Composites Research at The National Institute of Standards and Technology

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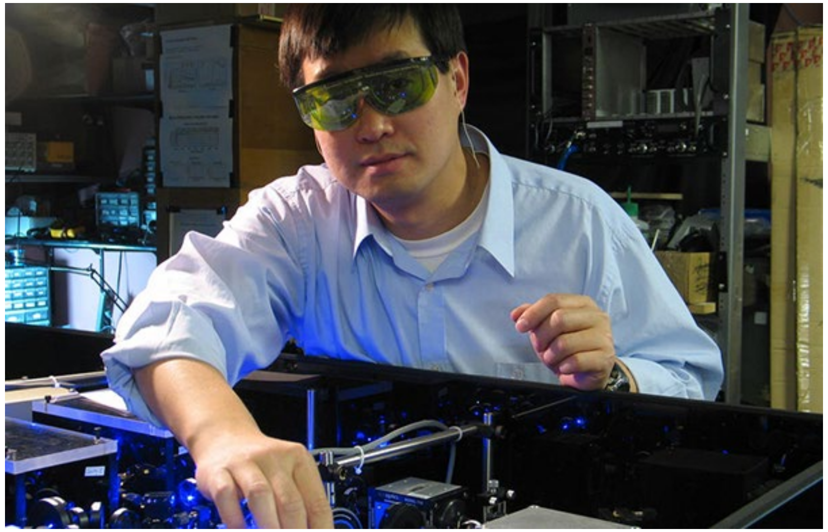
NIST Mission

To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, & technology in ways that enhance economic security and improve our quality of life

We are Industry's National Lab



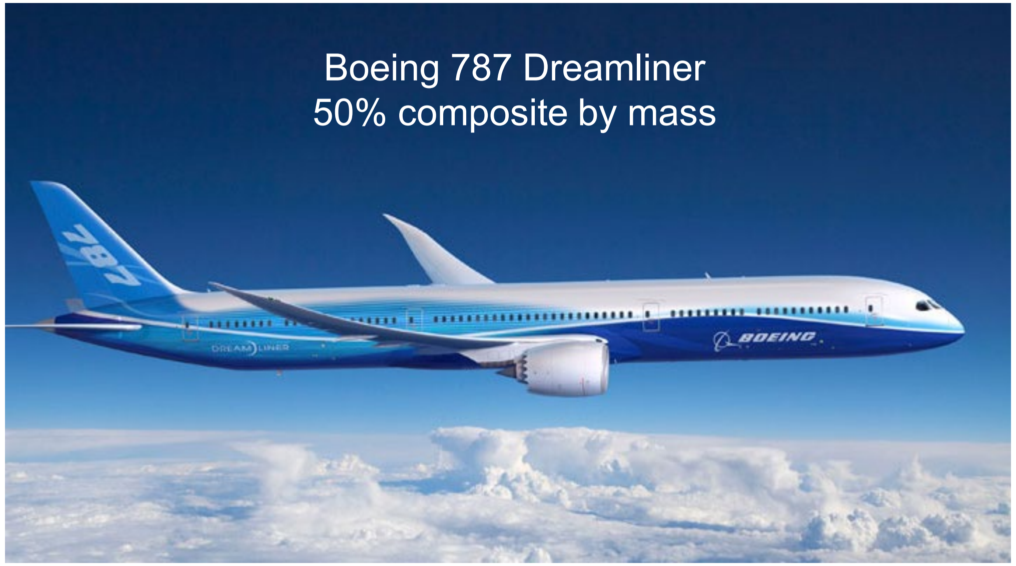
NIST's mission is to help industry with their most pressing measurement challenges!

Composites Revolutionize

few year service life

few year service life

few year service life



20 to 30 year service life

Quantitative Measurements

Materials Innovations

Manufacturing innovations

Modeling, design, & data

Testing & validation

Standards

CALIBRATED EQUIPMENT & MEASUREMENTS ARE ESSENTIAL

Boeing force measurements are traceable to the SI

NIST provides force standards for traceability

Photo Courtesy of Boeing

A Revolution is Needed

100+ year service life

Measurements
Needed

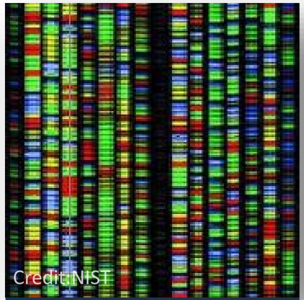
Durability Requirements

- extreme Ts
- moisture / water
- salt, pH
- UV radiation
- mechanical fatigue
- natural disasters

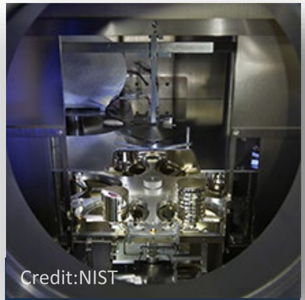
NIST can play a critical role to help develop the measurement basis to assess the durability of composites for infrastructure

NIST Laboratory Programs

Composite Activities Cross-Cut All NIST Laboratories



Material Measurement Laboratory ★

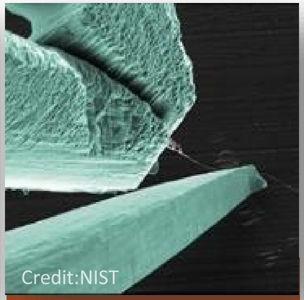


Physical Measurement Laboratory

Engineering Laboratory

Information Technology Laboratory

Communication Technology Laboratory



Center for Nanoscale Science and Technology

NIST Center for Neutron Research

metrology	technology	user facilities

★ My presentation emphasizes composites activities in our Materials Measurement Laboratory and primarily reflects low TRL (<4) measurement developments. Other parts of NIST operate in high TRL space.

Composites for Infrastructure Roadmap

NIST

NIST Special Publication 1218

ROAD MAPPING WORKSHOP REPORT ON OVERCOMING BARRIERS TO ADOPTION OF COMPOSITES IN SUSTAINABLE INFRASTRUCTURE

Richard Sheridan
Northwestern University

John P. Busel, Daniel Coughlin
American Composites Manufacturers Association

Jeffrey Gilman, Gale Holmes, James Fekete, Stephanie Watson, Jae-Hyun Kim, Aaron Forster, Ajay Krishnamurthy, Bharath Natarajan
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Robert W. Harris
National Rural Electric Cooperative Association

Jim Gutierrez
California Department of Transportation

Charles Bakis
Penn State University

Scott Holmes
Highland Composites

Robert Moser
US Army Engineer Research and Development Center

This publication is available free of charge from:
https://doi.org/10.6028/NIST.SP.1218

December 2017

AMERICAN COMPOSITES MANUFACTURERS ASSOCIATION

This February 2017 "Road Mapping Workshop" brought together **designers, engineers, manufacturers, researchers, owners and end-users** to identify barriers and potential solutions

National Institute of Standards and Technology
U.S. Department of Commerce

Composites for Infrastructure Roadmap

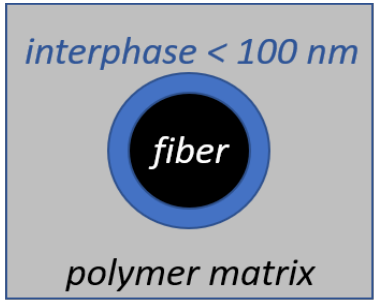
Durability Testing	Accelerated Test Data Analysis	Case Study and Correlation to Field Data	Model Prediction of 100 Year Service Life	Improved Costs and Sustainability
Design Data Clearinghouse	Guidelines Repository	Harmonize Standards	National to Global	Widespread Adoption
Education and Training	Curriculum Development	Program Certification	Apprenticeship	Trained Designers and Contractors

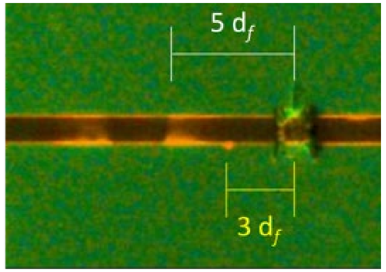
In the absence of legislation, NIST continues to make progress in two key areas at the low TRL levels, focusing on the measurement science

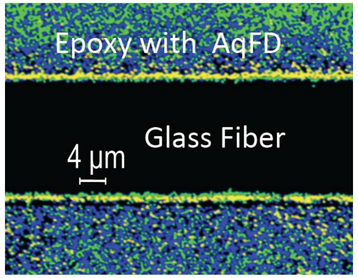
Polymer Matrix Composites

Motivation

The fiber-matrix **interphase** is critical for integrating the strength of high-performance fibers with the toughness of polymer resins into a composite material. However, the role of **interphase** in controlling the strength, toughness & durability of composites under environmental extremes is poorly understood or quantified.







