Multiscale Analysis, Detection & Prognosis

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Research Team
Damage Precursor Detection in Polymer Matrix Composites Using Novel Smart Composite Particles

PI: Aditi Chattopadhyay, Co-PI: Dr. Lenore Dai

Sponsor: Air Force Office of Scientific Research
- Program Manager: Dr. David Stargel

Objectives:
- Develop hybrid and multifunctional smart composite particles
- Exploit stress sensitive properties such as color and conductivity changes to provide information on damage precursor and propagation
- Integrate particle synthesis, characterization, sensing/monitoring in polymer matrix composites (PMCs)
Key Issues:

- Multiscale modeling from atomistic to structure level
  - Extraction of mechanical properties from Molecular Dynamics (MD) simulation
  - Simulation of epoxy network considering realistic curing process
  - Simulation of interfacial effect between smart particles & polymer matrix
  - Simulation of interfacial effect between carbon fiber & polymer matrix
  - Transfer of relevant information across length scales

- Synthesis of smart particles/ spheres & integration within structural composites
A Stochastic Approach to Structural Health Monitoring of Advanced Composites

PI: Aditi Chattopadhyay

Sponsor: U.S. Army Research Office

- Program Manager: Dr. Larry Russell

Objectives:

- Derive a fundamental understanding of physical phenomena unique to multiple damage modes & failure mechanisms in composites
- Study effects of uncertainties (geometry, material, loading effects, solution noise) & their propagation across length scales
- Integrate multiscale mode with data-driven detection techniques

Outcomes:

- Characterization and Effect of Microstructure Uncertainty
- Probabilistic Simulation of Damage Onset and Propagation
- Active Wave Based Damage Detection Scheme, and Advanced Data Mining and Classification Techniques
- Probability of False Alarm, Probability of Detection, Damage Size Confidence Interval
- Multivariate Risk Assessment and Prognosis Model
Stochastic Modeling and Experimental Validation

Challenges:

- Impact of stochastic nature of composites on modeling
- Effects of Microstructure on uncertainty in life prediction
- Capture damage initiation & evolution under complex thermo-mechanical loading conditions

Solutions:

- Use Latin Hypercube sampling in Monte Carlo simulations
- Compare to classical Monte Carlo based on completely random sampling
- Multiscale model of woven CMC for inelastic behavior & damage simulation
- Accurately predict as-produced damage state in woven CMC

\[ T = 1023\, ^\circ C \quad \text{versus} \quad T = 23\, ^\circ C \]

Latin Hypercube
Characterization and Testing of Biaxial and Triaxial Braided Composites for Fan Containment Structures in Turbofan Engines

Sponsor: Honeywell Aerospace
Project Manager: Alex Guerinot

Objectives:
- Analysis (thermal and mechanical) of the adhesively bonded load paths in engine fan containment structures
- Hygrothermal/mechanical testing of resin transfer molded triaxially braided composites and polymer matrix coupons
- Thermal/mechanical testing of adhesively bonded joints

Key Issues:
- Environmental aging effects of polymer matrix material and composite samples
- Novel test methods and specimens for characterization of composites and polymer material
- Failure surfaces from multiaxial cruciform specimens
- Couple experimental results with multiscale modeling theory
Characterization, Testing and Validation of Braided Composite Systems

Challenges:
- Material is globally orthotropic & locally anisotropic
- Multiple damage mechanisms vary with load direction
- High dependence on material coordinates leads to complicated specimen design

Solutions and Testing:
- Material characterization & validation using NDE
- 3D full strain field measurement
- Environmental aging & testing

<table>
<thead>
<tr>
<th>Modulus (GPa)</th>
<th>Room</th>
<th>Hot/Dry</th>
<th>Hot/Wet</th>
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<tr>
<td>Transverse Tension</td>
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Multi-Level Adaptive Remote Sensing Package for Bridge Scour Health Management

PI: Aditi Chattopadhyay, Co-PIs: Masoud Yekani Fard, Sandeep Gupta, Georgios Varsamopolous & Thanos Papanicolaou

Sponsor: US DOT, Research and Innovative Technology Administration (RITA)
- Program Manager: Mr. Caesar Singh

Objectives:
- Integrate & apply CRS&SI technologies for data collection
- Condition monitoring & autonomous data processing to identify scour distress
- Reduce/supplement current visual inspection

RFID sensing

Detection & prognosis

Decision support system
Multi-Level Adaptive Remote Sensing Package for Bridge Scour Health Management

Key Issues:

- Differentiating clear-water & live-bed scour
- Capturing the refilling of sediment during live-bed scour
- Predicting the time-depending scour under clear-water & live-bed conditions
- Developing a generalized framework for use by any DOT / agency
- Conducting field tests in Arizona & Iowa to study scour evolution
- Developing an interface for data communication between base station & the connecting nodes

Laboratory data
Melville et al. 1999

Field data
Mueller et al. 2005

Predictions with field data
EAGER: Smart Particles for Investigating Damage Initiation in Polymer Composites

