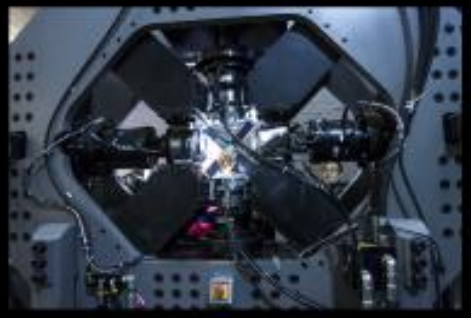
AIMS ADAPTIVE INTELLIGENT MATERIALS & SYSTEMS CENTER



ASU Ira A. Fulton Schools of Engineering
Arizona State University

AIMS

Bridging the Gap

From the Nano to the Structural Scale

aims.asu.edu

Mission of the AIMS Center

- **Research/exploit innovative & cutting-edge adaptive & intelligent technology for transdisciplinary applications**
- **Combine multidisciplinary research backgrounds in:**
  - **System Health Management & Prognosis**
  - **Multiscale Modeling: Molecular Dynamics & Continuum Mechanics**
  - **Material Characterization & Testing**
  - **Composite, Metallic, Hybrid, & Superalloy Materials**
  - **Intelligent Design & Multidisciplinary Optimization**
  - **Surface & Interface Mechanics**
  - **Multifunctional Materials & Adaptive Systems**
  - **Bioinspired Materials & Robotics**
  - **Information Management & Signal Processing**
  - **Data Fusion, Mining & Informatics**
  - **Thermal Energy Applications**

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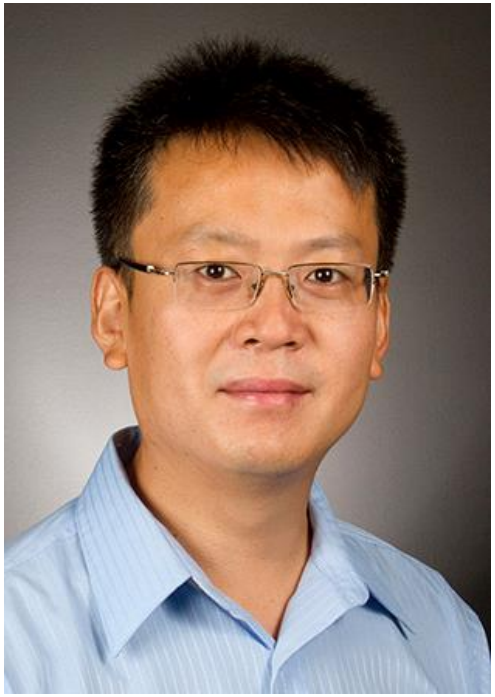

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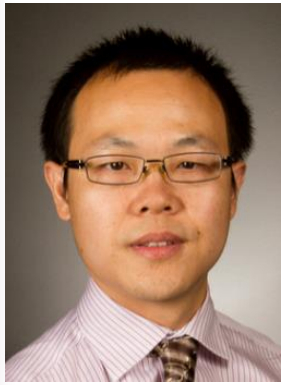

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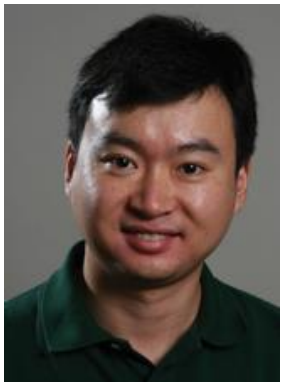

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Sponsors and Government Funding

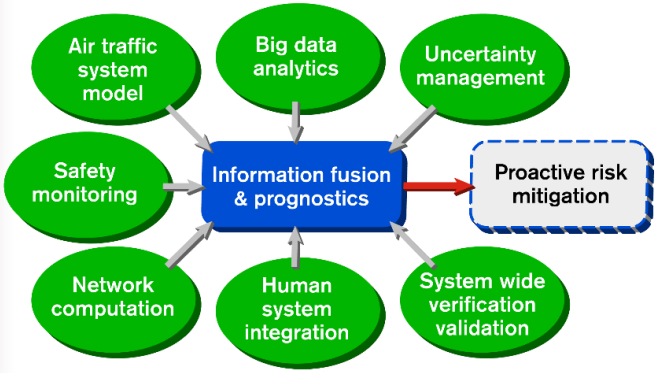
- $10M National Aeronautics and Space Administration (NASA)
  University Leadership Initiative (ULI)
- $6M Air Force Office of Scientific Research (AFOSR)
  Multidisciplinary University Research Initiative (MURI)
- $1.5M US Department of Transportation (USDOT)
  Research and Innovative Technology Administration (RITA)
- Air Force Office of Scientific Research (AFOSR)
- Air Force Research Laboratory (AFRL)
- Army Research Laboratory (ARL)
- Army Research Office (ARO)
- Department of Energy (DOE)
- DOE Nuclear Energy University Program (NEUP)
- DURIP (AFOSR)
- National Science Foundation (NSF)
- Naval Air Systems Command (NAVAIR)
- National Institutes of Health (NIH)
- Office of Naval Research (ONR)
- Honeywell International, Czech Republic

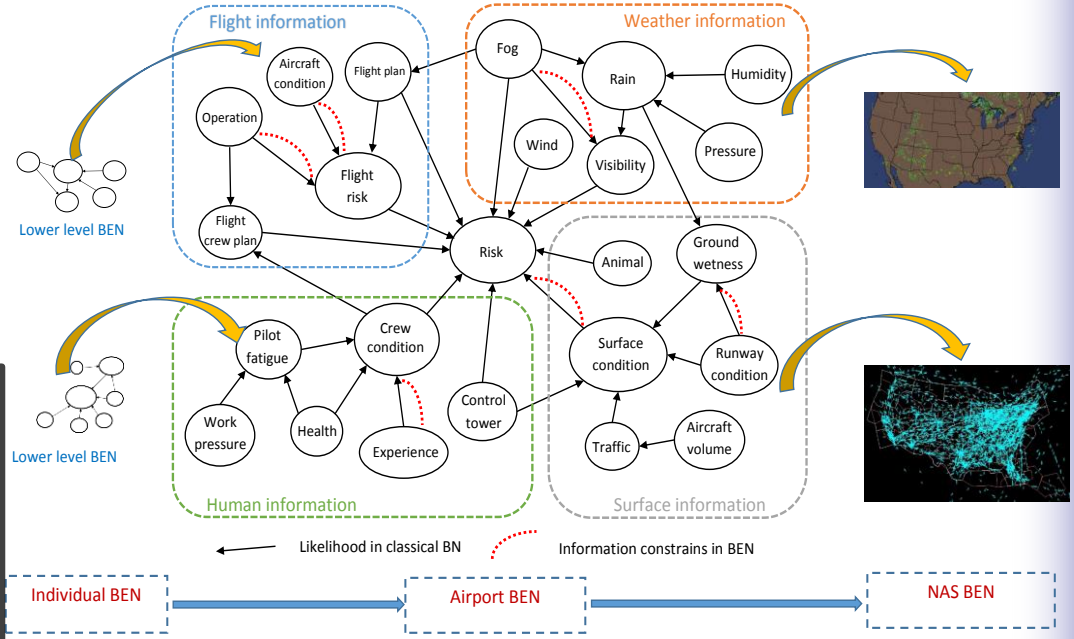
NASA University Leadership Initiative

Information fusion for real-time national air transportation system prognostics under uncertainty

PI: Yongming Liu

ASU co-PIs: Aditi Chattopadhyay; Nancy Cooke; Pingbo Tang; Lei Ying; Jingrui He; Mary Niemczyk
External co-PIs: Sankaran Mahadevan (Vanderbilt); Barron Bichon (SwRI); PK Menon (Optimal Synthesis Inc.)





- **Real-time system-wide information fusion methodology for prognostics & safety assurance of the NAS**
- **Various sources of uncertainties & their coupling effects for failure & risk assessment of extremely large-scale, complex system**
- **A community-based collaborative simulation platform for continued sustainable prognostics technology evolution**
- **Multidisciplinary team for integrated research & education**

- **Generalized Bayesian Entropy Network (BEN) for hierarchical complex human-cyber-physical system updating and prognostics**
- **Real-time system-wide decision making for risk mitigation**

Systems Health Monitoring and Prognosis

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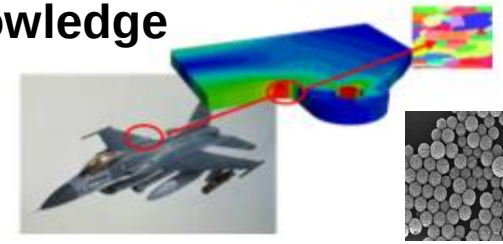
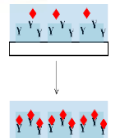
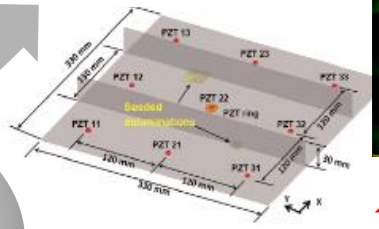
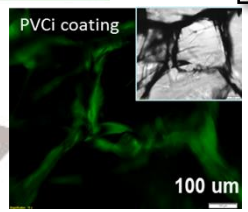
Knowledge



