

Facilities and Policies of the Mechanical Properties Research Laboratory (MPRL)

Last Updated September 1998
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The Mechanical Properties Research Laboratory (MPRL) is an interdisciplinary laboratory whose principal activities are directed towards the measurement and understanding of the mechanical properties of engineering materials. In its role as an interdisciplinary umbrella organization for experimental research in mechanical properties of materials, the MPRL provides a forum for joint research as well as coordination of equipment usage, training and maintenance. Principal research thrusts include:

1. Fatigue and fracture studies of structural materials and their joints used in high temperature applications such as aerospace vehicles, jet engines, rockets and power plants.
2. Development of constitutive equations for deformation and damage of structural metals, advanced alloys and composite materials.
3. Characterization and quantification of microstructure and damage in engineering materials.
4. Development of life prediction methodologies for application to components in the aerospace, power, electronic and ground vehicle industries.
5. Development of improved constitutive models and simulation capability for processing metals, ceramics and composites.
6. Assessment of thermal and environmental aging on mechanical performance of structural materials.
7. Mechanical property evaluations of materials and prostheses that are used in biomedical applications.

Research programs, supported by government and industry, are carried out under the supervision of faculty members drawn from various disciplines and Schools. These projects serve as the basis for theses and dissertations of students seeking M.S. And Ph.D. degrees. In addition to faculty and post-doctoral students, a technician, a secretary and an administrative assistant support MPRL activities.

There are major external opportunities involving mechanical properties research. First, there is a strong demand for M.S. and Ph.D. graduates with a background in mechanical properties of advanced engineering materials. Second, there is high federal priority on materials research and development with regard to processing and performance initiatives. Third, there is increasing national and international emphasis on telecommunications, electronics and superconductivity and development/characterization of new materials.

DESCRIPTION OF AVAILABLE FACILITIES

The capabilities currently available at Georgia Tech are described in the following sections.

Tensile and Fatigue Test Facilities

Ten closed-loop, servohydraulic testing systems are available for monotonic, low cycle/high cycle fatigue testing, fatigue crack propagation and fracture studies. Each machine has a capacity at or exceeding 10 tons. Either load, specimen gage length displacement, or stroke of the crosshead/ram can be prescribed to follow a desired function, at frequencies in the range of 0.0001-100 Hz, by means of closed-loop control. Dedicated or mobile computer control is available on most systems. One 10-ton screw driven Instron machine is available for performing monotonic and low cycle fatigue testing. It can also be fitted with a 1/2-ton load cell for accurate mechanical property measurements of small samples. For even more accurate measurements there is a 50 Kg screw driven table top MTS machine. Most systems routinely support testing at temperatures ranging from room temperature to 1000EC, and equipment is available for tests with temperatures up to 1500EC. A computer-controlled, axial-torsional load frame with high temperature capability is available for multiaxial studies.

Crack length can be measured during tests using mechanical, optical, electric potential or unloading compliance methods. An assortment of high precision diametral and longitudinal strain extensometers, including a ZYGO laser extensometer capable of resolving displacements of 10^{-6} in, are available for use over a wide range of temperatures and frequencies.

The laboratory routinely conducts tensile, cyclic stress-strain, low cycle and high cycle fatigue, plane strain fracture toughness (K_{IC}), stable crack growth (J_R -resistance curve), and fatigue crack growth tests over a wide range of temperatures on metallic and non-metallic materials.

High Temperature High Vacuum Test Facility

A high temperature and high vacuum (10^{-10} torr) mechanical testing facility is available within the MPRL. The test chamber is large enough to hold compact type fracture toughness and crack growth specimens, as well as standard low cycle fatigue specimens. A residual gas analyzer is attached to the system. The system is capable of conducting fatigue tests from essentially static load levels to 10 Hz with a load capacity of 10 metric tons.

Long Focal Length Optical Microscopes

The MPRL has several Questar QRMS-M remote measurement system with a QM-100 optic that can resolve objects as small as 1 μm . The long focal length ability of the Questar means that specimens can be studied during testing in controlled environments that would preclude the use of normal microscopes. This makes the Questar a particularly good tool for monitoring small, dynamic defects in advanced materials, such as growing cracks and interfacial failures in composites. Visual information from the Questar is transferred via a CCD camera to a high resolution monitor and can be recorded on video tape. Live or recorded action can be displayed on an integrated microcomputer with frame grabbing capabilities. These capabilities can freeze any moving video within five frames and digitally store the still image. The digitized images have been used to clearly explain the progression of damage in advanced metal matrix composites.

