09:26:07 OCA PAD INITIATION - PROJECT HEADER INFORMATION 09/26/95

Active

Project #: E-25-T89 Cost share #: E-25-393 Rev #: 0
Center # : 10/24-6-R8688-0A0 Center shr #: 10/22-1-F8688-0A0 OCA file #:
Work type : RES
Contract#: CMS-9512368 Mod #: Document : GRANT
Prime #: Contract entity: GTRC

Subprojects ? : N CFDA: 47.041
Main project #: PE #: N/A

Project unit: MECH ENGR Unit code: 02.010.126
Project director(s):
MCDOWELL D L MECH ENGR (404)894-5128

Sponsor/division names: NATL SCIENCE FOUNDATION / GENERAL
Sponsor/division codes: 107 / 000

Award period: 950915 to 970831 (performance) 971130 (reports)

Sponsor amount	New this change	Total to date
Contract value	205,000.00	205,000.00
Funded	205,000.00	205,000.00
Cost sharing amount		137,000.00

Does subcontracting plan apply ?: N

Title: ACQUISITION OF INTEGRATED MATERIAL SIMULATION & TEST CONTROL CAPABILITY

PROJECT ADMINISTRATION DATA

OCA contact: Jacquelyn L. Bendall 894-4820

Sponsor technical contact	Sponsor issuing office
OSCAR DILLON (703)306-1361	MARIA VALERIO (703)306-1218
NATIONAL SCIENCE FOUNDATION 4201 WILSON BLVD. ARLINGTON, VA 22230	NATIONAL SCIENCE FOUNDATION 4201 WILSON BLVD. ARLINGTON, VA 22230

Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): N
Defense priority rating : N/A NSF supplemental sheet
Equipment title vests with: Sponsor GIT X

Administrative comments -
INITIATION OF PROJECT. THIS IS AN EQUIPMENT GRANT.

PROJECT CLOSEOUT - NOTICE

Closeout Notice Date 02-DEC-1997

Project Number E-25-T89 Doch Id 37005

Center Number 10/24-6-R8688-0A0

Project Director MCDOWELL, DAVID

Project Unit MECH ENGR

Sponsor NATL SCIENCE FOUNDATION/GENERAL

Division Id 3393

Contract Number CMS-9512368 Contract Entity GTRC

Prime Contract Number

Title ACQUISITION OF INTEGRATED MATERIAL SIMULATION & TEST CONTROL CAPABILITY

Effective Completion Date 31-AUG-1997 (Performance) 30-NOV-1997 (Reports)

Closeout Action:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	N	
Final Report of Inventions and/or Subcontracts	N	
Government Property Inventory and Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

Comments
LETTER OF CREDIT APPLIES. 98A SATISFIES PATENT REPORT.

Distribution Required:	
Project Director/Principal Investigator	Y
Research Administrative Network	Y
Accounting	Y
Research Security Department	N
Reports Coordinator	Y
Research Property Team	Y
Supply Services Department/Procurement	Y
Georgia Tech Research Corporation	Y
Project File	Y

DEC 3 1997

NATIONAL SCIENCE FOUNDATION
4201 Wilson Blvd.,
Arlington, VA 22230

PI/PD Name and Address

David L. McDowell
Department of Mechanical Engineering
GA Tech Res Corp - GIT
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Atlanta GA 30332-0405

NATIONAL SCIENCE FOUNDATION FINAL PROJECT REPORT

PART I - PROJECT IDENTIFICATION INFORMATION

1. Program Official/Org. Sunil Saigal - CMS

2. Program Name MECHANICS & MATERIALS PROGRAM

3. Award Dates (MM/YY) From: 09/95 To: 08/97

4. Institution and Address

GA Tech Res Corp - GIT
Administration Building
Atlanta GA 30332

5. Award Number 9512368

6. Project Title

Acquisition of Integrated Material Simulation and Test Control Capability

** You are encouraged to submit ... through the NSF FastLane ...

This Packet Contains
NSF Form 98A
And 1 Return Envelope

FINAL REPORT
NSF AWARD NO. 9512368

NSF EQUIPMENT GRANT FINAL REPORT

Submitted to Mechanics and Materials Program - CMS Division
National Science Foundation
Sunil Saigal, Program Manager