Sensing

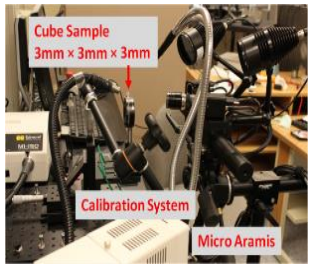




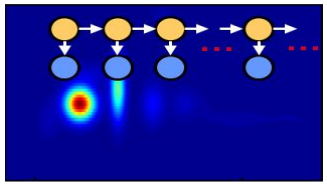


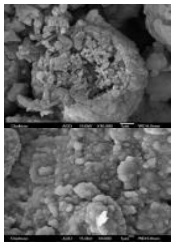
Integrated Systems Health Management

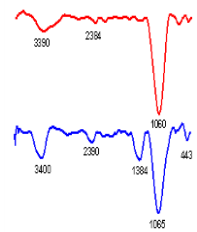
Testing



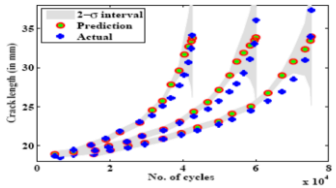
Signal Processing

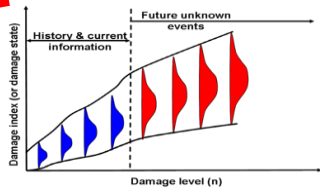


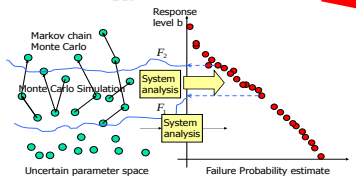




Prognosis







Technical Approach

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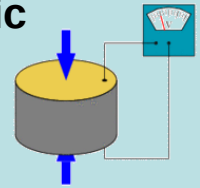
Detection ⟷ **Localization** ⟷ **Quantification** ⟷ **Prognosis**

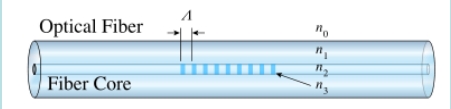
Advanced Sensors

- Piezoelectric



- Macro fiber composite

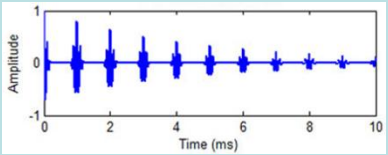
- Fiber Bragg grating



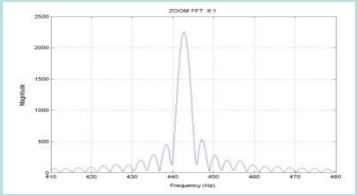
- Acoustic emission
- Accelerometer
- ……
- Self-sensing (with nanomaterials)

Signal Processing

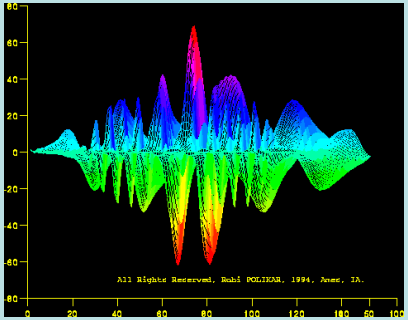
- Time domain



- Frequency domain

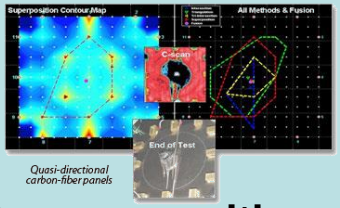


- Time- frequency

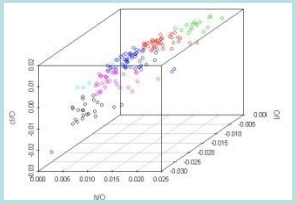


Mathematical Modeling

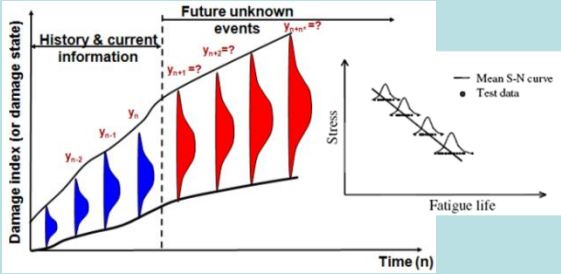
- Localization algorithm



- Pattern recognition

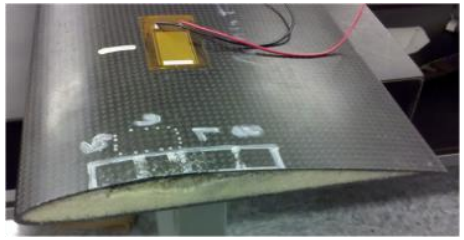


- Prediction model

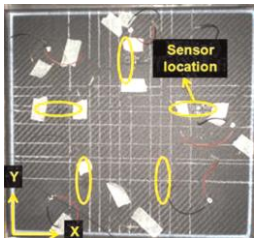


Sensors & Applications

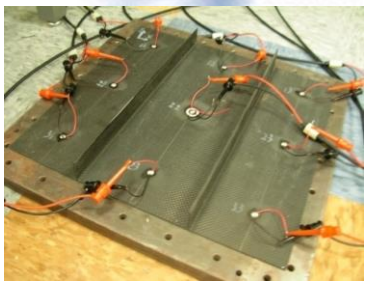
Lead Zirconate Titanate sensors on aluminum lug joint



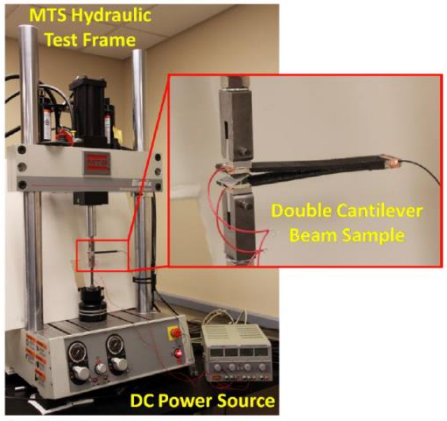
Macro fiber composites for barely visible impact damage

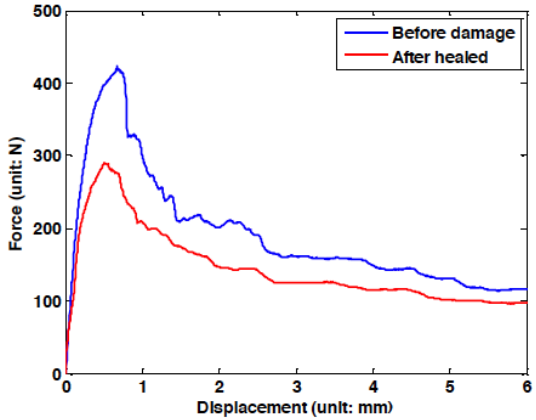


Fiber bragg grating sensors for impact damage monitoring

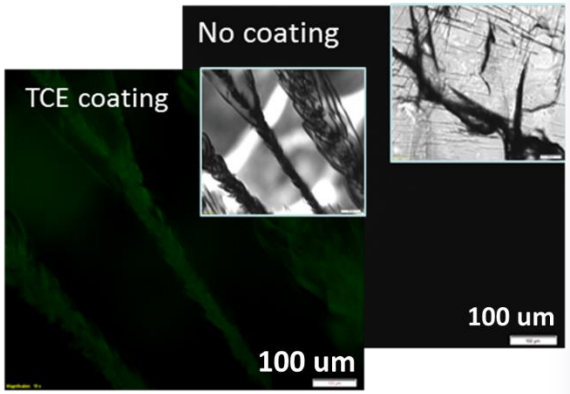


Stiffened panel damage monitoring



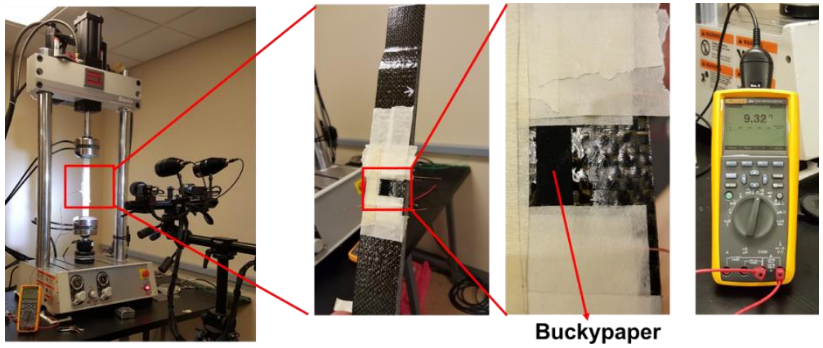


Self healing nanocomposite

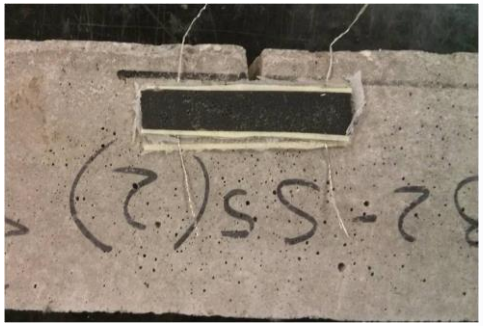


Mechanophore material

Deployable CFRP boom



Strain sensing in foam core composites using buckypaper



Strain sensing in concrete

Information Management

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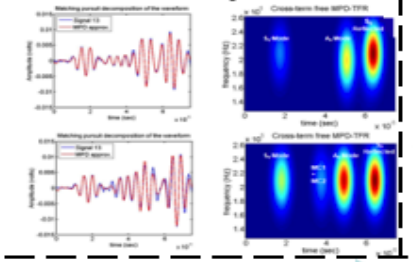
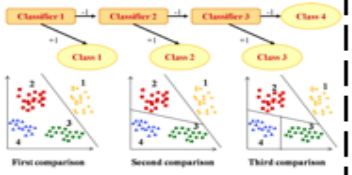
Matching Pursuit Decomposition (MPD)

- Represent signal in TF domain
- Detect damage by identifying converted mode in guided waves



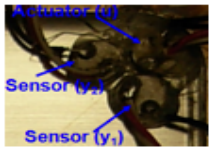
Supervised Machine Learning (SVM)

- Damage classification
- Applicable to metals & composites under complex load & environmental conditions

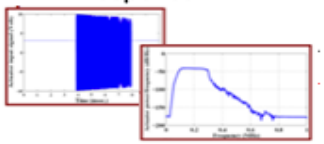


Real-Time State Awareness

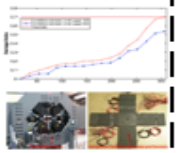
In-situ **monitoring using dual-sensor**

