Fatigue & Fracture of Engineering Materials & Structures*
    - Min Zhou, Editor, *Engineering Materials and Technology*
    - R.W. Neu, Co-Editor, *Materials Performance & Characterization*
    - R.W. Neu, Associate Editor, *Wear*
    - R.W. Neu, Associate Editor, *Tribology Transactions*
    - S.D. Antolovich, Associate Editor, *Materials at High Temperature*

Plans for 2016-2017

- Continue to work with the Director of IMat, D.L. McDowell, to make MPRL a strategic user facility in IMat and participate in both large center proposals and cooperative partnerships with industry where MPRL will have a significant role.
- Complete the process of incorporating MPRL into the Materials Characterization Facility (MCF) with the user facility component of MPRL being re-branded as the Mechanical Properties Characterization Facility (MPCF).
- Complete cost center study and incorporate MPCF equipment in the Shared User Management System (SUMS). Note that even after MPCF is set up as a formal Cost Center, additional support will be needed to cover all of the instructional use of the Center. Note that the lab historically has collected voluntary support from sponsored research funds to help fund operating costs, so transitioning to a Cost Center will not necessarily raise a large amount of additional income. It is anticipated that the current voluntary support will now go through the Cost Center.
- Place the non-equipment activities of MPRL (multidisciplinary certificate admin, proposal collaborations, seed funding for exploratory projects, leadership) under a new umbrella tentatively titled, Mechanical Properties Research Center (MPRC). This change in name better aligns with the branding that the EVPR put out recently.
- J.D. Huggins is expected to increase his time working for MPRL up to close to 100% since Professor Wayne Book's last funded research program ends Fall 2016. To help with transition, we plan to continue to employ additional experienced part-time staff, typically a senior graduate student.
- Upgrade and refurbish an old Instron electromechanical test system obtained from Dr. Joe Cochran (MSE) in 2015 after he retired for use of lower force testing needs, a current gap in the capabilities of the facility, using an open-source system control platform, which is anticipated to greatly reduce future costs of maintaining and upgrading MPRL test systems.
- Hold a users meeting to get feedback and publicize the capabilities of the new Mechanical Properties Characterization Facility.
- Engage recent new faculty hires in ME, MSE, and AE that may be potential users and if appropriate add as a Participating Faculty.
- Publicize 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, 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; 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