Submitted by

DAVID L. MCDOWELL
Regents' Professor
George W. Woodruff School of Mechanical Engineering

W. STEVEN JOHNSON
Professor
School of Materials Science and Engineering

November 1997

EXECUTIVE SUMMARY

NSF GRANT NO. CMS-9512368
Period: 9/15/95 to 8/31/97 (Amount: $205,000)
Acquisition of Integrated Material Simulation and Test Control Capability
co-PIs: D.L. McDowell and W.S. Johnson, Georgia Tech

This project funded acquisition of state-of-the-art digital computer-control and data acquisition capability for approximately half of the existing testing machines within the interdisciplinary Georgia Tech Mechanical Properties Research Laboratory (MPRL), directed by D.L. McDowell. This equipment grant supported purchase of appropriate upgrades of digital test machine controllers, elevated temperature extensometry, grips, etc. Several long focal length microscopes were purchased for stand-off image analysis capability to support fatigue and fracture studies, interfacing through a CCD camera to digital imaging devices. These upgrades are supporting a host of research projects conducted by over 15 member faculty and 30 graduate students, with annual research expenditures of approximately $2.5M. During fiscal year 1996-97, MPRL faculty produced 114 papers, gave 57 presentations, and graduated 8 MS and 5 PhD students.

OVERVIEW OF MPRL

The Mechanical Properties Research Laboratory (MPRL) at Georgia Tech is a leading U.S. university facility engaged in studies of the deformation, fatigue and fracture studies of high temperature structural materials. Principal research areas include fatigue and fracture testing of structural materials used in high temperature applications; development of constitutive equations for deformation and damage of structural metals, advanced alloys and composite materials; quantification of microstructure and damage in engineering materials to establish structure/property relationships; development of life prediction methodologies for remaining life assessment of components; and simulation and enhancement of processing/forming techniques for metals, ceramics and composites. An array of interests are represented, including those of the aerospace, power generation, electronic and ground vehicle industries. In addition to mechanical testing and characterization, several MPRL researchers are at the forefront of constitutive equation development and implementation in computational algorithms for primary forming, structural analyses, failure analyses, etc.

The MPRL has consistently focused on the link between structure and properties of engineering materials. As such, many of its research programs have concerned simulation of material behavior, based on physical principles and experimental findings. This linkage of material microstructure with process route as well as with in-service properties and performance, is consistent with the AMPP objectives as set forth by the NSF. The MPRL maintains nine servohydraulic or screw driven test systems, most with high temperature capability and one with axial-torsional capability, as well as a creep laboratory and various quantitative material characterization capabilities.

Research programs, supported by government and industry, are carried out under the supervision of 18 faculty members and 25-30 graduate students, broadly representative of various disciplines and academic units. In addition to faculty and post-doctoral students, a research equipment specialist assists in equipment maintenance and utilization. The MPRL contributes to research which supports major national initiatives such as the National Aerospace Plane, the High Speed Civil Transport, the Advanced Gas Turbine Program and the F-22, as well as advanced materials and processing topics related to the NSF AMPP initiative. The MPRL has actively promoted for the past decade the integration of relevant aspects of materials science and mechanics of materials in education and research. Graduate students working in mechanics typically take courses in materials science and vice versa. A graduate certificate is available in Mechanical Properties of Solids.