Objectives

Deliver tools that quantify the **interphase** and how it affects:

- Strength, Damage, and Toughness
- Polymer Dynamics, Relaxation, and Water Transport
- Data, Modeling and Design Tools

Interphase dominates

Extremes in T

H_20, O_2, solvents, salts

Mechanical Fatigue

Customers and Partners:

Polymer Composites for Extreme Environments

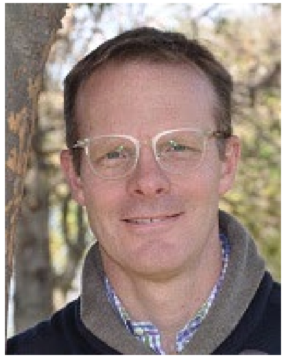
NIST's Materials Genome Initiative Center of Excellence

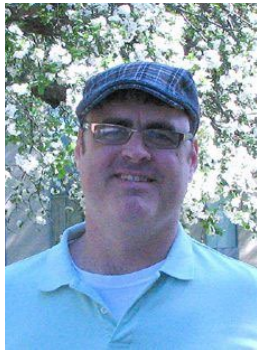

Jeff Gilman (NIST)


Sinan Keten (NU)


Ken Shull (NU)


Ange-Therese Akono (NU)


Chris Soles (NIST)


J Woodcock (NIST)


Jack Douglas (NIST)


Gale Holmes (NIST)


Douglas Fox (NIST/AU)

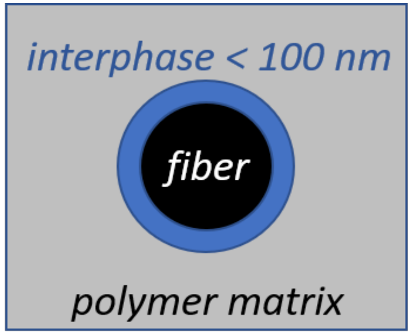

Jan Obrzut (NIST)


Fred Phelan (NIST)

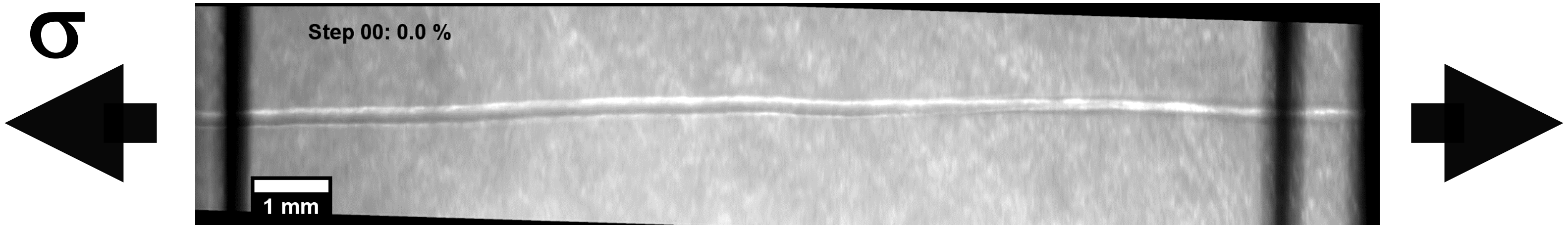
High performance aerospace composites

- T cycles from 80 to 400 K
- Low O_2 permeability
- Cryogenic toughness
- Durable interphase
- Modeling & data Sharing tools

Interfacial Shear Strength (τ_{IFFS})