Thermal Aging Facility

Three 12 cubic feet Thermotron programmable thermal aging ovens are available. These ovens are used to age specimens for several thousands of hours at temperatures as high as 600EF. Humidity controlled cannisters are available for use in the ovens for combined aging at humidity and temperature.

Creep Testing Facilities

One 20 KIP capacity and six 12 KIP capacity dead weight load type creep machines are available for conducting creep deformation and rupture tests as well as creep crack growth tests. One of these machines is also equipped with a cyclic module to conduct tests at very low frequencies (on the order of one cycle per day). The facility is being used to conduct creep crack growth, creep-fatigue crack growth and creep deformation and rupture tests on a variety of materials.

Hardness Testing

Facilities for various types of hardness measurements are available in the MPRL. These include the Knoop hardness, Vicker's hardness, Rockwell hardness and Brinell hardness.

Transmission Electron Microscopy (TEM)

Several electron microscopes are available to MPRL researchers at Georgia Tech. A Hitachi HF-2000 field emission TEM provides a resolution of 0.1 nm (lattice) resolution and 0.23 nm (point-to-point) when operated at 200 keV. Accessories include a Noran energy dispersive x-ray spectrometer with detection capabilities down to boron, a Gatan parallel electron energy loss spectrometer for light element analysis, a slow scan CCD camera, an electron holography unit for three-dimensional analysis of crystals, and a double-tilt holder for diffraction studies. This field emission microscopy lab is one of the best facilities available at a U.S. university. Georgia Tech also has a JEOL 4000EX, 400 keV ultrahigh resolution, top entry TEM. Operated with the single crystal LaB₆ (lanthanum hexaboride) filament at 400 keV, the lattice resolution is 0.14 nm and the point-to-point resolution is 0.19 nm.

Scanning Electron Microscope (SEM)

Georgia Tech has a state-of-the-art Hitachi S-800 Field Emission Scanning Electron Microscope equipped with an EP-1050 image processor, a Kevex level V Microanalysis system, low voltage modification, and magnetic shielding.

Image Analysis Equipment

This laboratory facility includes both automatic and semi-automatic image analysis equipment. The Zeiss Videoplan System, coupled with a Zeiss ICM 405 inverted light microscope, handles all functions of quantitative microscopy on a semi-automated basis. The Videoplan performs routine data acquisition, storage and manipulations. An interface with local workstations permits more sophisticated data manipulation. Measurements of area, diameter, angle, length, centroid, and form factor can be made, as well as the digitizing of irregular curves such as fracture profiles. This instrument significantly reduces the level of effort necessary to quantitatively analyze micrographs or curves, and plays a central role in our analyses for quantitative fractography.

X-Ray Diffraction Laboratory

Available instrumentation includes a Philips automated powder diffractometer (PW 1800) with Micro-Vax II, high resolution graphics, JCPDS Powder Diffraction File, and analysis software, a Huber, computer-controlled Seenan-Bohlin thin film diffractometer and analysis software, four general purpose x-ray generators, three Philips vertical diffractometers (two equipped with diffracted beam monochromators and the third with a high temperature specimen state), a G.E. horizontal diffractometer, two high resolution double crystal diffractometers (one with computer control), assorted cameras for powder and single crystal studies, and a Kratky small angle x-ray scattering apparatus.

The diffractometers are used to collect data for qualitative and quantitative polycrystalline phase analysis. Bulk specimens as well as crystalline thin films and surface layers may be studied. Diffraction profile analysis is used for crystallite size and strain measurements and for texture analysis of plastically deformed polycrystalline solids. Diffraction data can be collected in static air or variable dynamic atmospheres and under high-temperature conditions. All data collection is now in digital form. The double crystal diffractometers are used for extremely high precision measurements of stress and strain in metal and semiconductor crystals and in thin films grown on substrates. This instrumentation has been used to study strains in plastic zones at notches.

MPRL researchers also have access to the facilities of the Crystal Physics Laboratory in the School of Physics at Georgia Tech, including a computerized pole figure device for texture measurements, a small angle x-ray scattering apparatus, and a microfocus x-ray generator for high resolution radiography.