PI: Aditi Chattopadhyay, Co-PI: Dr. Lenore Dai

Sponsor: National Science Foundation

- Program Manager: Dr. Grace Hsuan

Objectives:

- Establish relationship between structural properties & multifunctional particles
- Identify nanoparticle-matrix interactions & detection capabilities of damage precursor
- Validate environmental responsiveness & multifunctionality in composite particles
- Investigate impact on structural composites
Self-sensing Adhesive for Monitoring Composite Bonded Joints

PI: Aditi Chattopadhyay

Sponsor: NAVAIR

- Program Manager: Dr. Nam Phan

Objectives:

- Develop self-sensing capabilities in composite adhesive joints using single-walled and multi-walled CNTs.
- Investigate sensing performance under complex loading conditions, such as impact and fatigue.
- Study the effects of local agglomeration on the self-sensing capability.
- Validate the use of CNT integrated self-sensing epoxy in complex joints (such as stiffened structures).

Key Issues:

- Uniform dispersion of CNTs in epoxy
- Novel test methods and specimens for characterization of composites
- Validation of developed self-sensing system under multiple loading conditions
Viscoelastic & Fracture Behavior of Polymer Matrix Composite Laminates for Pipe Coatings, Repair & Rehabilitation of Structures

PI: Masoud Yekani Fard, Co-PI: Aditi Chattopadhyay

Sponsor: Pipe Reconstruction Inc. (PRI)

Objectives:

- Characterization of stitch-bonded biaxial polymer matrix composites
- Understanding damage initiation & evolution under different load cases & environmental conditions
- Develop design guidelines for short-term & long-term mechanical behavior

- Epoxy resin testing
- Advanced measurement technique
- Fracture study

120” steel pipe, external wrap
Courtesy to PRI
Fatigue, Modes of Fracture & Durability of Advanced Polymer Matrix Composite Materials

PI: Masoud Yekani Fard, Co-PI: Aditi Chattopadhyay

Sponsor: Pipe Reconstruction Inc. (PRI)

Key Issues:

- Fracture Modes I, II, III & mixed modes I & II crack initiation & propagation behavior including environmental effects
- Delamination criteria for mode I & II interaction for stitch-bonded composites
- Determine ‘safe load’ levels & residual strength/stiffness for biaxial fatigue including environmental effects
- Develop a micro-mechanic based FE model
- Model validation & implementation

Damage evolution mechanism

Smooth/non-smooth crack propagation

Damage detection
Consortium Projects
Validation Testing for Bolted Joint & Sandwich Panel Repair Analysis Tools

PI: Aditi Chattopadhyay
Graduate Student: Scott Leemans

Sponsor: Advatech Pacific

Objectives:
- Multi-Modal Data Acquisition Strategy for Progressive Failure Analysis
- Calibration, Validation, and Uncertainty Quantification of Analysis Models

Key Tasks:
- Designing biaxial (& other) test specimens for both projects
- Developing multi-modal data acquisition methodology to track degradation, damage and failure progression during testing
Validation Testing for Bolted Joint & Sandwich Panel Repair Analysis Tools

Challenges:
- Digital signals processing and synergistic combination of modalities
- Generating desired degradation, damage, & failure modes in tests

Solutions:
- Develop solid mechanics thermodynamic representation of each type of specimen

Analysis & Test:
Modeling of Adhesively Bonded Joints in Composite Laminate

PI: Aditi Chattopadhyay
Graduate Student: Jinjun Zhang

Sponsor: Honeywell Aerospace and Science Foundation of Arizona

Objectives:
- Evaluating available data and resources that can be applied to solving the project, includes surveying literature, manufacturer’s data and HON data
- Development of modeling Techniques for adhesively bonded joints
- Guidelines and analysis procedures for adhesively bonded joints

Key Issues:
- Representing material property and matching mechanical response at multiscales
- Capturing multiple failure modes simultaneously and comprehensively
- High simulation efficiency and accuracy to predict damage evaluation and fatigue crack growing

Modeling of cohesive zone → Damage index formulation → Damage criterion
Biaxial Testing of Advanced Hybrid Fiber Metal Laminate and Monolithic Materials

PI: Aditi Chattopadhyay
Graduate Student: Joel Johnston

Sponsor: ALCOA

Objectives:
- Fatigue and static biaxial performance of various advanced hybrid fiber metal laminate concepts for next generation aero-structures
- Predict 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
Multiscale Modeling of Ceramic Matrix Composites

PI: Aditi Chattopadhyay
Graduate Student: Luke Borkowski

Sponsor: Pratt and Whitney Rocketdyne (PWR)

Objectives:
- Development of multiscale modeling framework to capture the response of woven C/SiC composites
- Predict behavior of C/SiC – Inconel 625 adhesively bonded joints

Key Issues:
- Modeling effects of CVI manufacturing process on material behavior
- Coefficient of thermal expansion mismatch causes micro-cracks
Questions?!