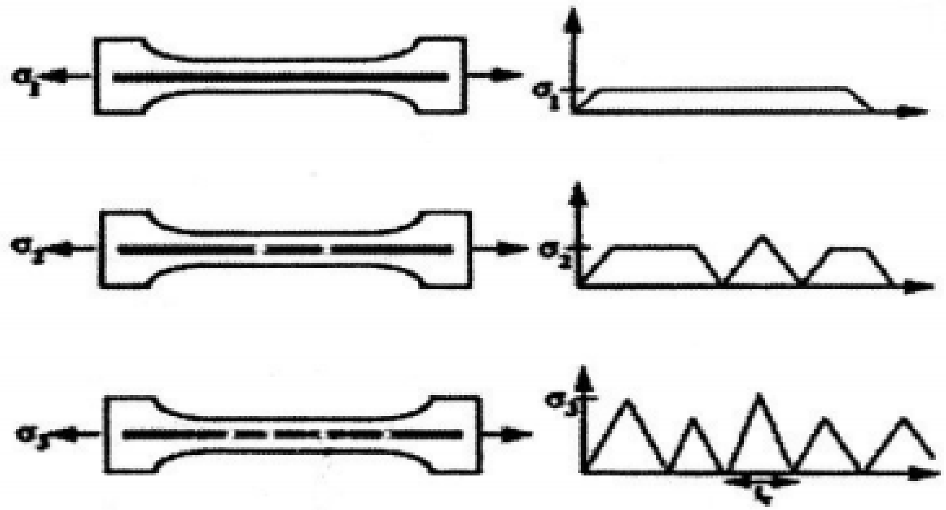


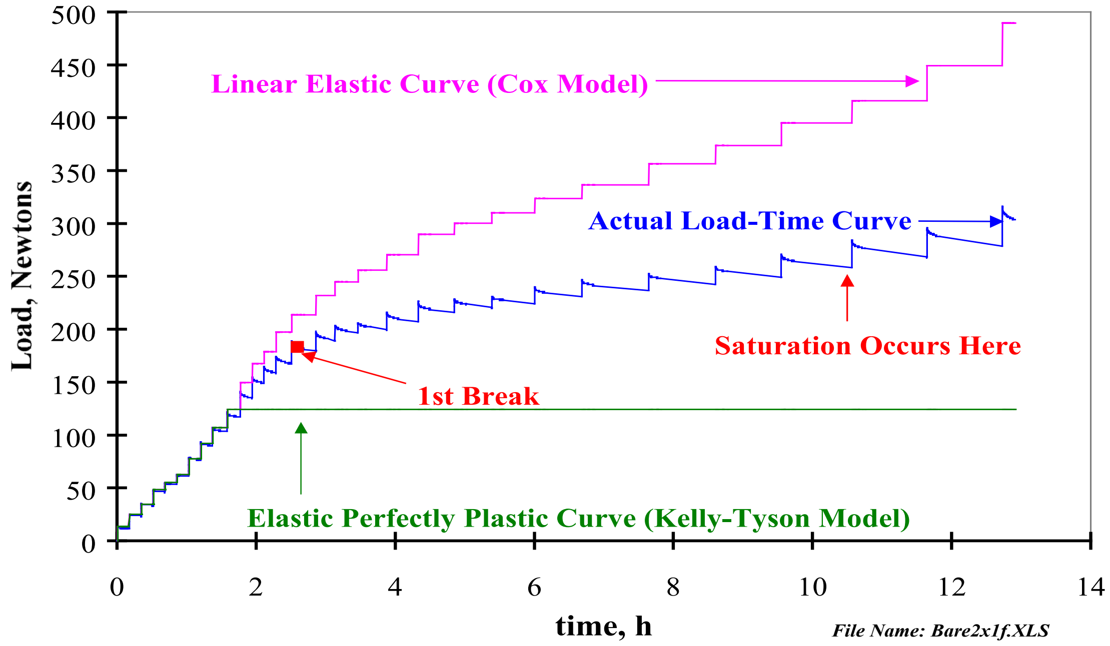
Interphase transfers load to fiber



McCarthy et al, Composites Science and Technology, 121, 73–81

$$\tau(IFSS) = f\left[\left(\frac{1}{l_c}\right)\right]\sigma_f(l_c)$$

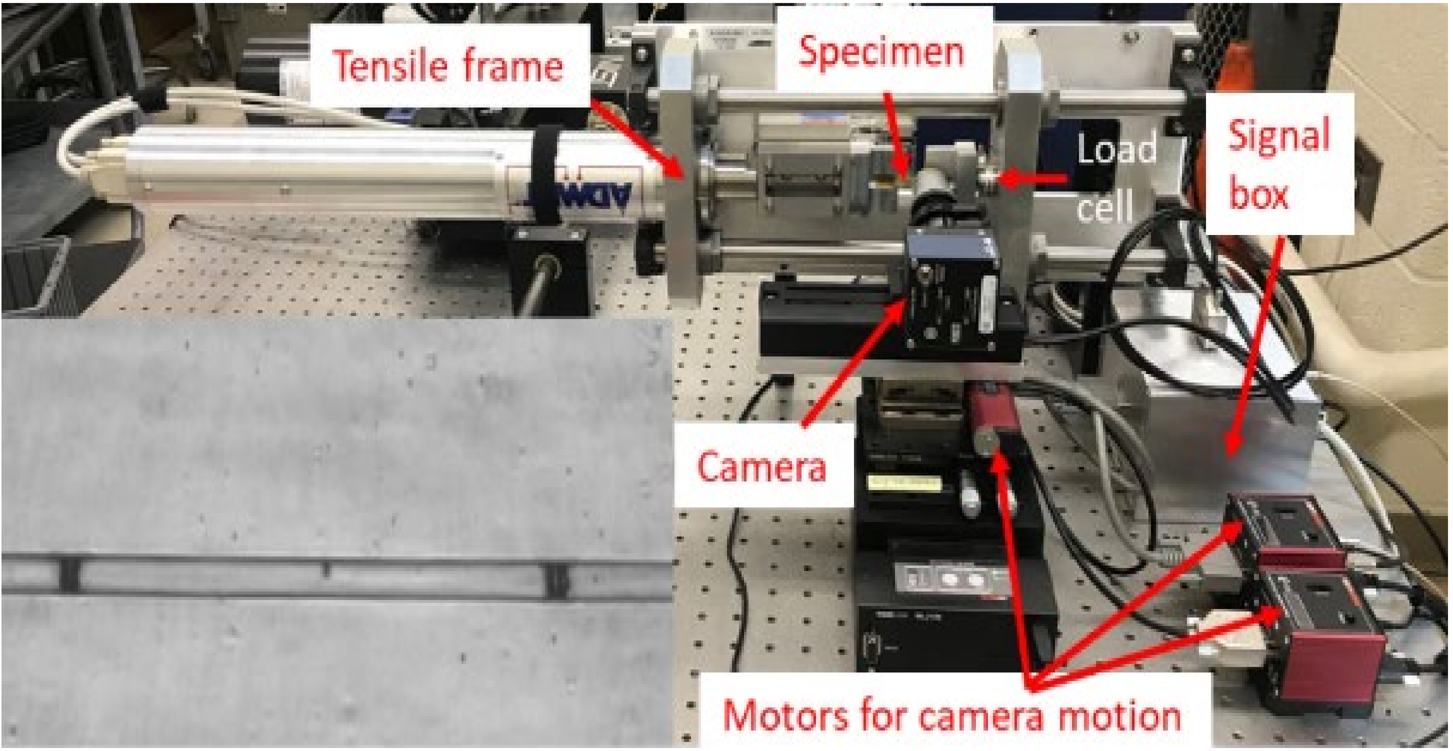


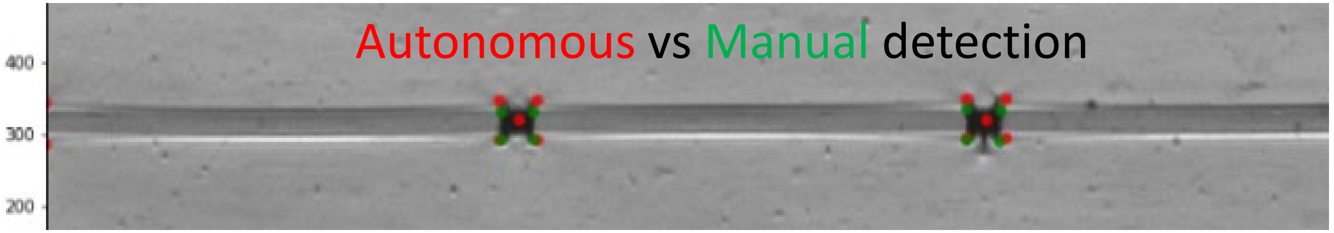


Tedious & Model Dependent Analysis

Autonomous Interfacial Shear Strength (τ_{IFFS})

SNAPPY: Autonomous Fiber Fragmentation

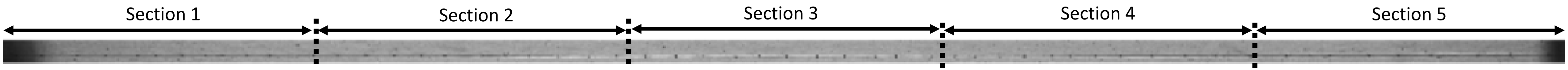


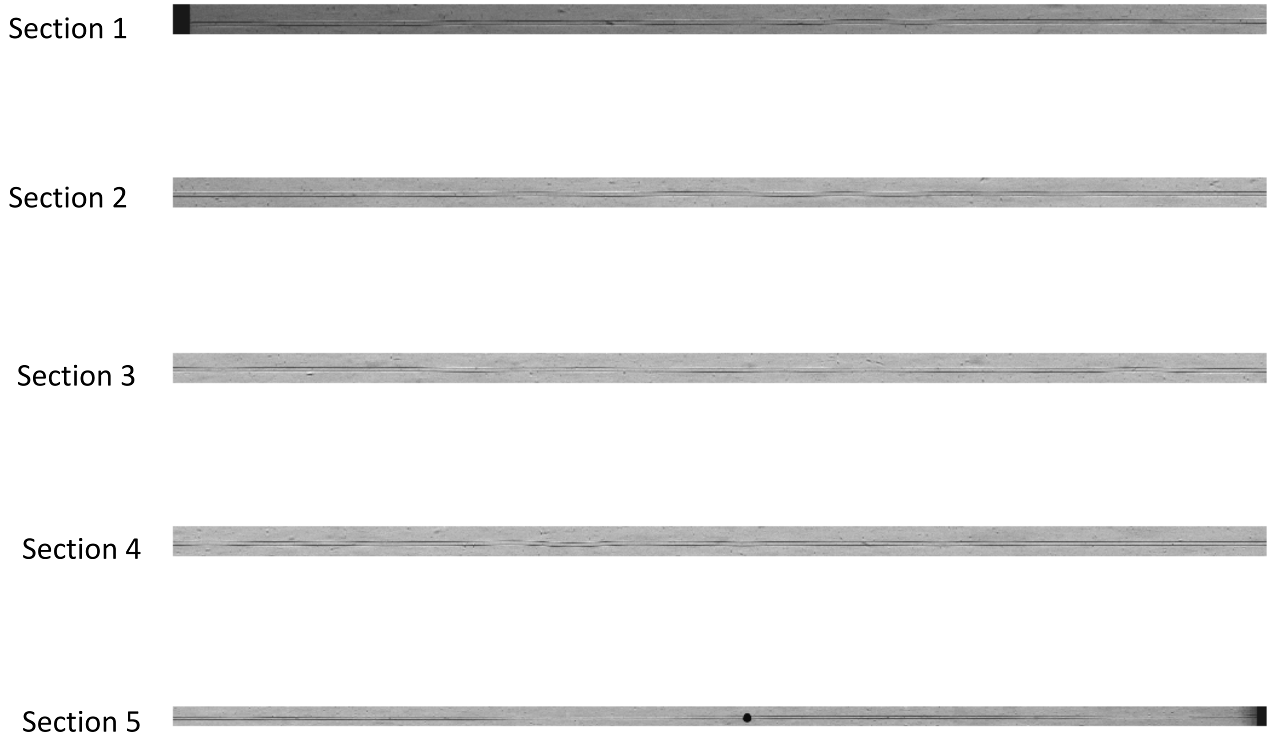


SNAPPY uses computer vision and autonomous methods for real time and high-speed tracking of:

- Break locations
- Fiber fragment length
- Debond lengths at fiber ends
- Break morphology
- Stress relaxation
- Improved τ_{IFSS} calculations

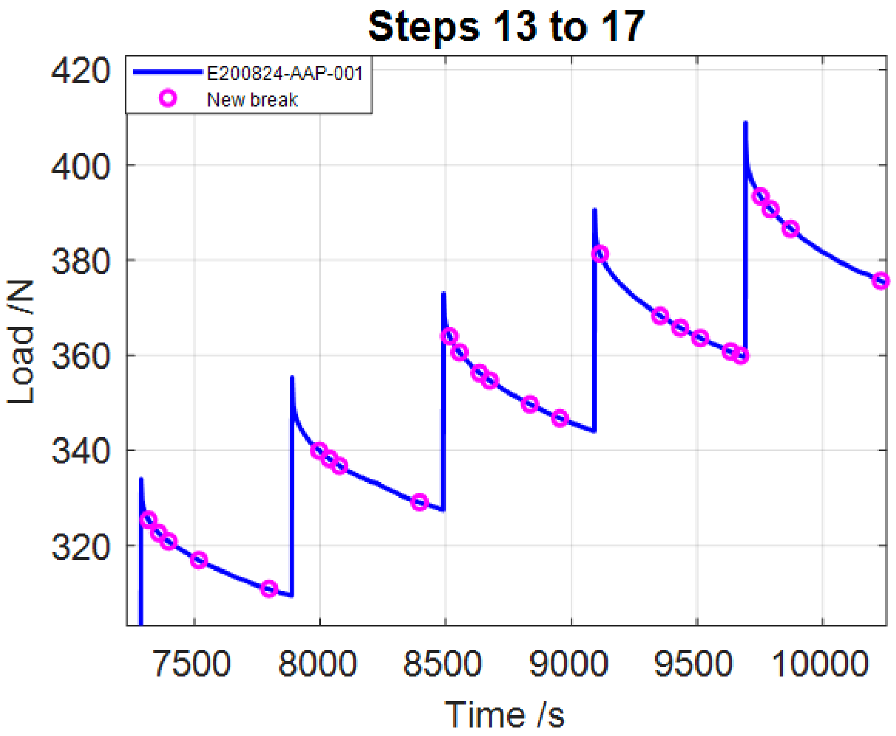
Autonomous Interfacial Shear Strength (τ_{IFFS})