The principal activities of the interdisciplinary Mechanical Properties Research Laboratory (MPRL) are directed towards the measurement and understanding of the mechanical properties of engineering materials. High temperature structural materials are emphasized. In its role as an interdisciplinary umbrella organization for experimental research in mechanical properties of materials, the MPRL provides coordination of equipment usage, training and maintenance, as well as a forum for joint research. Principal areas of research include:

1. Fatigue and fracture studies of structural materials used in high temperature applications such as aerospace vehicles, jet engines 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 to establish structure/property relationships.
4. Development of life prediction methodologies for remaining life assessment of 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. Mechanical property evaluations of materials and prosthetic devices 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 academic units. 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. The MPRL receives an allocation from research overhead return each year to cover maintenance costs of equipment and partial support for salaries of its staff. The research equipment specialist, Richard C. Brown, is in charge of maintenance, training and scheduling of usage of equipment, in consultation with the MPRL Director, David L. McDowell, and Associate Director, W. Steven Johnson. A Faculty Governance Board consisting of active MPRL faculty meet at least quarterly to discuss laboratory directions, priorities and maintenance/acquisition issues. The structure of the MPRL has been in place at Georgia Tech for over a decade.

Faculty involved in the MPRL represent a broad range of disciplines and academic units within Georgia Tech:

E.A. Armanios, School of Aerospace Engineering - Analysis, design and testing of elastically tailored composite structures, failure characterization and damage modeling of laminated composites, computational solid mechanics.
A. Gokhale, School of Materials Science and Engineering - Quantitative fractography and microscopy (stereology), modelling of microstructures, quantitative relationships between microstructure and mechanical behavior of materials.
J. Hampikian, School of Materials Science and Engineering - Microstructural and analytical characterization of materials through transmission electron microscopy; high temperature oxidation kinetics and modes of coating failure for high temperature materials; thermal barrier coatings.
W.E. Hutton, G.W. Woodruff School of Mechanical Engineering/Emory University - Mechanical behavior of orthopaedic devices.
W.S. Johnson, School of Materials Science and Engineering - Experimental and analytical characterization of fatigue and fracture behavior of advanced materials including nonlinear and temperature dependent behavior. Development of life prediction methodology.
W.J. Lackey, G.W. Woodruff School of Mechanical Engineering - Processing of ceramics and ceramic composites using CVI/CVD. Process/structure/property relations for composites and laminated matrix composites.
C.S. Lynch, G.W. Woodruff School of Mechanical Engineering - Constitutive behavior of materials: ferroelectric single crystals and ceramics, ceramic matrix composites, laminated matrix composites. Reliability of materials, fracture mechanics.
D.L. McDowell, G.W. Woodruff School of Mechanical Engineering - Cyclic plasticity, viscoplasticity, nonlinear and time-dependent fracture mechanics, fatigue and creep-fatigue interaction, finite strain inelasticity, intelligent materials, damage and deformation of metal and ceramic matrix composites.
R.W. Neu, G.W. Woodruff School of Mechanical Engineering - Thermomechanical fatigue, environmental effects, composite materials, fracture mechanics, creep, fatigue life prediction methods, mechanics of phase transformations.
J. Qu, Associate Professor G.W. Woodruff School of Mechanical Engineering - Micromechanics of composites, wave propagation and non-destructive evaluation of composites.
T.H. Sanders, School of Materials Science and Engineering - Kinetics of aging of Al alloys; microstructure/property relations
A. Saxena, School of Materials Science and Engineering - Fracture mechanics and its application to materials testing and life prediction of structural components, with particular emphasis on high temperature materials and applications

involving creep and creep-fatigue loading.
T.L. Starr, School of Materials Science and Engineering - Processing and properties of ceramic matrix composites. Measurement of the mechanical and transport properties of ceramic matrix composites, modeling of the chemical vapor infiltration (CVI) process and development of composites based on a silicon nitride matrix.
S.R. Stock, School of Materials Science and Engineering - Damage accumulation in a wide variety of structural and electronic materials using x-ray diffraction and x-ray computed tomography.
R. Talreja, School of Aerospace Engineering - Damage durability and nondestructive evaluation of composite materials of polymeric, ceramic and metal matrices, and with fiber architectures ranging from short fibers to long, continuous, woven and braided fibers.
N. Thadhani, School of Materials Science and Engineering - 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.
C. Ume, G.W. Woodruff School of Mechanical Engineering - Temperature dependent material property characterizations of thin laminates, including development of both contact and non-contact procedures for characterizing in-plane and out-of-plane behavior of thin laminates.
M. Zhou, G.W. Woodruff School of Mechanical Engineering - High strain rate behavior of materials, experimental and computational studies of shear banding and deformation of heterogeneous materials