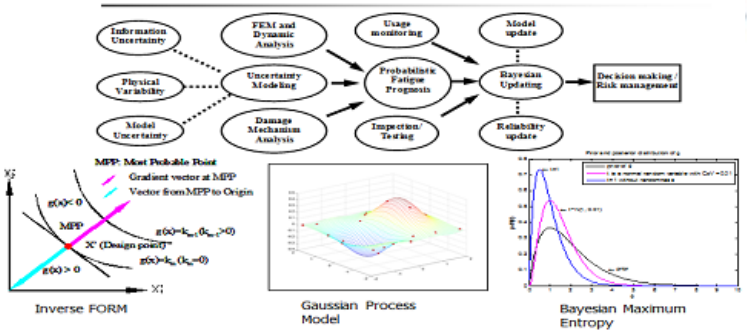


Broad band input & TF response

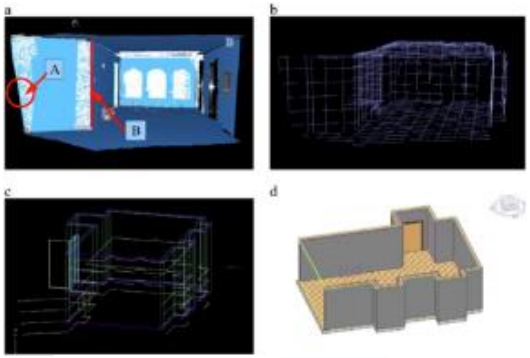


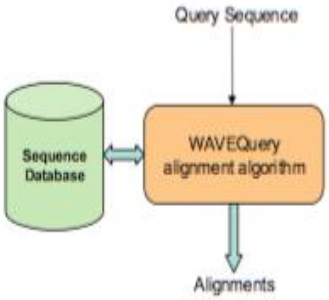
Real-time awareness

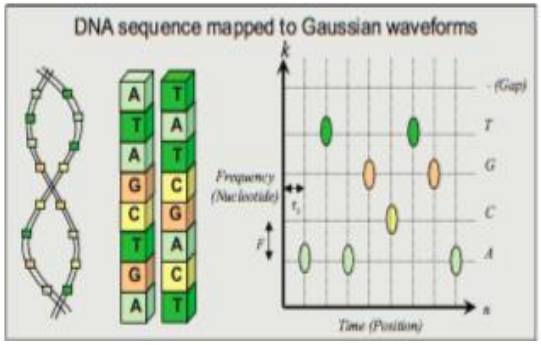


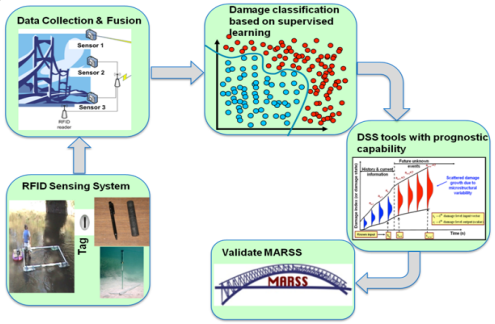


Uncertainty Quantification and Reliability Assessment









Waveform Mapping of DNA Sequences

Infrastructure Management

Intelligent Materials

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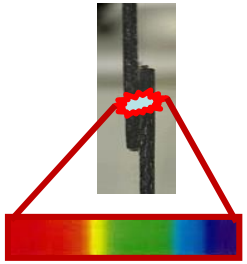
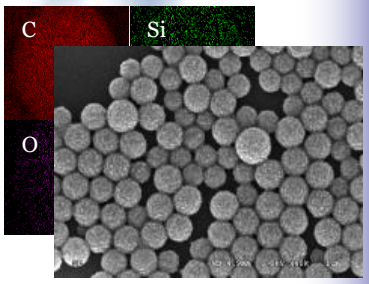
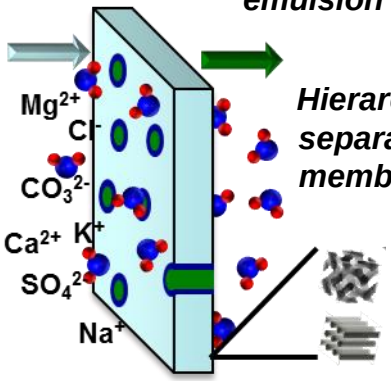
- **Novel Hybrid Materials**
  - Synthesis of self-sensing and self-healing (mechanophore) materials
  - Development of emulsions, colloids, and gels for environmentally responsive materials
- **Ion-Containing Block Copolymer**
  - Synthesis of hierarchical separations membranes
  - Development of stimuli-responsive solution assemblies
- **Soft Matters & Composites Materials**
  - Synthesis of biologically-inspired hybrid materials and electrically conductive polymer (sensors/actuators)
  - Development of organic optoelectronics



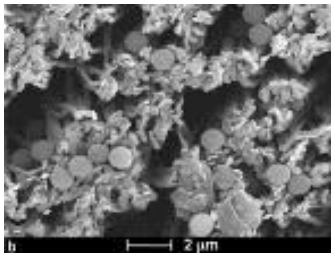
Mechanophore, damage sensor



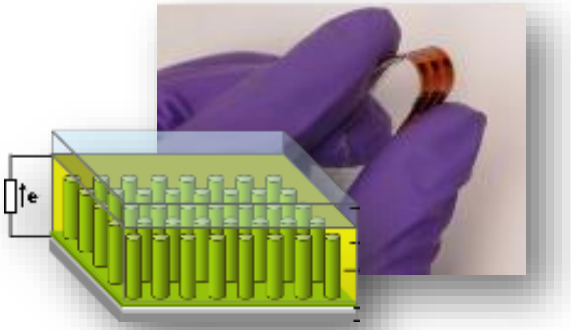
Self-assembled emulsion



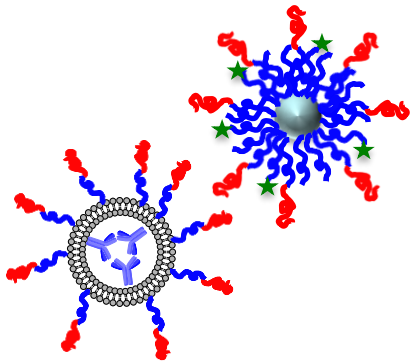
Hierarchical separations membranes



Conductive polymers



Smart systems, optoelectronics



Stimuli-responsive solution assemblies

Intelligent Materials (Contd.)

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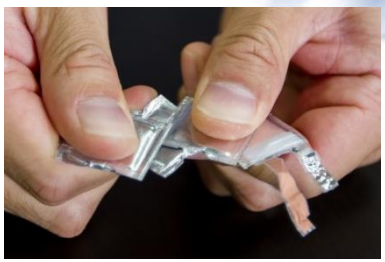
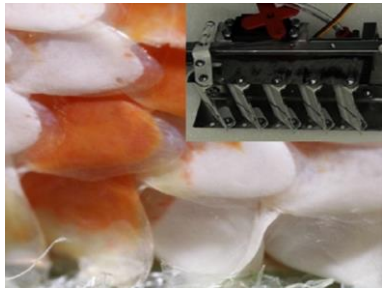
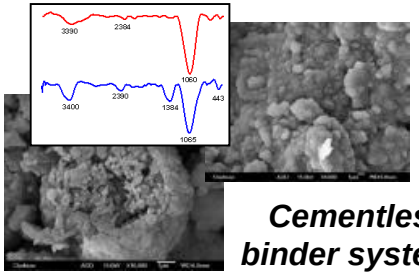
- **Origami (Kirigami) Electronics**
  - Development of stretchable and flexible structure for electronics and energy storage device (battery)
- **Bio-Inspired Robotics/Structure**
  - Design, fabrication and characterization of interfacial structures (mimic snake skin) for active control of friction, adhesion, and drag
- **Advanced Cementitious Materials**
  - Novel materials for high volume cement replacement and cementless binder systems
- **Biomaterial Design**
  - Development of biomimetic, dynamic-cell and orthopedic materials
- **CNT Membrane Sensor**
  - Development of self-sensing composite using CNT-membrane (Buckypaper)



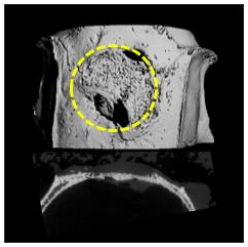
Stretchable battery



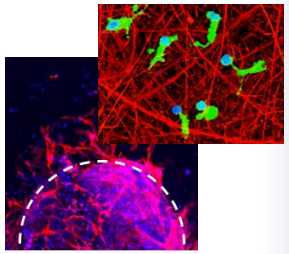
Snakes Mimic Earthworms



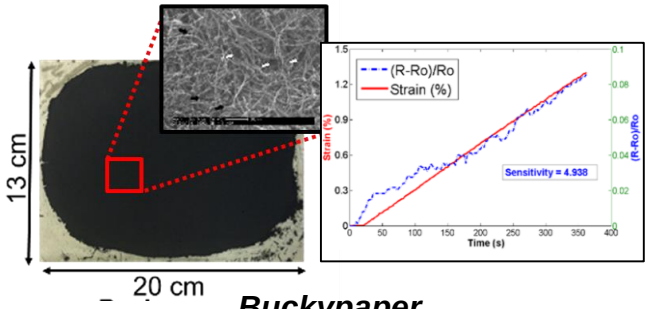
Cementless binder systems



Orthopedic materials



Dynamic Cell-Material Interactions



Buckypaper

Multidisciplinary Design Optimization

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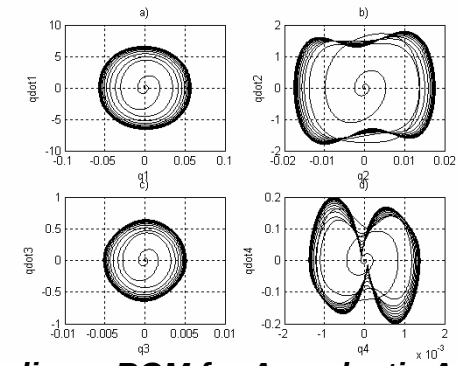
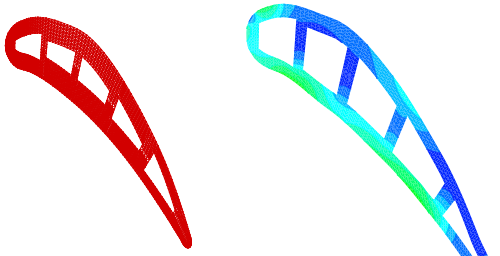
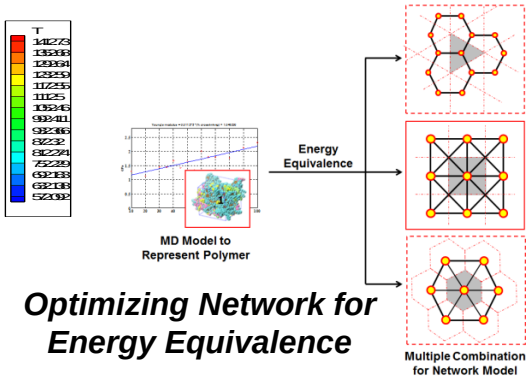
- Multiobjective Optimization
- Design and Shape Optimization
- Discrete Optimization / Integer Programming
- Multilevel Decomposition
- Reduced Order Modeling / Response Surface Methods