X-Ray Computed Tomography

Facilities for x-ray computed tomography in the School of Materials Science and Engineering include two dedicated workstations with 8 mm tape drives and a total of 1.8 Gbytes of dedicated hard disk space. Two other workstations are also used extensively to process the tomography data; 2.1 Gbytes storage is reserved for tomography. Several copies of IDL and clones (PV Wave), advanced imaging languages, and a number of high resolution imaging monitors are in use analyzing the tomography data. The tomography group has been licensed to use the Lawrence Livermore National Laboratory's software for high resolution computed tomography. Capabilities are therefore in place for analyzing x-ray tomographic microscopy and industrial computed tomography data recorded at remote sites. A unique small load frame for in situ loading of sample during tomographic data collection has also been developed.

Surface Analysis Facilities

State-of-the-art surface analysis facilities are available at Georgia Tech's Microelectronics Research Center.

Secondary Ion Mass Spectrometry (SIMS) apparatus is used for sensitive determination of atomic composition variation with depth and position in a specimen. Depth resolutions of 10 nm are typical and elemental sensitivities of 10^{14} cm^{-3} are achieved in many cases. Elemental distribution can be mapped with a 3-micron lateral spatial resolution. The Microelectronics Research Center also has state-of-the-art equipment for conducting Scanning Auger Microscopy (SAM), Electron Spectroscopy for Chemical Analysis (ESCA), angle resolved Auger spectroscopy and Ultraviolet Photoelectron Microscopy (UPS). These techniques allow researchers to obtain elemental and chemical composition data from the outer few

atomic layers of most solids. In combination with inert gas ion sputtering they also provide information on composition as a function of depth beneath the surface.

High-Strain-Rate Facility

This facility includes an 80 mm (barrel) diameter compressed-gas gun capable of launching 500 g projectiles at speeds of around 1 km/s. The launch tube is mounted with a catcher tank which permits safe recovery of targets for post-shock microstructural characterization and mechanical property measurements. Experiments can be conducted at ambient, elevated and low temperatures as well as under different atmospheres. Impact velocity measurements are made using a pressure transducer system with signals recorded on a digital oscilloscope. The gas gun is presently being utilized mainly for performing controlled recovery experiments, although the upgrade for real-time instrumented pressure measurements is underway. A split hopkinson bar assembly for intermediate strain rate testing is also available.

Computing Facilities

Georgia Tech operates primarily in a distributed processing mode, making use of workstations, PCs and network links with mainframes and supercomputers both on and off campus.

POLICIES AND PROCEDURES

In order to maintain an equitable distribution of machine usage, to meet sponsored research requirements and to ensure proper, safe usage of complex equipment within the MPRL, certain policies and procedures are instituted and enforced by the Director, Associate Director, and other laboratory personnel. Violation of these policies can lead to disciplinary actions, including denial of access to MPRL facilities, particularly for repeated offenses or for blatant disregard of established policies and procedures.

I. Priority for MPRL facilities usage

Potential users of the MPRL are required to fill out an application for use of MPRL facilities well in advance of the desired dates (> 1 month) of usage, carefully outlining the proposed test matrix as well as all equipment and instrumentation needs. All proposals which involve usage of MPRL facilities must be submitted for review and signature of the MPRL Director or Associate Director in addition to the other administrative signatures required at the time of submittal. This is in accordance with Georgia Tech policy, and provides input for advance planning. In some cases, new or additional facilities must be identified to carry out the proposed work if the equipment is already projected as 100% utilized or does not presently exist. In all cases of external proposals for funding, line item funding should be provided for supplies, maintenance cost and support of technician time commensurate with the level of the proposed work. A guideline for expected level of line item funding support is 10% of the fraction of externally sponsored research associated with MPRL facilities for supplies and maintenance costs (including overhead), and 5% for technician support.

To assist the MPRL staff in scheduling and advance planning for new research programs within the lab, faculty should submit the form in Appendix A to the MPRL Director or Associate Director as soon as possible after notification of funding of any proposal which involves use of MPRL facilities, preferably at least 3-4 months in advance of the proposed starting date.