A wide range of x-ray, electron and chemical characterization apparatus are available to MPRL researchers in the Schools of Materials Engineering and Physics and in the Microelectronics Research Center. In addition, several facilities of the nearby Oak Ridge National Laboratories (ORNL) are also available to Georgia Tech researchers through the Oak Ridge Associated Universities (ORAU) program. Available facilities include the Small Angle Neutron Scattering Center, the Melting and Processing Laboratory and the High Voltage Electron Microscopy Laboratory.

The capabilities currently available at Georgia Tech are described below.

Tensile and Fatigue Test Facility

Over ten closed-loop servohydraulic testing machines are available for monotonic, low cycle/high cycle fatigue testing, and fatigue crack propagation studies. Each machine has a capacity of 10 tons. Load or strain of the specimen or crosshead motion can be electronically controlled to follow a prescribed function, at frequencies in the range of 0.0001-100 Hz, by means of closed-loop electronics. Dedicated or mobile Computer control is available on all systems.

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 10^{-6} in displacement are available for use over a wide range of temperatures and frequencies.

The laboratory routinely conducts tensile, cyclic stress-strain, plane strain fracture toughness, K_{IC}, J_R-Resistance Curve, fatigue crack growth testing, low and high cycle fatigue tests over a wide range of temperatures on metallic and non-metallic materials. A facility is also available to conduct tension-torsion loading tests for deformation and fracture studies at elevated temperature.

Creep Testing Facility

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). In addition, two stress relaxation machines (10 KIP capacity) are available with tension compression cyclic load capabilities. The test machines are being interfaced with a personal computer for automatic monitoring of test parameters and data acquisition. These machines are being used for conducting creep deformation, rupture and crack growth tests.

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 at Georgia Tech. A JEOL 100C microscope provides flexible specimen examination. It is fitted with attachments for both scanning transmission (STEM) and scanning electron microscopy (SEM) and an energy dispersive x-ray spectrometer. This instrument is capable of 3.4A lattice resolution in the TEM mode. Various attachments for the JEOL are used to obtain additional information. These include secondary and backscattered electron (scanning) imaging for fractographic and microstructural analysis, chemical analysis of microconstituents (200A resolution for thin foils), microelectron diffraction for orientation and phase analysis from areas of a thin foil (300A resolution). The microscope is also equipped with a specimen rotating holder. The holder is designed to rotate the specimen 360° in the plane of the specimen, and tilt +60° about the rotation axis. The attachment is crucial in carrying out detailed quantitative analyses of microstructural features.

Sample preparation facilities for TEM include two Streuers Tenupols equipped with a cooling unit to perform dual jet polishing at controlled temperatures as low as -80°C, an ISI sputter/coater, and Commonwealth Scientific ion-milling equipment. Also, spark machining capabilities are available for machining delicate specimens such as single crystals.

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, Kevex level V Microanalysis system, low voltage modification, and magnetic shielding. This unit was purchased new in 1991.

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. There is also an interface to our main-frame Cyber computer which allows 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.

Surface Analysis Facilities

State-of-the-art surface analysis facilities are available to researchers in the School of Materials Engineering at Georgia Tech's Micro Electronics Center. This center is located across the street from the Materials Engineering Building.

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 Micro-electronics 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.

Computing Facilities

Georgia Tech has a CRAY Y-MP supercomputer and an IBM SP2 parallel computer. In addition, access to the national supercomputing centers provides us with sufficient computational resources for carrying out the proposed finite element simulations. Our group has a cluster of IBM and Sun UNIX-based workstations, along with NT-based high end PCs, that serve as the work environment for code development and support for model development, for postprocessing (graphics generation and video animation) and for access to supercomputers.