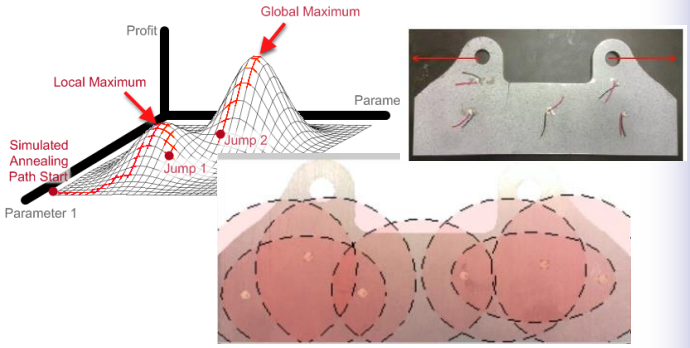
Nonlinear ROM for Aeroelastic Analysis



Turbine Blade Shape Optimization

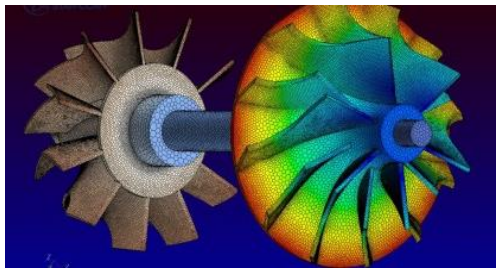


Optimizing Network for Energy Equivalence



Optimization of Sensor Placement for Crack Detection

Applications



Materials and Structures

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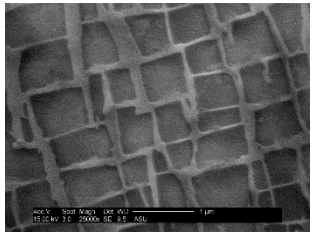
Metals

Superalloy

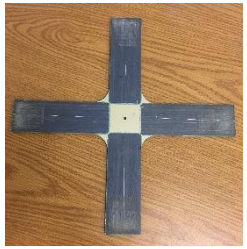
- High temperature, jet engine applications
- Single crystal and polycrystalline superalloys



Rene N5 Single Crystal Microstructure

Hybrid Laminates

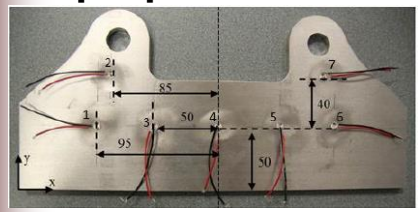
- Investigating multiaxial fatigue properties of Alcoa's GLARE hybrid laminate



GLARE cruciform

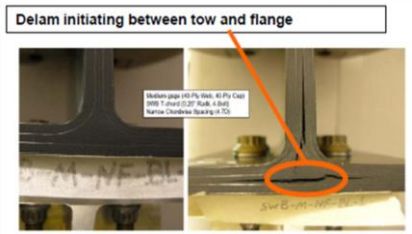
Aluminum 6061

- Aerospace grade alloy
- Investigating multiaxial fatigue properties



Aluminum lug joint instrumented with PZT sensors

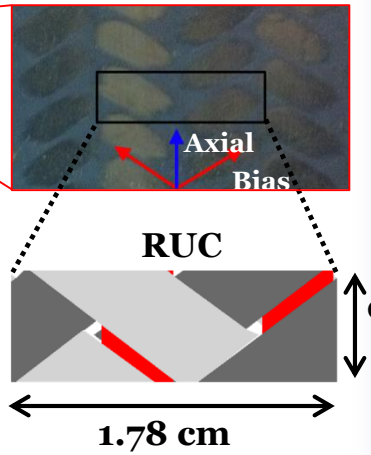
Composite T-Joint



Advanced Composites

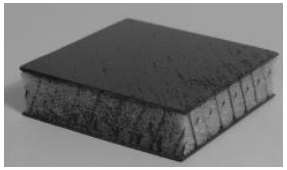
Braided Composites

Jet engine fan blade containment system



- Modeling triaxially braided PMCs subjected to ballistic impact loading
- Large mesoscale RUC complicates modeling

Foam Core Composites



X-COR

Pultruded Z-pins

- Damage detection and quantification
- Wave based SHM difficult due to complex wave propagation, dispersion, and dissipation

Multiscale Modeling - Composites

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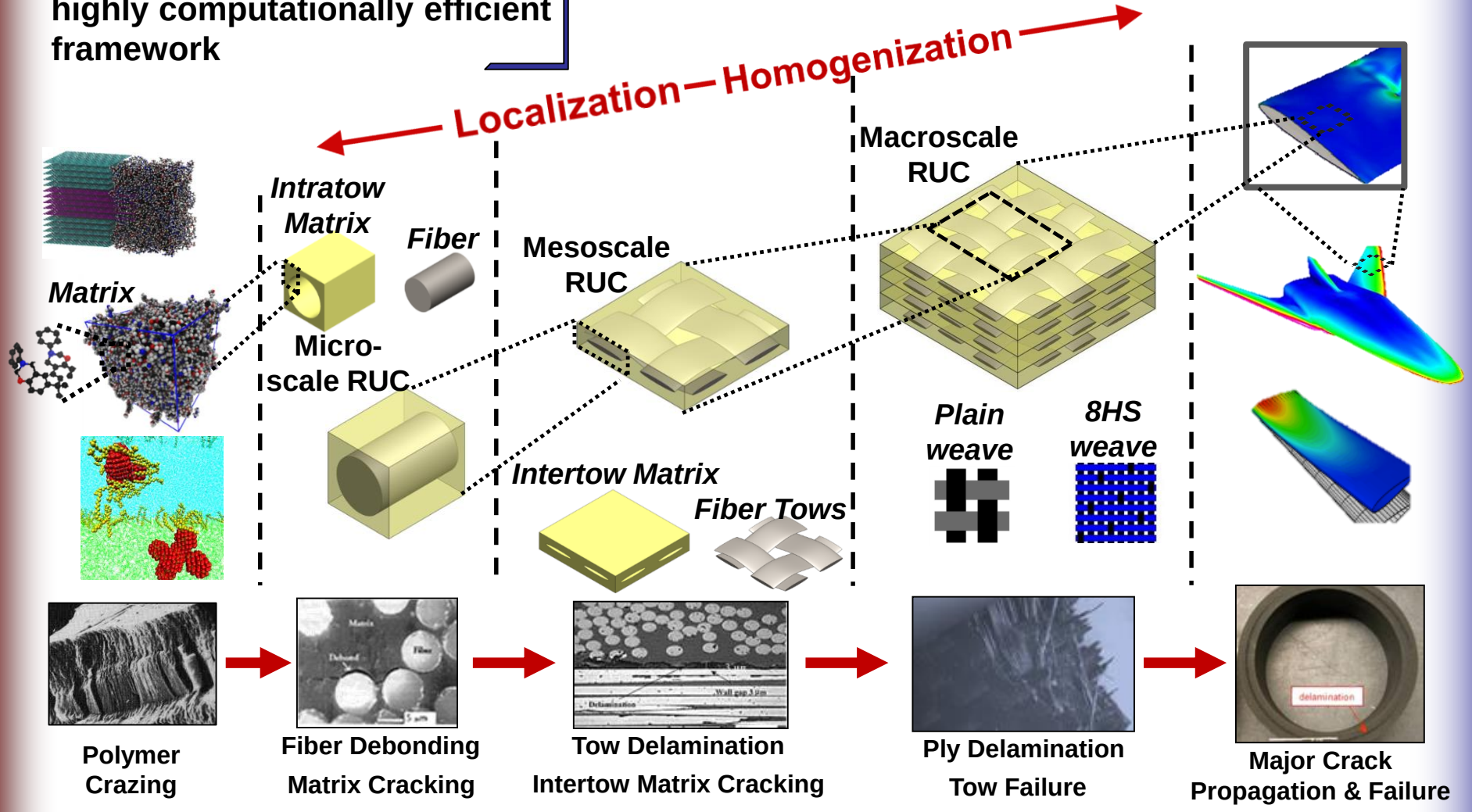
Allows for concurrent analysis of complex composites in a highly computationally efficient framework