Externally sponsored research work is given highest priority for scheduling. Internally sponsored projects which seek results for purposes of feasibility studies or proposal development are scheduled at the next highest level of priority. Exploratory research without external support is permitted from time to time, but is not encouraged as a routine matter. For such programs, the test matrix must be defined as minimal in order to achieve objectives; it will receive very low priority in the event of high utilization of requested facilities by sponsored research. No guarantees of machine time can be made.

In cases which may be judged as a service provided by the MPRL in support of industrial development or needs of the State of Georgia, somewhat higher priority may be given than to unsponsored exploratory research. Such cases should be referred at the outset to the MPRL administration for consideration prior to any commitments or negotiation.

In the absence of financial support for the program, preference is given in such programs to individuals or groups whom have demonstrated some long term commitment to and support of the laboratory.

A sample application form for MPRL facility usage appears as Appendix B.

II. Training and staff support

Potential users unfamiliar with operating procedures for any item of equipment must receive training in order to operate safely, knowledgeably and productively.

A sample application form for training on MPRL equipment appears as Appendix C. Training will only be approved in conjunction with approval of MPRL facility usage. Advanced graduate students with acknowledged expertise in usage of instruments and laboratory technician(s) may provide such training. Prior to facility usage, training must be completed to the satisfaction of the individual conducting the training. Please remember that requests for training impact the programs of other faculty and students involved in the laboratory; accordingly, it is expected that considerable effort will be devoted to the process by the trainee, and that your own students or technical staff, once properly trained and experience, will in turn be made available to train others.

Often, it is necessary to develop fixtures or adaptors to conduct a unique set of experiments. In such cases, it is incumbent upon the party wishing to conduct the experiments to provide all funding for both the materials/machining costs as well as technician time for design and implementation. It is highly preferable to supply your own technical support for such endeavors, interfacing with the MPRL technical staff as necessary. Time spent by MPRL technical staff in support of activities outside of the realm of the MPRL must be requested of the MPRL administration and funded directly. See Appendix D for an application form. Preference will be given to faculty whom have been involved with and supported the MPRL infrastructure in such requests. Access to such technical support is often very limited, depending on the current level of utilization of the laboratory.

Safe operation of MPRL equipment is a key issue and is a major objective of the training. Hence, all individuals who conduct training exercises should seek periodic refresh of their safety procedures from the laboratory technician/equipment specialist, or seek instruction from same if any questions arise. Certain safety procedures must be obeyed at all times in the MPRL, including the use of safety glasses in all MPRL lab spaces, warning others of any potentially hazardous conditions such as service of high pressure oil lines, and identification, notification of MPRL staff/students, and proper handling of any potentially hazardous substances or chemicals.

III. Consulting policy

It is recognized that consulting activities (non-state business related activities) in many instances may serve to enhance the reputation and professional knowledge of MPRL faculty. In cases where faculty or staff seek to use MPRL facilities for consulting purposes, it is expected that (i) they secure written permission to do so from the MPRL Director or Associate Director, including a time estimate and description of the nature of such usage, (ii) consult with the MPRL research equipment specialist regarding the project and facilities it will make use of, (iii) ensure that all training guidelines which apply to research

are met, and (iv) make payment to the MPRL in an amount not less than 20% of the total funds received which may be identified as related to testing/characterization tasks *or* \$300 per day of usage.

The facilities of the MPRL may not be used for consulting work which has no clear prospect of enhancing the professional development of the involved faculty, or which may be deemed as standard experiments with no intrinsic research-related value that may be performed by private industrial testing/characterization companies. This assessment will be made by the Director or Associate Director upon application. Students are not permitted to use MPRL facilities for their own consulting arrangements.

The necessary form for permission of use of facilities for consulting activity appears in Appendix E. Neglecting to submit this form to request use of facilities for consulting purposes and providing financial support for the activity as appropriate may constitute grounds for limitation on use of the facilities for future research. Consequences of misuse of equipment in conduct of consulting are defined in current Institute guidelines.

IV. Interdisciplinary Certificate Program in Mechanical Properties of Solids

Graduate students conducting research within the MPRL are strongly encouraged to pursue the interdisciplinary certificate in Mechanical Properties of Solids. This certificate is awarded along with the graduate degree, and denotes a specialty in mechanical properties and affiliation with the MPRL which may be useful in seeking future employment opportunities in addition to providing a well-balanced educational program. A thorough description of the certificate program appears in Appendix F, along with administrative forms.