Georgia Tech has recently been announced as one of 12 universities each awarded a grant from Intel Corp. to acquire 32 of quad pentium pro or pentium II processors to form two 64-processor massively parallel computing environments. One will be UNIX-based and the other NT-based. D.L. McDowell serves as a co-PI (with nine others).

EQUIPMENT ACQUIRED BY GRANT

The purpose of this equipment grant was to to develop an *integrated simulation and test control/data acquisition capability*, upgrading our existing facilties which in large part were obsolete or inadequate to support studies of micro-mechanisms of deformation, fatigue and fracture of a broad range of enginering materials. While the MPRL has developed an impressive array of testing and characterization equipment, there were several areas which suffered from lack of digital computer control and data acquisition/image analysis capablities:

(i) Most of the existing MPRL servohydraulic control systems, furnaces, extensometry, etc. were intended for only isothermal testing and significantly lags the current state-of-the-art. Much of the control electronics was circa late 1970s-early 1980s vintage, and was significantly inferior to the the speed, memory, and user interfaces of the newer digital control systems.

(ii) Sufficient extensometry for displacement measurement and processor-interfaced optical instrumentation for acquiring images of damage development in alloys and composites were lacking in the laboratory, hindering the pursuit of joint micromechanics modeling programs to complement the experimental effort.

The proposal requested funds to acquire state-of-the-art digital computer-control and data acquisition capability for approximately half of the existing testing machines within the MPRL, introducing appropriate upgrades of elevated temperature extensometry, grips and furnaces, and enabling the interface of experiments with computational modeling.

Items Purchased with Grant:

NSF Funds:$205,000

MTS Systems Digital Control upgrade
MTS Systems Digital Controller (TEST STAR)
Gateway computer for interface to test control
Extensometer (SATEC)
Epsilon Technologies Axial-Torsional Extensometer
Srain Extensometer
Strobe Light system
Tangent computer upgrade card
MTS grips (uniaxial and axial-torsional)
Jeol SEM (partial cost of acquisition)
Questar long focal length microscope
Image analysis: 2 Gateway computers, VCR,Video Card, Digital Camera
3 Printers

Georgia Tech Matching Funds: $137,000

MTS control system (TEST STAR)
MTS control system upgrade
MTS Systems Digital Controller (TEST STAR)
MTS Systems pump and manifold assembly
Questar long focal length microscope

Impact on Infrastructure

The upgrades described in this final report have been selectively identified and pursued to strengthen the capabilities of the MPRL to conduct state-of-the-art work in support of new developments in materials science and the emerging field of micromechanics of heterogeneous materials. The students and faculty involved in the MPRL at Georgia Tech are from the Schools of Aerospace Engineering, Chemical Engineering, Materials Science and Engineering, and Mechanical Engineering. This commitment to interdisciplinary materials research at Georgia Tech results in our graduates being uniquely qualified to enter the workforce and contribute in meaningful ways.

The MPRL is committed to the involvement of underrepresented groups and women in pursuit of advanced degrees in engineering. Presently, two african-american Ph.D. students conduct research in the MPRL, and several female students are involved. The Georgia Tech faculty also has a commitment to performing challenging, leading-edge research that has a specific goal or requirement in mind. Faculty participants within the MPRL arguably form the most significant representation of any single U.S. University to the historically important ASTM Committee E.08 on fatigue and fracture, as well as to Committee D-30 on reinforced composites. Accordingly, results which emerge from this enhancement of capability will be widely communicated. Furthermore, it is expected that this instrumentation will serve the community more broadly through collaboration with other universities, with visiting researchers and post-docs.

All of the reported upgrades have been successfully installed and are presently integrated within the day-to-day activities of the laboratory. These upgrades have placed the MPRL in a position of having a state-of-the-art testing capability for the rest of this decade, thus enabling response to the testing and analysis needs of associated with emerging federal and industrial priorities that relate to high temperature materials in the automotive industry, aerospace, utilities, electronic packaging, etc.