Multiscale Modeling - Metals

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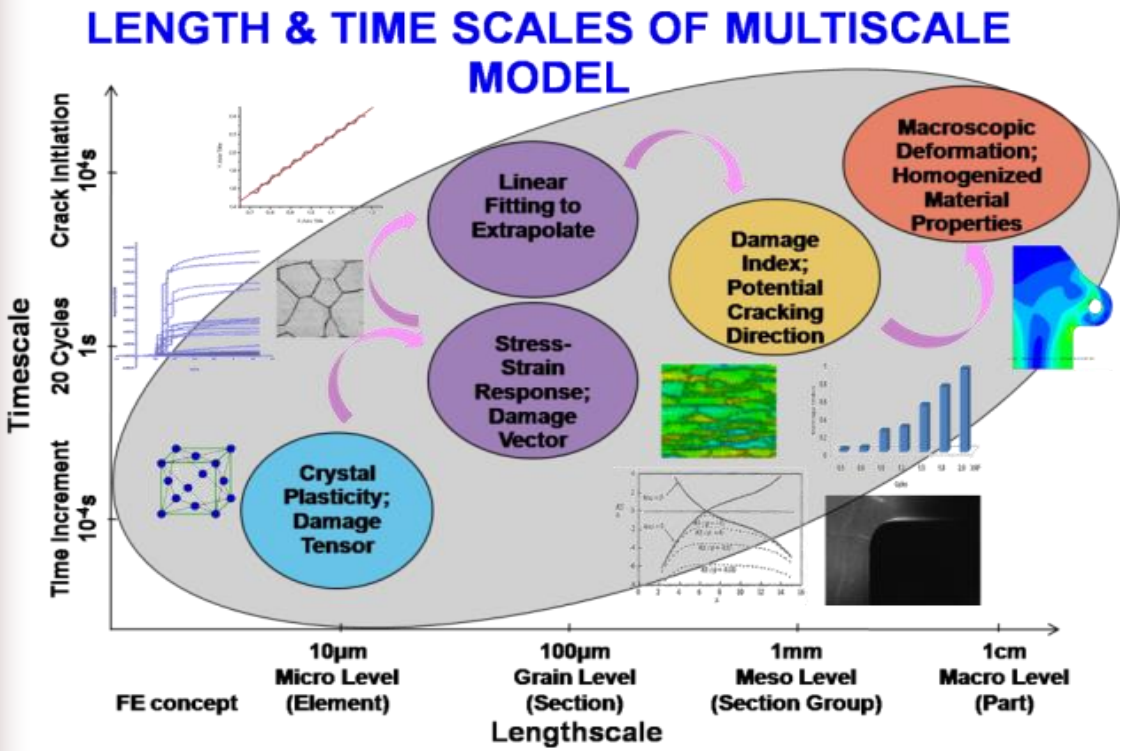
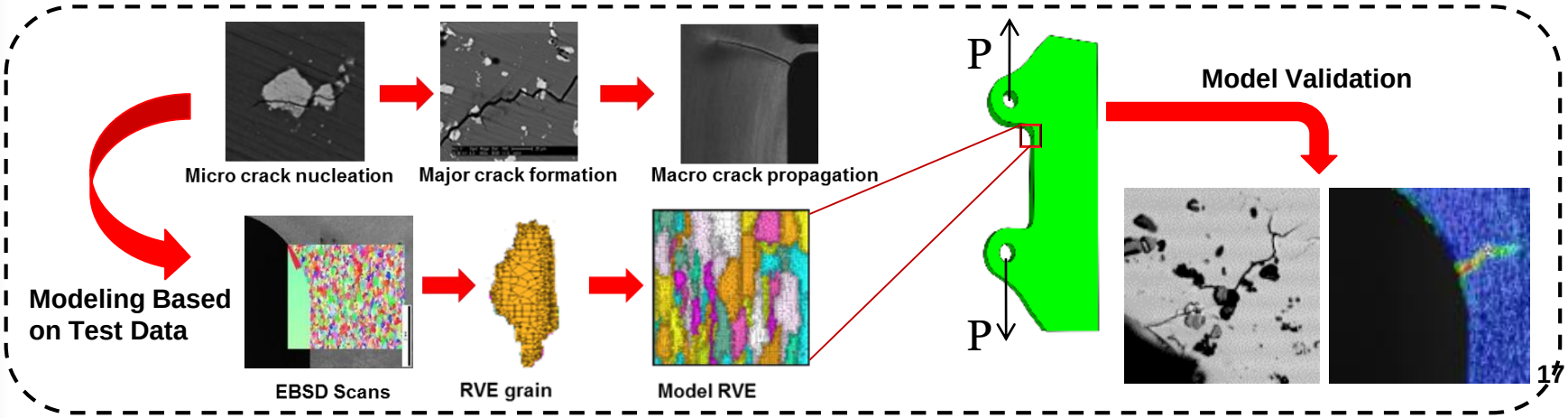


- Multiscale fatigue damage criterion for metals and alloys
- Verified under multiaxial loading
- Materials of interest:
  - Al 7075
  - Al 2024
  - Nickel based super alloys



Fatigue & Fracture of Metallic Materials

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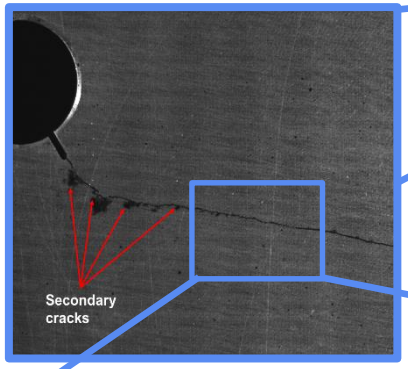
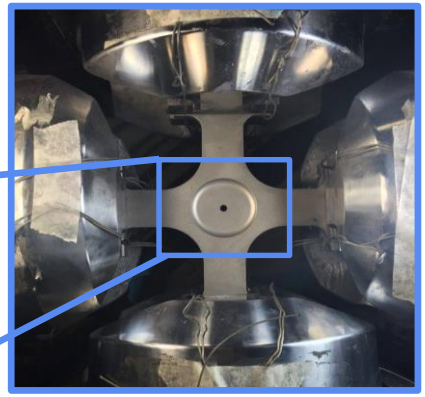
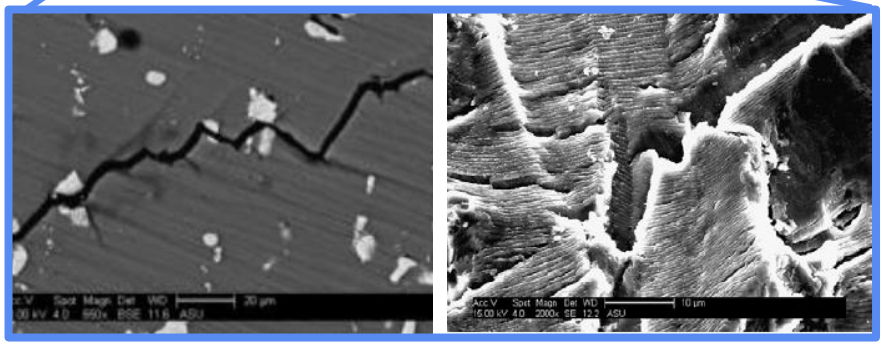
Fatigue under complex loading

Fatigue crack growth analysis





Multiaxial fatigue setup



Failure analysis and fractography

- Various complex multiaxial loading conditions under investigation
- Variable amplitude loading
- Proportional/non-proportional loading
- In/out-of-phase loading

Relating fatigue damage to microstructural characteristics

Fatigue & Fracture of Composite Materials

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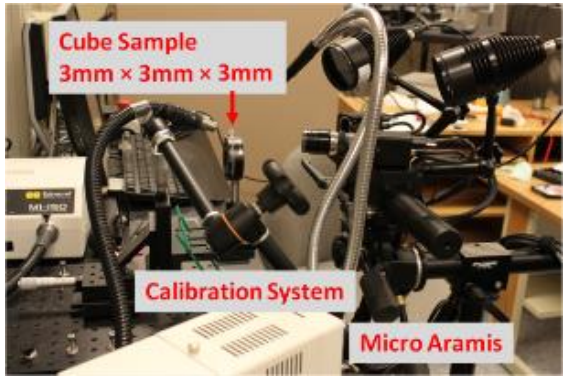
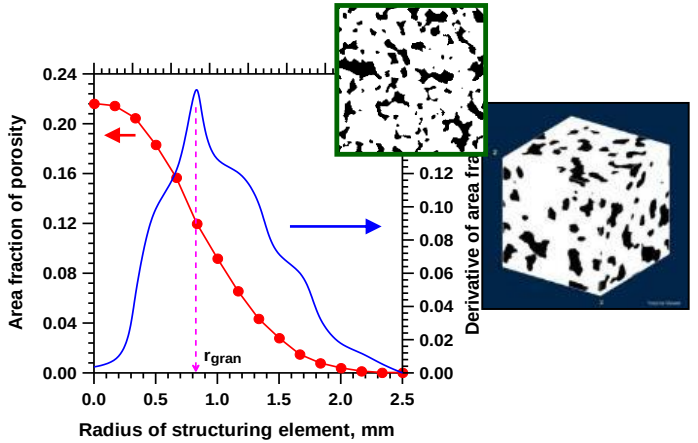
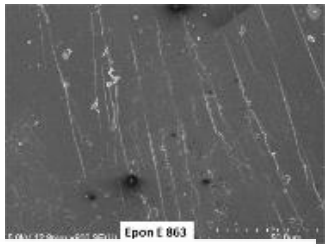
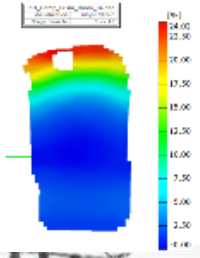
Experimental approach to understand polymer behavior at different time & length scales