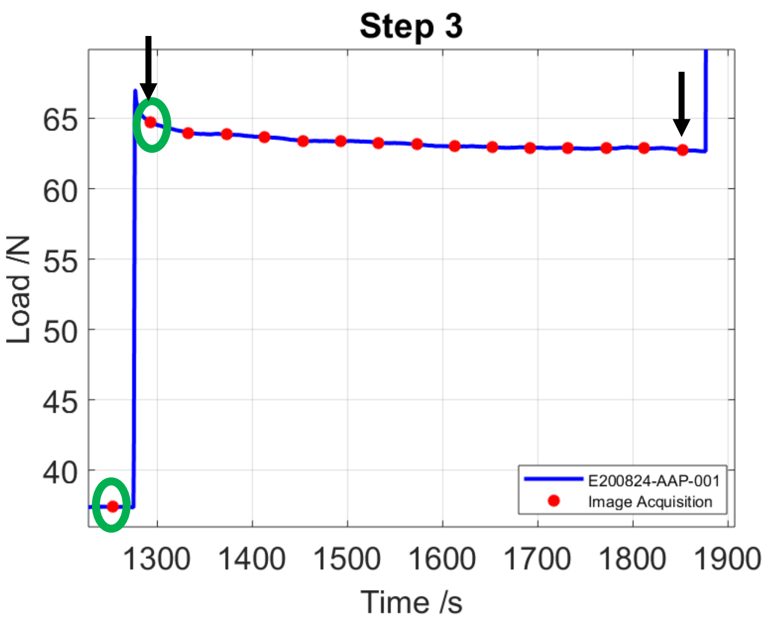
Step 14: 1.8 % strain

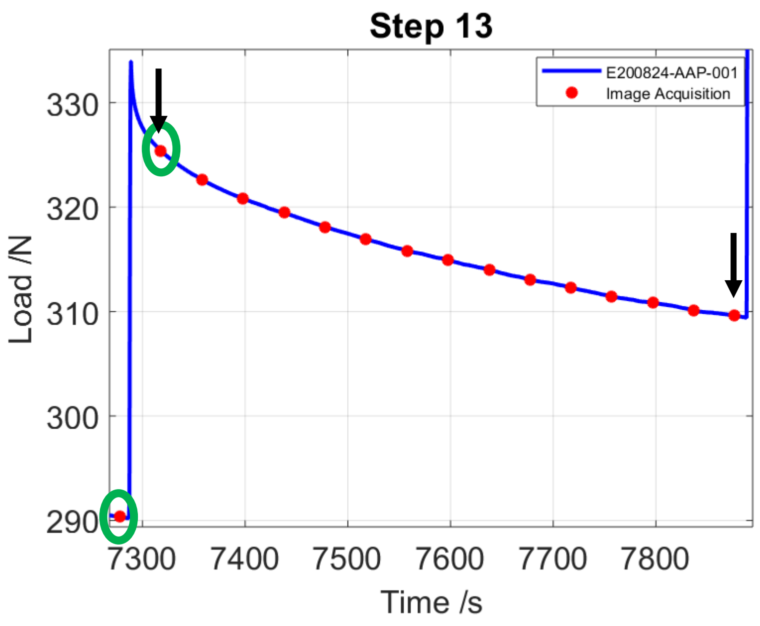
SNAPPY greatly improves counting statistics – reduced uncertainty

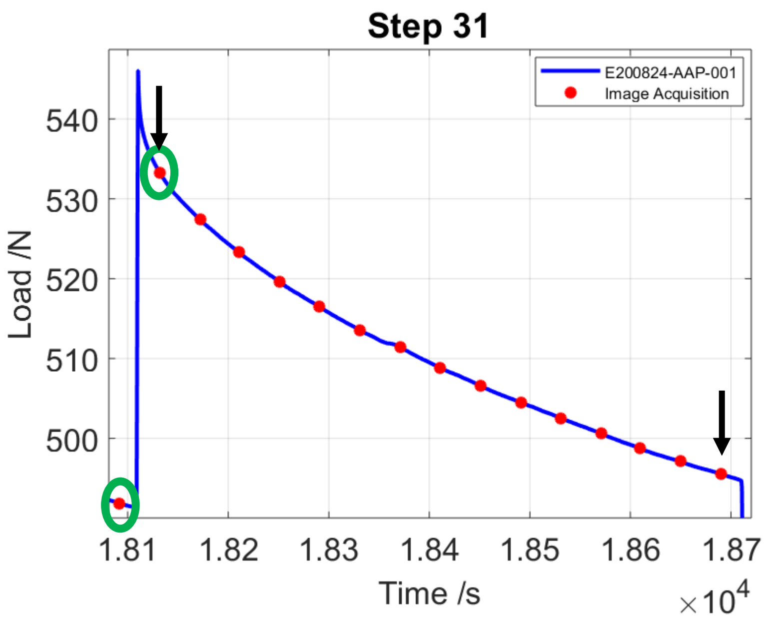


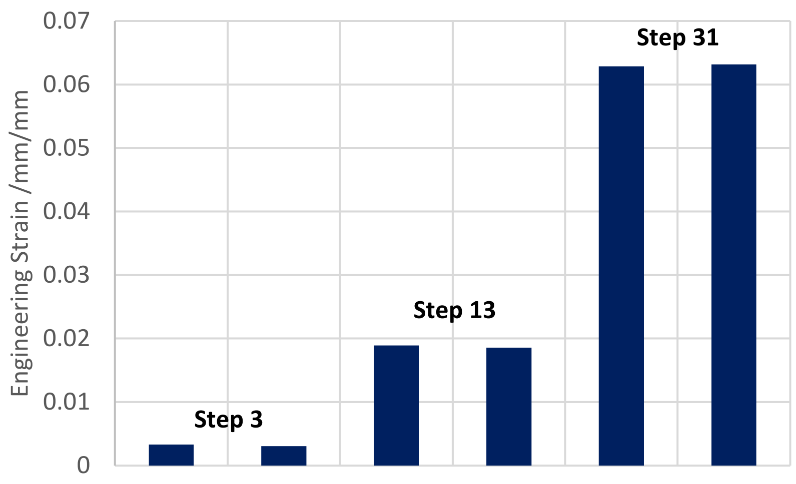
SNAPPY quantifies stress relaxation – new information from SFFT measurements!

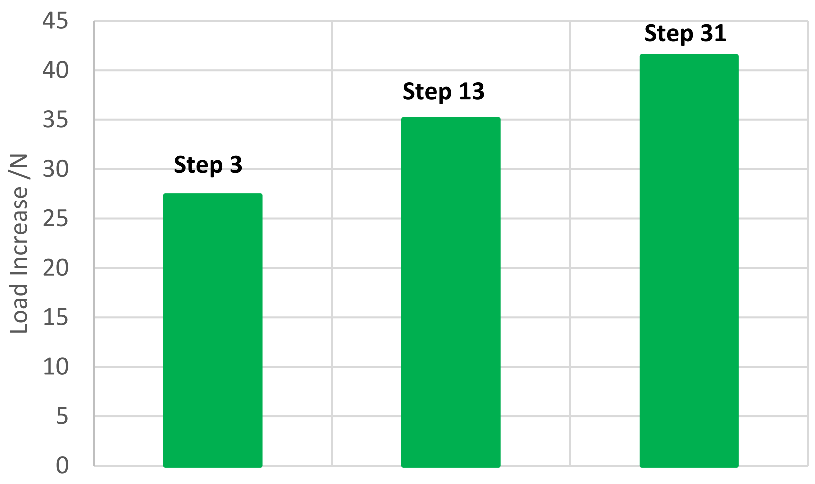
Autonomous Interfacial Shear Strength (τ_{IFFS})

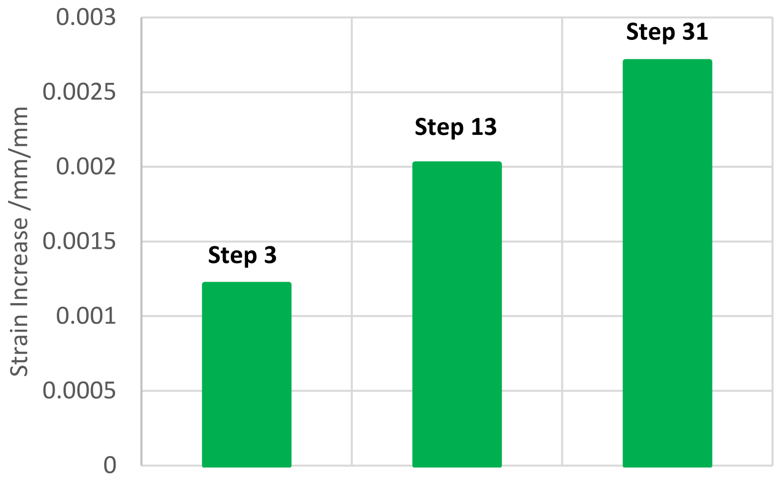




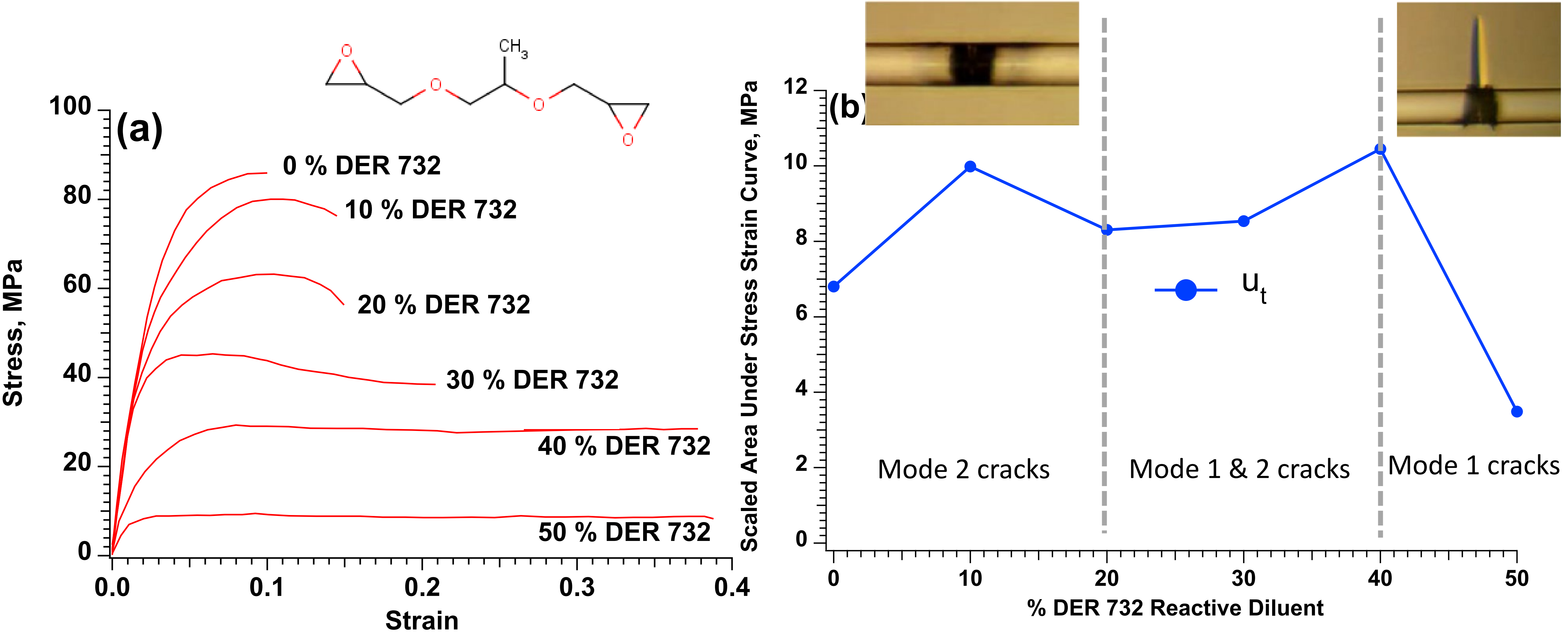








Fiber Fragmentation Break Morphology



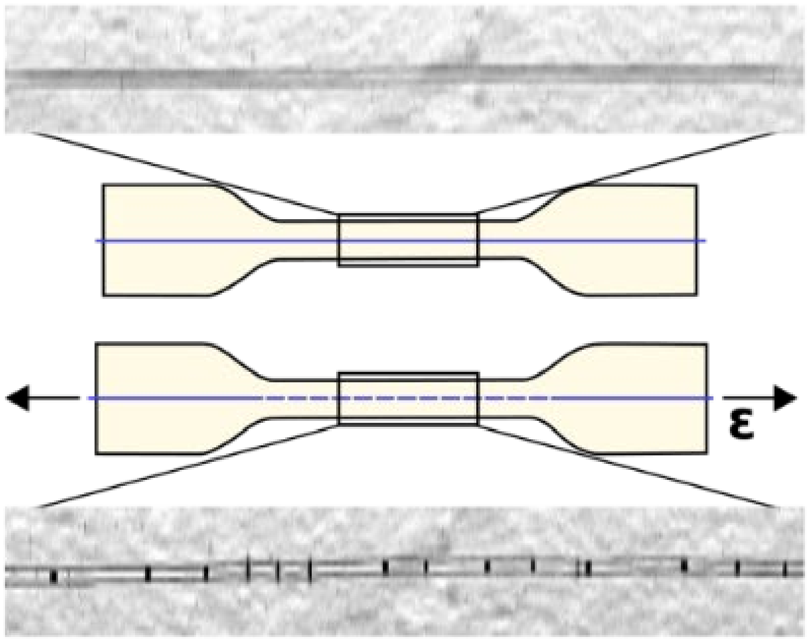
Different resins lead to different break morphologies – affects τ_{IFFS} calculations!

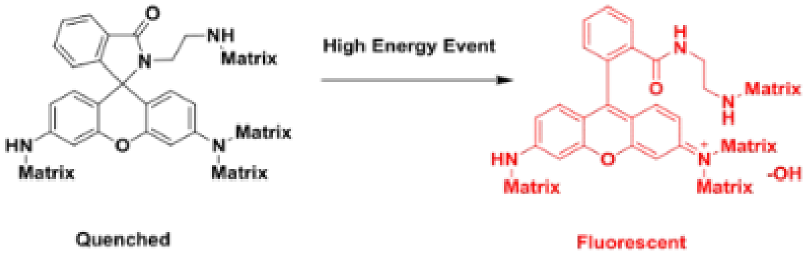
Mechanophores to image matrix damage

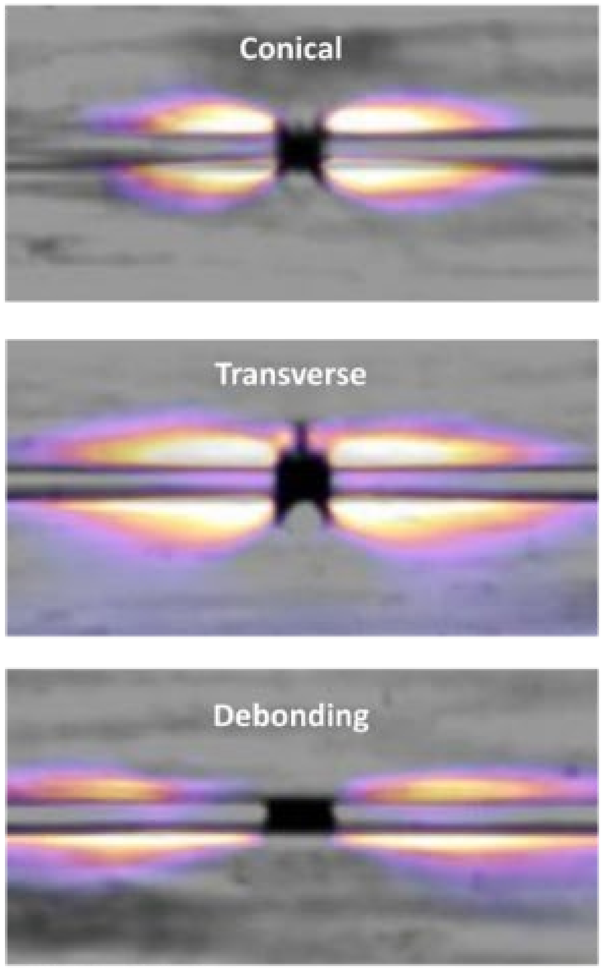
Single Fiber Fragmentation Test
Interfacial Shear Stress

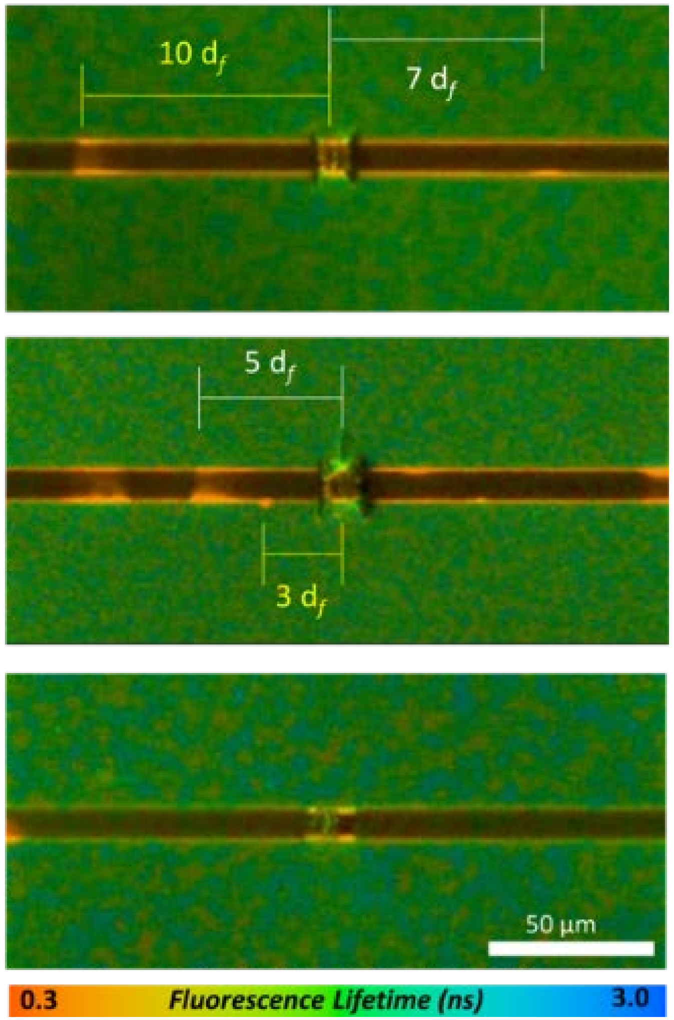
Birefringent Images
(stress fields)