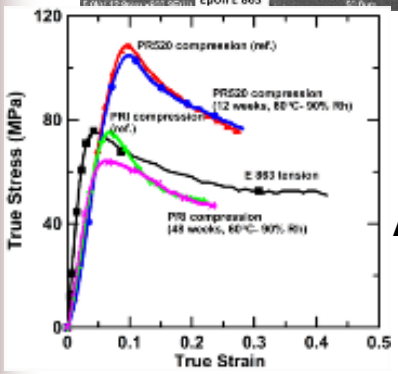


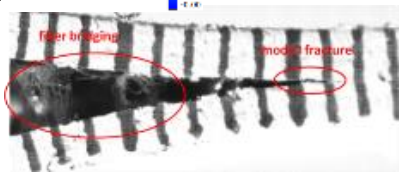


Fundamental characterization and reconstruction of porous media microstructure

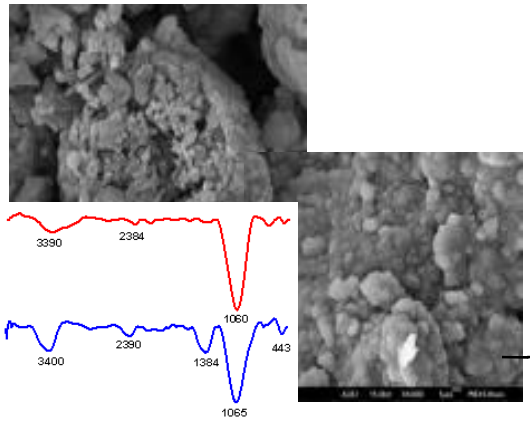




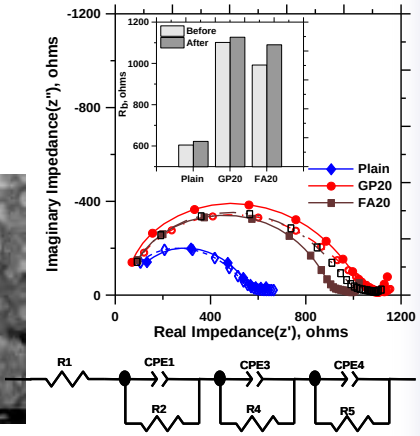




Analysis of different fracture modes



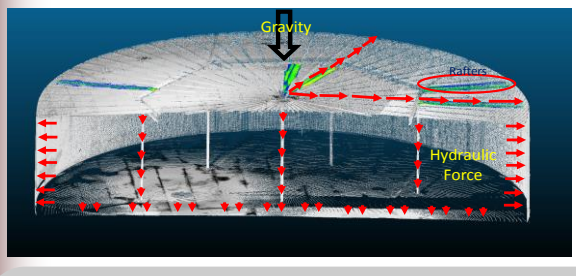
Structure and signature of cement-less binder systems

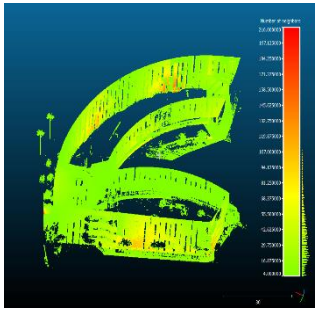


Electrical impedance based material behavior prediction

Automation in Civil Infrastructure Construction and Maintenance

PI: Pingbo Tang, Del E. School of Construction



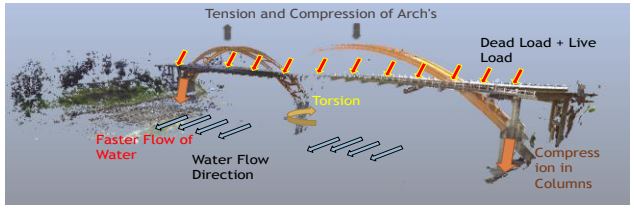


Rapid 3D imagery data collection for reliable condition assessments of bridges, canals, water tanks, and complex buildings

(Source: photo adapted from Wikipedia)

(Source: photo adapted from book "Radiation Protection at Light Water Reactors")

Real-time outage control of nuclear power plants for preventing accidents and delays of power plant maintenance



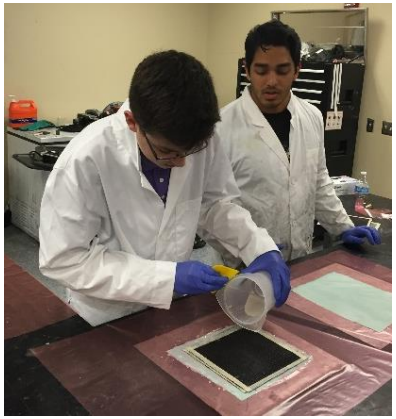
Rapid 3D imagery data collection for reliable condition assessments of bridges, canals, water tanks, and complex buildings

AIMS Center Outreach

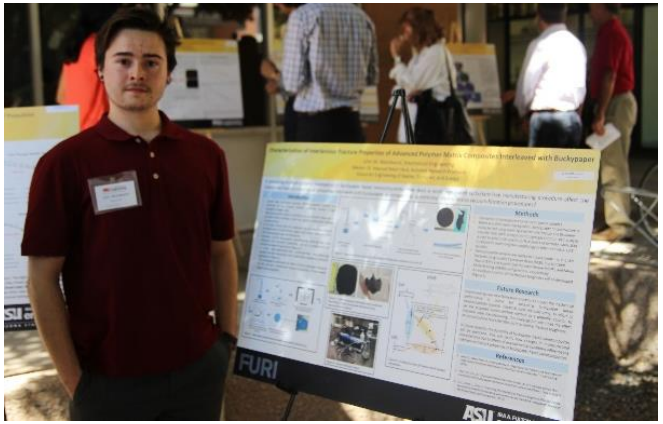
From grade school to college, the AIMS Center provides students with real-world experience through internships, hands-on exhibits and fellowships.

Undergraduate students at SPIE conference, 2016

DiscoverE day



High School Outreach



FURI 2016

AIMS Center Outreach (Contd.)

From grade school to college, the AIMS Center provides students with real-world experience through internships, hands-on exhibits and fellowships.

URAP 2014

URAP 2016

Night of the Open Door

AIMS Center Consortium Members

- **Alcoa (2011 – present)**
- **Boeing (2014 – present)**
- **Intel (2016 - present)**
- **Raytheon (2017)**
- **Aerojet Rocketdyne (2011 – 2015)**
- **Advatech Pacific (2011 – 2014)**
- **Honeywell (2012 – 2013)**

Consortium Core Projects

Projects:

- **Biaxial Testing of Advanced Hybrid Fiber Metal Laminate and Monolithic Materials, *Alcoa***
- **Damage Detection in Advanced Foam Core Composites using NDE and SHM, *Boeing***
- **Multiscale Modeling of Ceramic Matrix Composites, *Aerojet Rocketdyne***
- **Modeling of Adhesively Bonded Joints in Composite Laminates, *Honeywell***
- **Validation and Testing of Bolted Joints and Sandwich Panel Repair Analysis Tools, *Advatech Pacific***
- **Damage Detection in Electronic Packaging Materials, *Intel***
- **Prognosis Health Management, *Raytheon***

Damage Detection in Advanced Foam Core Composites using NDE and SHM

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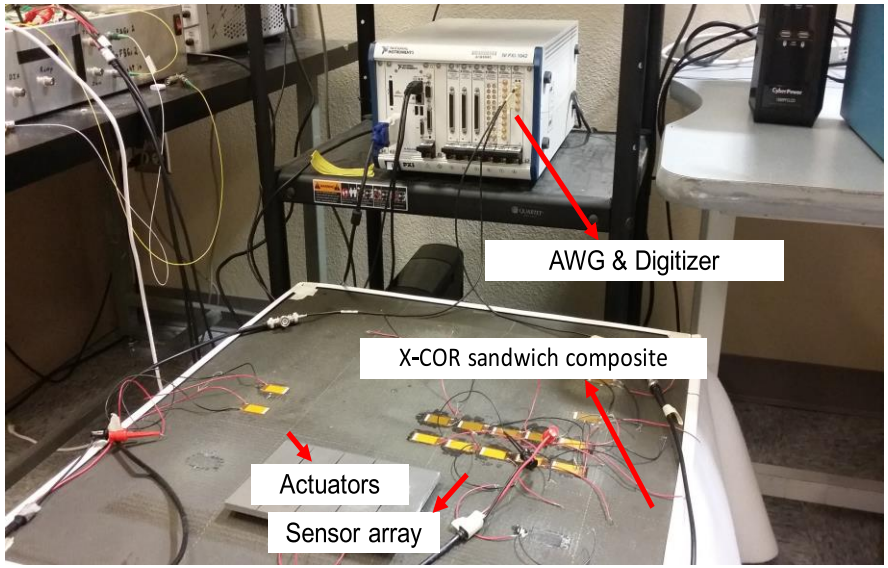
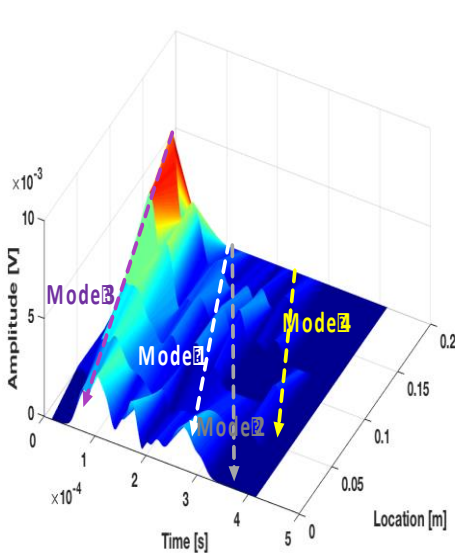
Objectives:

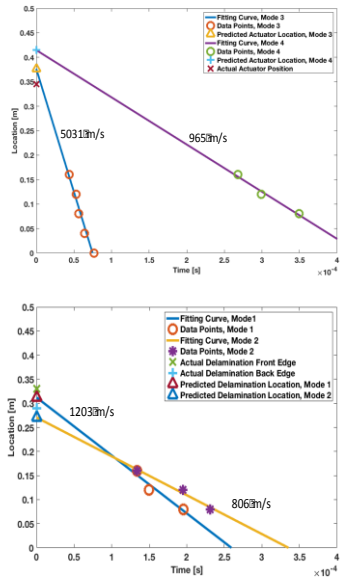
- Detect, localize, & quantify damage in X-COR sandwich composite structures
- Calibrate parameters & test capabilities of NDE & SHM techniques using multiple types & locations of damage
- Implement SHM system to provide in-situ real-time damage detection & localization capabilities

Outcomes:

- NDE (flash thermography & ultrasonic C-Scan) results of damage localization and quantification for multiple damage types (delamination & foam core separation)
- In-situ guided wave based SHM framework to detect and localized delaminations and foam core separations







Biaxial Testing of Advanced Hybrid Fiber Metal Laminate and Monolithic Materials

AIMS
ADAPTIVE INTELLIGENT MATERIALS & SYSTEMS CENTER

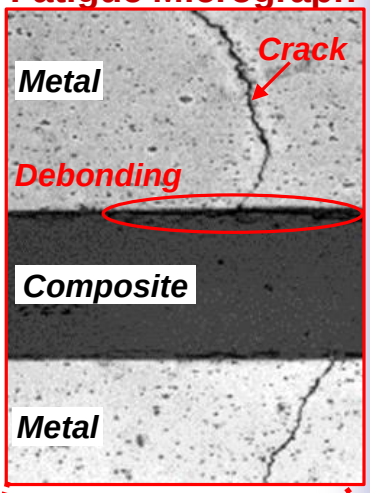
Objectives:

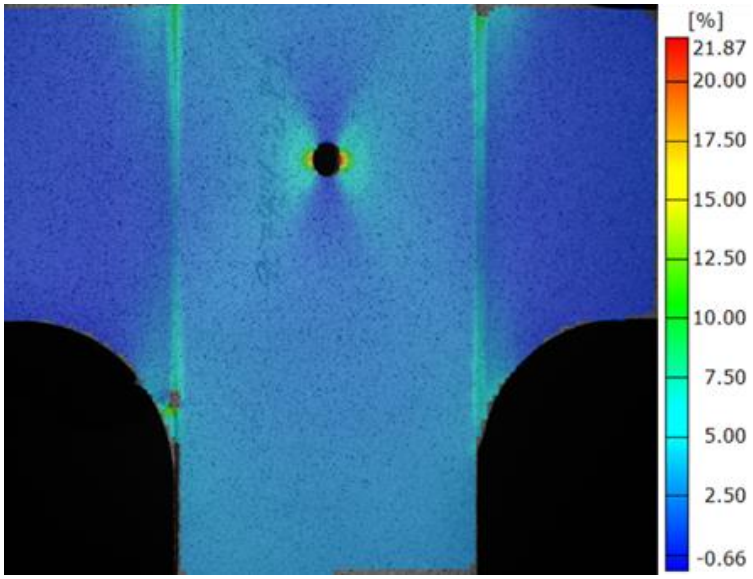
- Fatigue and static biaxial performance of various advanced hybrid fiber metal laminate concepts for next generation aero-structures
- Characterize fatigue and static behavior with biaxial loading

Key Issues:

- Biaxial cruciform design for hybrid and monolithic specimens
- Tracking crack growth and failure progression during testing

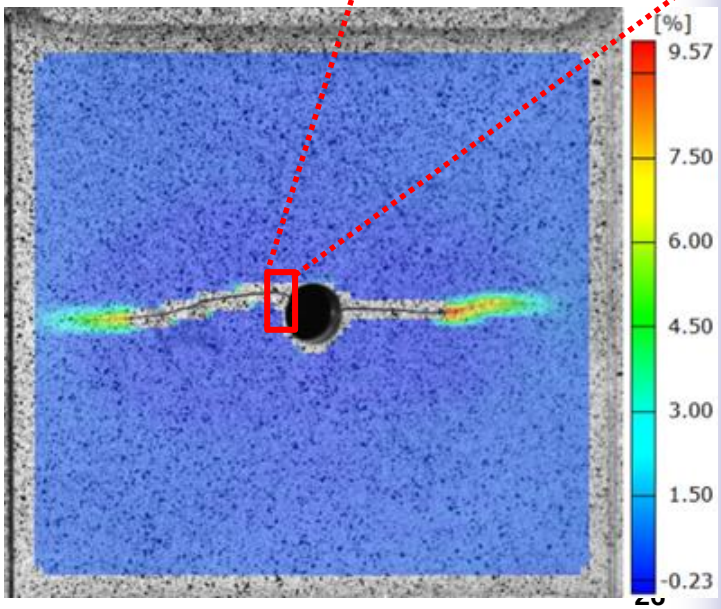
Fatigue Micrograph





GLARE Strap – Static

Major Strain DIC Contours



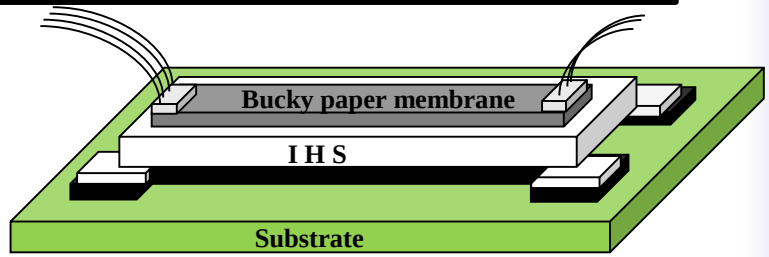
GLARE Strap – Fatigue

In-Situ Sensing of Interface Delamination in Complex Laminates

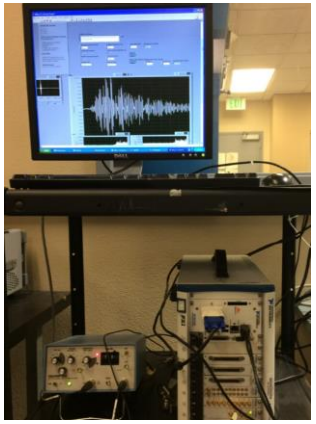
AIMS
ADAPTIVE INTELLIGENT MATERIALS & SYSTEMS CENTER

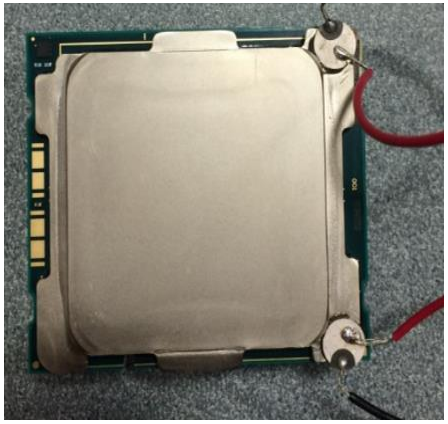
- Pre-existing damage detection using guided waves
- Stress sensitive CNT & CNF multifunctional membrane
- In-situ sensing of delamination precursors
- Magnetostrictive materials

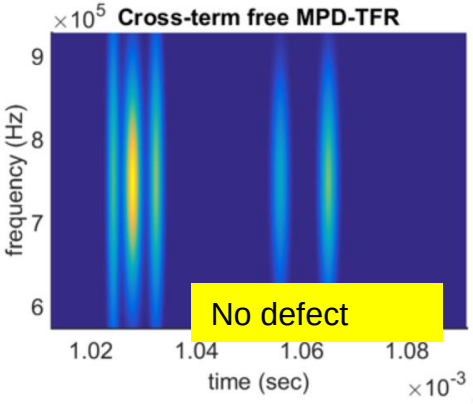
- PZT actuators/sensors
- Ultrasonic transducers
- CNT Buckypaper
- Time frequency analysis



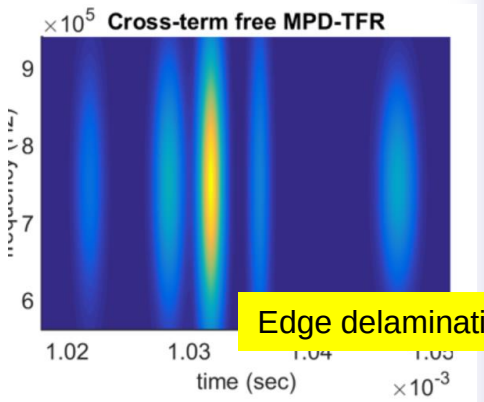
Bucky paper multifunctional membrane



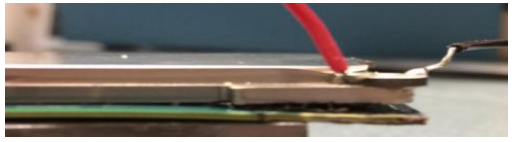




No defect



Edge delamination



AIMS Consortium Membership

- Membership fee: $30k annually
- Reduced facilities & administration costs: 10% instead of 67.7%
- Allocated graduate student(s) to work on Consortium projects
- Access to secure web site with research data, presentation and reports
- Participation in semi-annual research reviews and workshops
- Allocated seat in the consortium industrial advisory board
- Authorized to recommend and vote on research projects
- Involved directly with center faculty
- Granted access to the university's partner fee for AIMS Service Center members
  - Access to laboratory and equipment such as the unique MTS Biaxial/Torsion load frame
  - Much lower equipment usage fee than that charged to external users (non consortium members)
- Intellectual property agreement: licenses for inventions and copyrightable materials

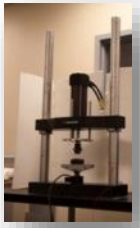
Intellectual Property Agreement

- Title to inventions jointly developed by both university and member inventors vest in both institutions.
- Members can be granted non-exclusive, royalty-free licenses to patents on inventions arising out of Consortium research.
- Options to negotiate revenue-bearing non-exclusive licenses with the right to sublicense and exclusive licenses.
- Members can be granted irrevocable, non-exclusive, royalty-free licenses to copyrightable materials, including the right to sublicense to affiliates.
- Options to negotiate revenue-bearing non-exclusive licenses with the right to sublicense to others.
- University reserves the right to publish in scientific journals, but members have the right to review any paper and delay publication to remove or approve member owned confidential information.