Mechanophore Images
(matrix yield)

A


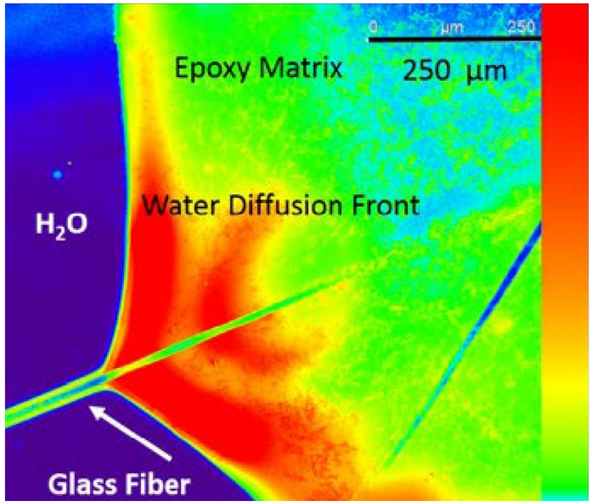
B


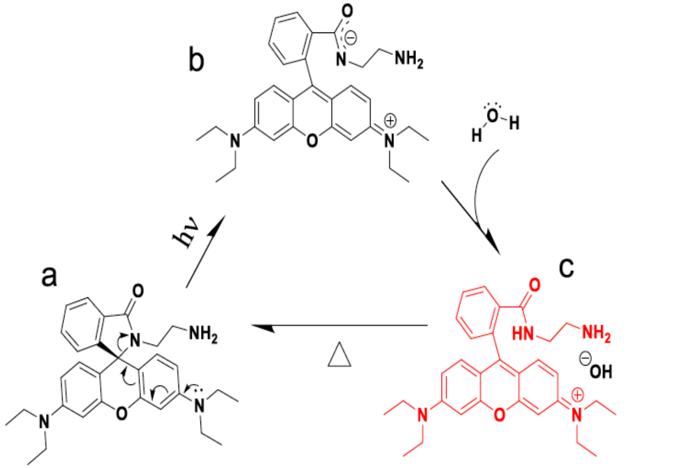
C


D


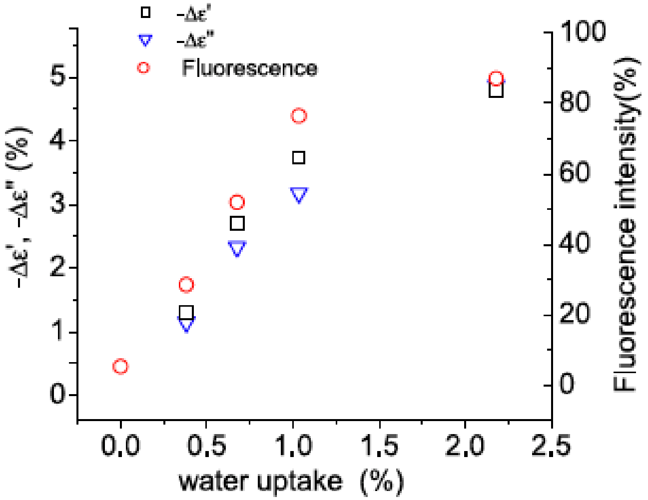
Aquaflors to image absorbed water

Water Sensing Fluorescent Dye Molecules (AqFDs)

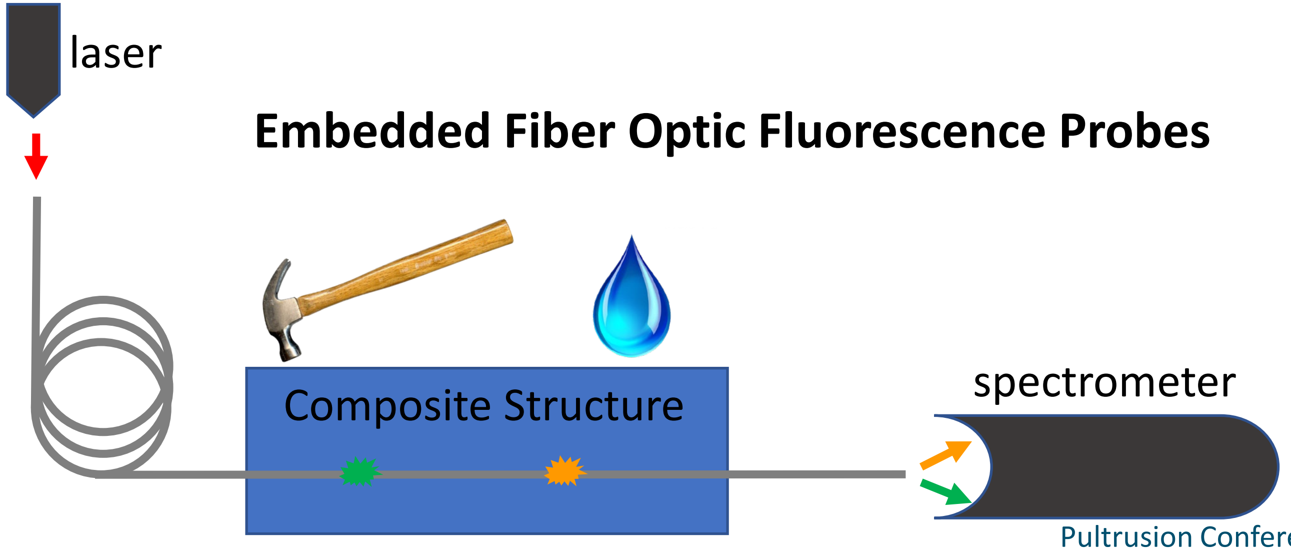




Non-Contact Microwave Dielectric Measurements



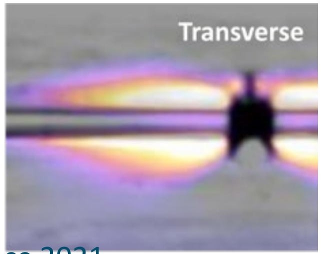
4 H_20 per AqFD dye
? photons per H_20 ?



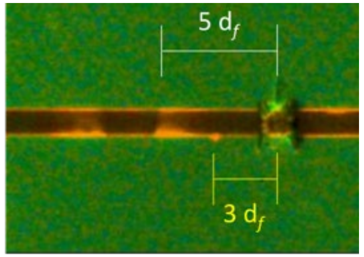
Embedded Fiber Optic Fluorescence Probes

Activation of AqFD creates measurable change in dipole strength!

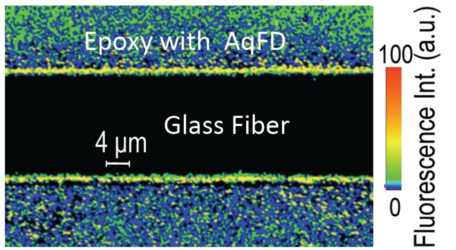
Stress Fields



Matrix Damage

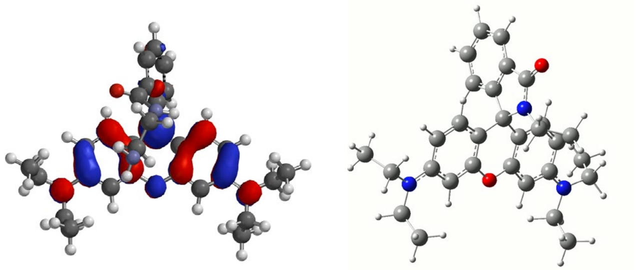


Interfacial H_2O

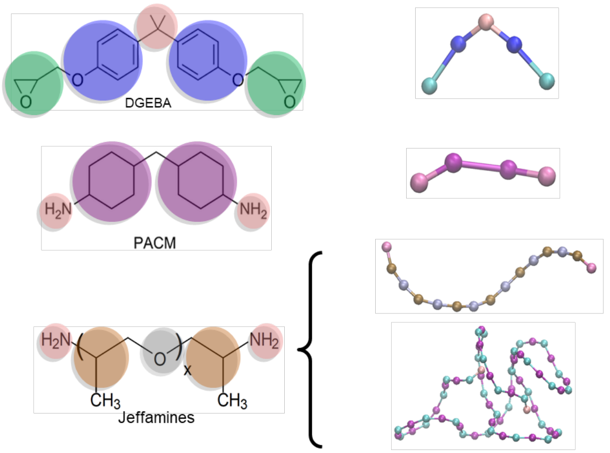


Composites Modeling & Data

Mechanophore Design



Coarse Graining – Mesoscale Modeling

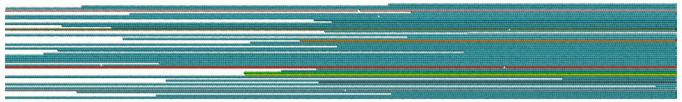


All-atom (AA) → **Coarse-grained (CG)**

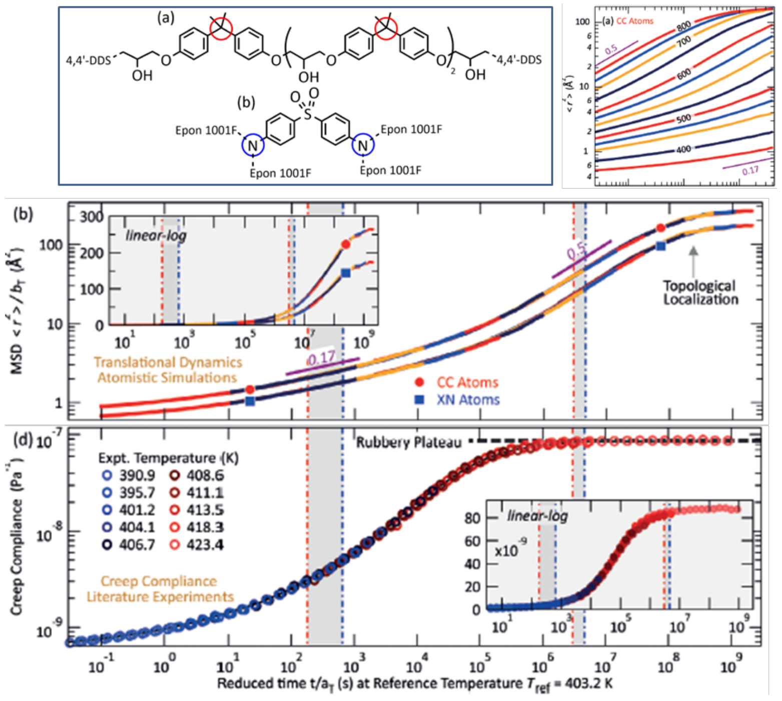
Menu of CG Options

- Iterative Boltmann Inversion (structure)
- Strain Energy Mapping (order)
- Energy Renormalization (local dynamics)
- Dissipative Potentials (viscous dissipation)

Mechanical Deformation of CNC Films

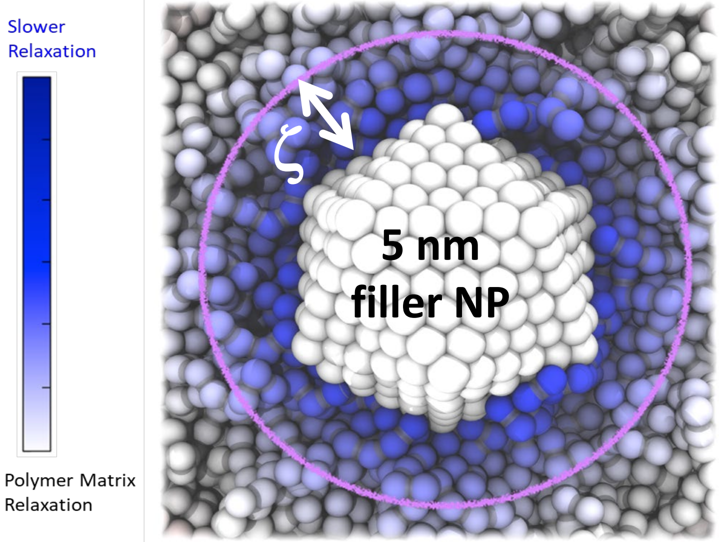


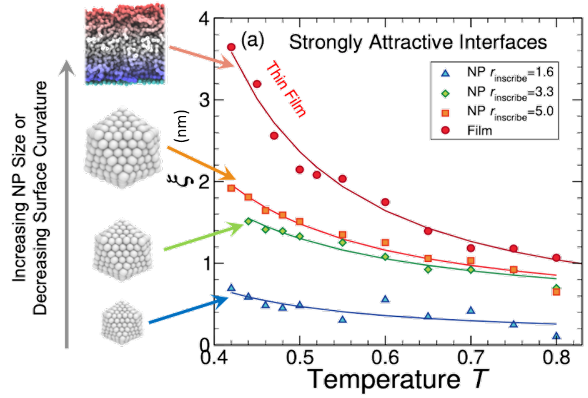
Atomistic Modeling of Composite Epoxies



Validate modelling out to ~ 30 years!

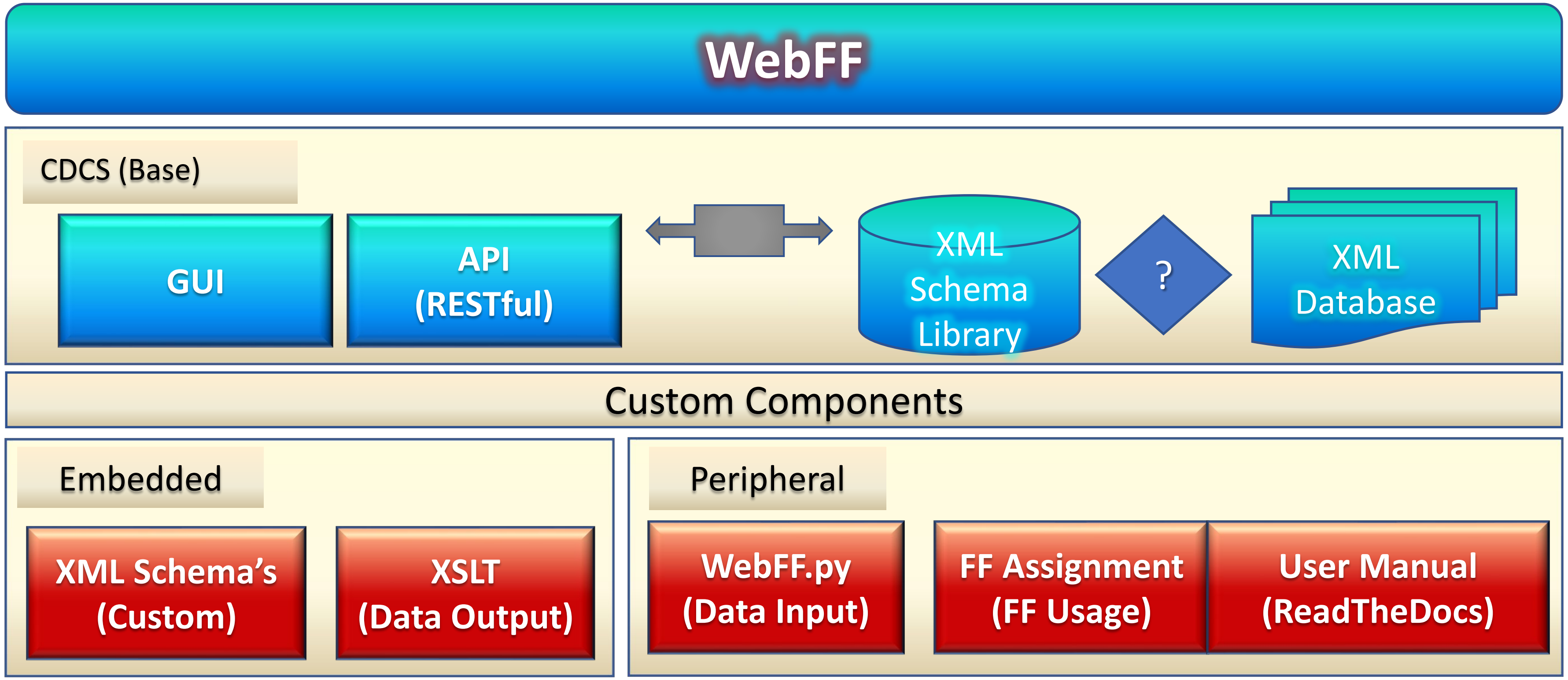
Interphase Dynamics





WebFF (data archiving & sharing) **Comsoft Workbench (data tools)**

WebFF – A Platform for Sharing Simulation Data



Findable
Accessible
Interoperable
Reusable

WebFF is a public, central repository being developed by NIST for atomistic modeling force field data for composites material. Data is curated from published sources (community) with metadata to provide provenance and quality. This infrastructure can be expanded into a composites data clearinghouse

COMSOFT Tools

Modeling tool set to work with shared atomist force field data (WebFF)

Iterative Boltzmann Inversion (IBI)

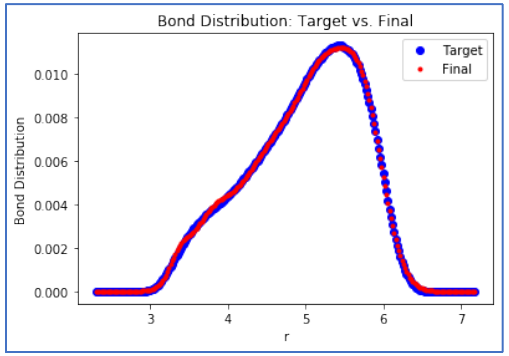
Application Specific Code

Functional Libraries
- Data Handling (I/O)
- Chemical Perception
- Molecular Construction