AIMS Service Center

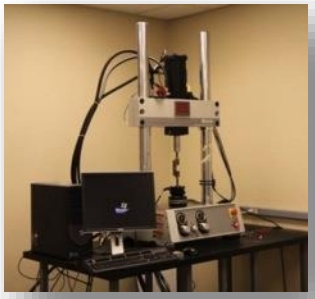
- State of the art experimental facilities available in the AIMS faculty laboratories
  - Mechanical Testing
    - Dynamic, static, multiaxial, thermomechanical, ultrasonic fatigue, noncontact measurement
  - Material Fabrication
    - Composite ovens, hot press, carbon nanotube, nanoparticle
  - Nondestructive Evaluation (NDE) & Structural Health Monitoring (SHM)
    - Ultrasonic, acoustic, laser based, piezoelectric, FBG
  - Material Characterization
    - Multiphoton imaging, viscosity and viscoelasticity, thermal analysis, confocal microscopy
- Reasonably priced relative to industry costs
- Website: http://sharedresources.asu.edu/facilities/83
- Contact: Dr. John Rajadas (rajadas@asu.edu) & Ashwin Rai (Ashwin.Rai@asu.edu)

Mechanical Testing



TRI T1000 Fatigue Frame

- 1000 lb, 30 Hz capacity
- Primary use: Small specimens, such as polymers



MTS Bionix Frame

- 5000 lb, 50 Hz capacity
- Primary use: Metallic & composite testing

Instron 5985 Frame with Thermal Chamber

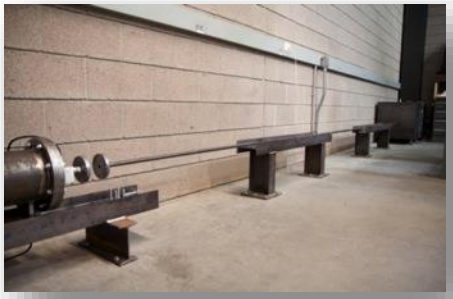
- 60000 lb capacity
- 70°C to 250°C temperature range
- Primary use: Composites & thermal testing

Trilion 3D Aramis

- Full field strain measurements
- Dual system for front/back measurements
- Microaramis for <3 mm samples

Low Speed Impactor

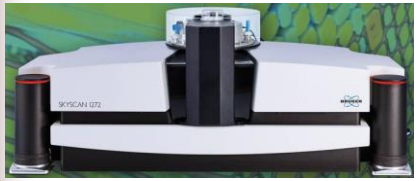
- Inverted pendulum
- 100 J capacity
- Load cell
- Rotary encoder



High Speed Gas Gun

- Up to 400 m/s
- 1/2” diameter projectile
- Large target area

NDE & SHM



SkyScan 1272 Micro-CT

- Nondestructive 3D microscopy
- World's first micro-CT with over 200 Megapixels in a single cross section

C-scan AS400A/HR

- 40-200 kHz air-coupled transducers
- Can handle thick specimens (8"+)

Physical Acoustics AE

- Up to 2 MHz broadband sensors
- 8 channels
- High temperature sensors

Ultrasonic Probe

- High frequency mechanical excitation
- Crack detection in metals

EchoTherm Flash Thermography

- Delamination, disbond, & void detection in composites

FBG Interrogator

- Dual channel interrogator up to 19 kHz
- 16 gratings/channel

Laser Vibrometer

- Scanning head
- 80 kHz capacity
- Piezoelectric actuator
- Shaker actuator

Impedance Analyzer

- High frequency broadband (100Mhz)
- BNC Probe for sensor health

NI PXI Chassis DAQs

- Arbitrary waveform generators
- High speed digitizers
- Multiplexer

Material Fabrication and Preparation

Tetrahedron Hot Press

- Fabrication of composite panels
- 15” x 15” section
- 350°C, 40 tons force capacity
- Programmable cycle

Laboratory Oven

- 300°C capacity
- Gas purge capability
- Access ports

Isotemp Oven

- Vacuum & purge ports
- Controllable vacuum / temperature
- 200°C capacity

Temperature / Humidity Chamber

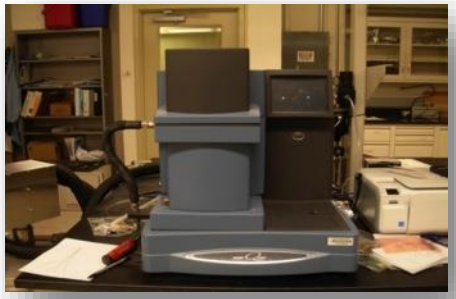
- 3 ft^3 volume
- 0-98% RH
- 65 to 200°F
- Programmable cycle

Ultrasonic Cell Disruptor

- Primary use: nanocomposite fabrication

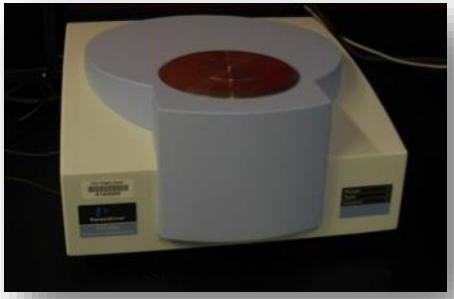
Material Characterization

AIMS
ADAPTIVE INTELLIGENT MATERIALS & SYSTEMS CENTER



Dynamic Mechanical Analyzer

TCS SP5 MicroscopeSystem

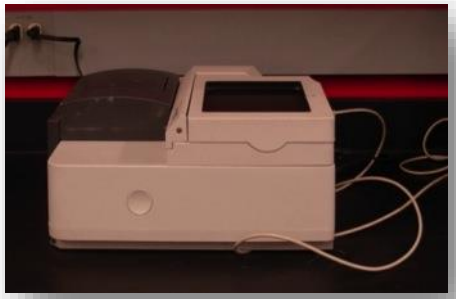


Simultaneous Thermal Analyzer

Rheometer

Ultrasonic Cell Disruptor

Isothermal Calorimeter



Fourier Transform Infrared Spectrometer

Microscopy Preparation & Analysis

Ultrasonic Cleaner

- Cleaning microscopy samples
- Timed cleaning

Zeiss LSM 700

- Confocal & optical microscopy
- Two channel laser
- Fluorescent capability

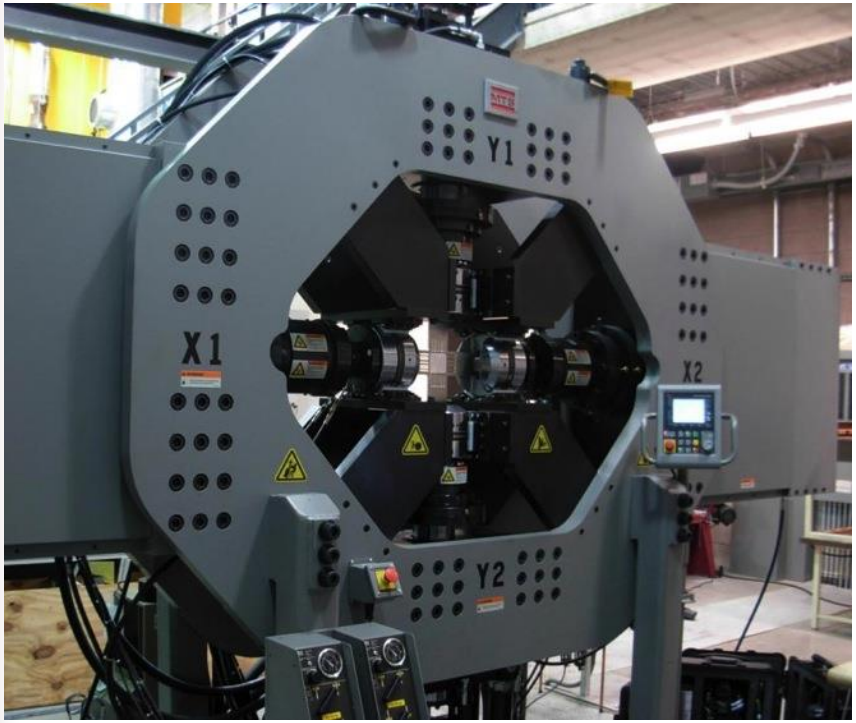
Struers LaboPol 5

- Grinding & polishing
- 50-500 rpm
- Force & fluid control

Allied Saw

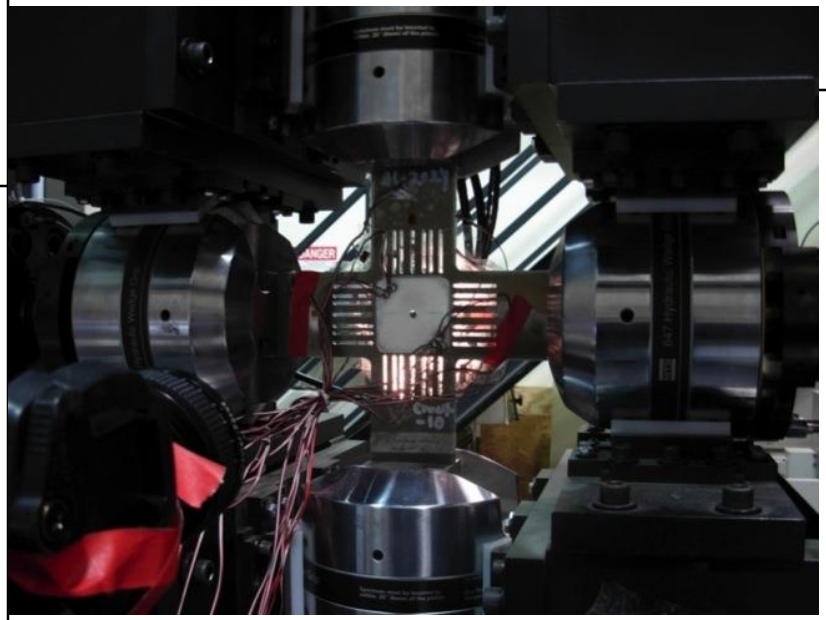
- Low speed diamond saw
- 10-500 rpm
- Micrometer sample indexing

Biaxial/Torsion Fatigue Testing



Features

- 100 kN planar biaxial
- 10 k in-lbf (1100 N-m) torsion
- 6 independent precision controlled actuators
- Biaxial fatigue with varied non-proportional loading ratio
- Added torsional capability allows multiaxial tension/torsion cyclic tests



Applications

- 2D stress state static testing
- Planar tension/comp. cycle
- Planar tension/shear cycle
- Tension/torsion cycle
- Advanced composites
- Aerospace materials

Thermomechanical Fatigue Testing

Instron 8801

Lasur Ultrasonic Frame

Ultra High Cycle Fatigue System

- High cycling frequency of 20 kHz
- Superimposed static & cyclic loadings
- Combined with a 100 kN fatigue frame & in-situ thermal chamber (up to 250 C)
- Applications: advance material with fatigue life of 10^6 to 10^9 cycles

Instron E3000 Thermomechanical Frame

- Applications: polymer & multifunctional materials
- Dynamic load range of 30 N to 3 kN
- Temperature range from -100 to 350 ° C

Contact Information

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We invite you to join the AIMS Center
You can make an impact on research & curriculum!

AIMS Website:

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