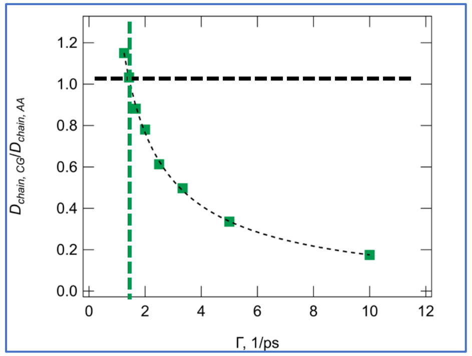
Data Classes
- MD Data
- Force-Field
- Atom Types

Peripheral Engines
- MD Simulator
- Database
- AI/ML

Validated CG Methods



Coarse-grained FF
(Conservative Forces)



Coarse-grained dynamics
(Dissipative Forces)

Proper coarse graining is critical to improve modeling efficiency and extend simulations & predict long term performance

Modeling tool for designing new composite materials

Summary

NIST is supporting a broad range of composites research across our campus and laboratories

Composites for infrastructure is a strategic area where we are currently making investments

The NIST Composites Project / Materials Measurement Laboratory focuses on:

- Role of the fiber-matrix interphase on mechanical properties / interfacial shear strength
- Fluorescence dyes to image matrix damage and deleterious absorbed water
- Non-contact microwave inspection tools for matrix damage and water
- Modelling, data sharing, and analysis tools for composite materials

NIST is interested in measurement and standards issues facing the composites community

CONTACT FOR MORE INFORMATION

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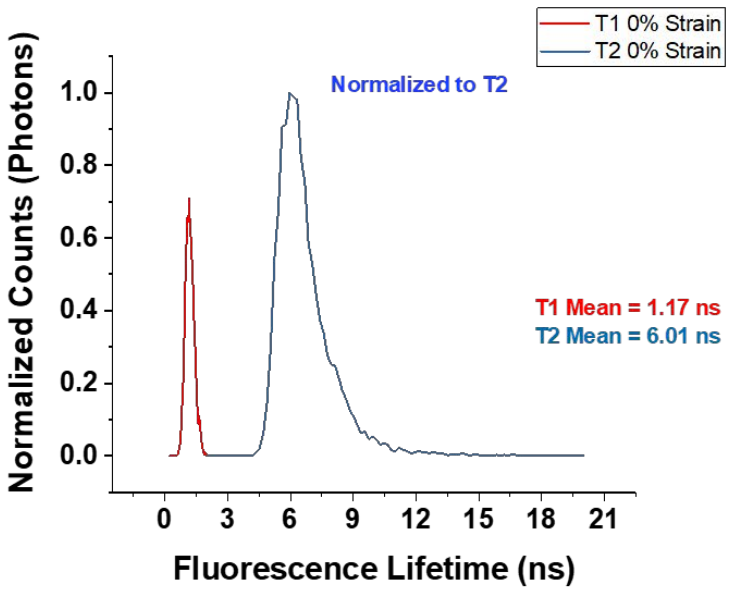
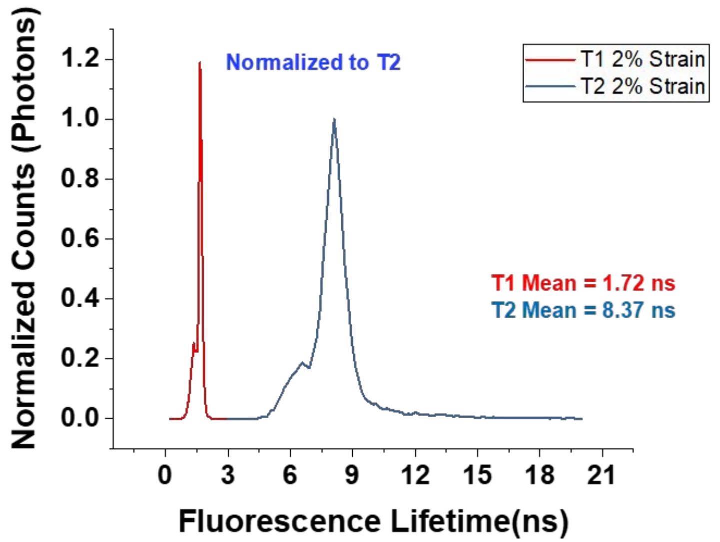
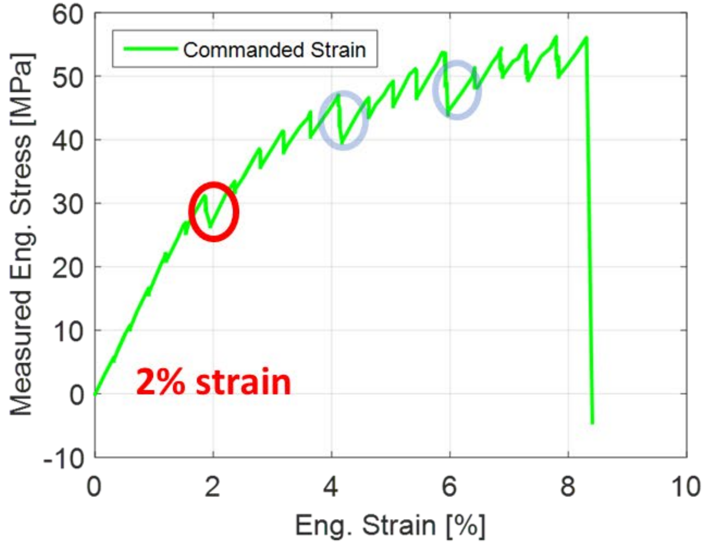
https://www.nist.gov/mml/materials-science-and-engineering-division/functional-polymers-group

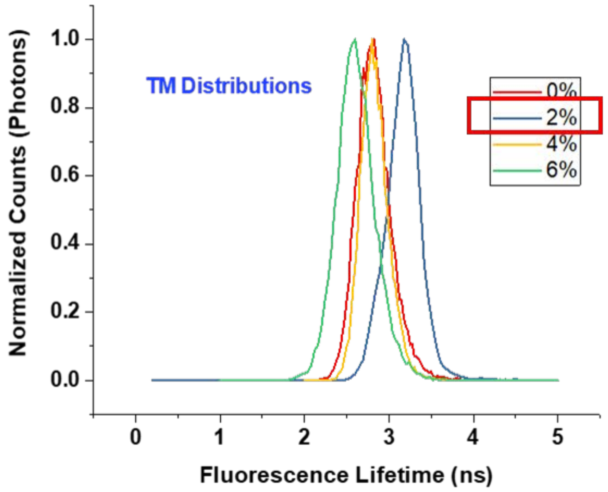
Mechanophores to image matrix damage

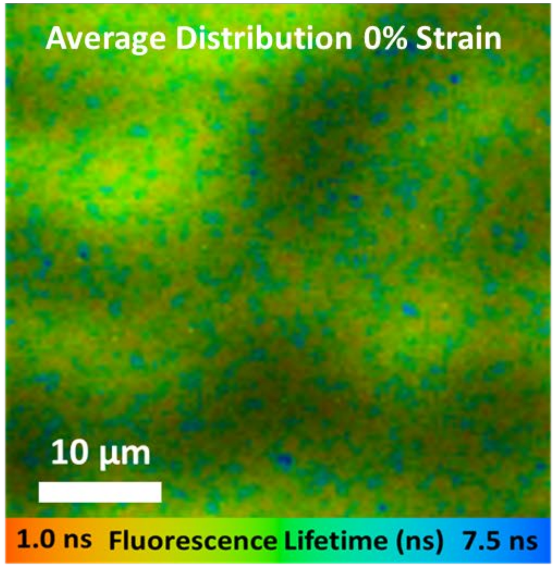


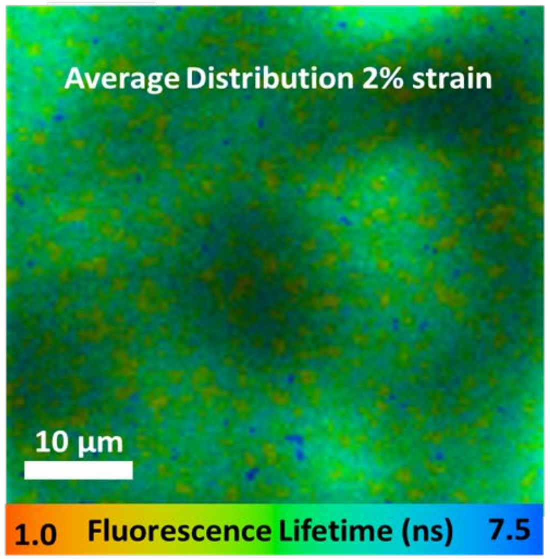


Observed Lifetime with Strain (0 and 2% Strain)

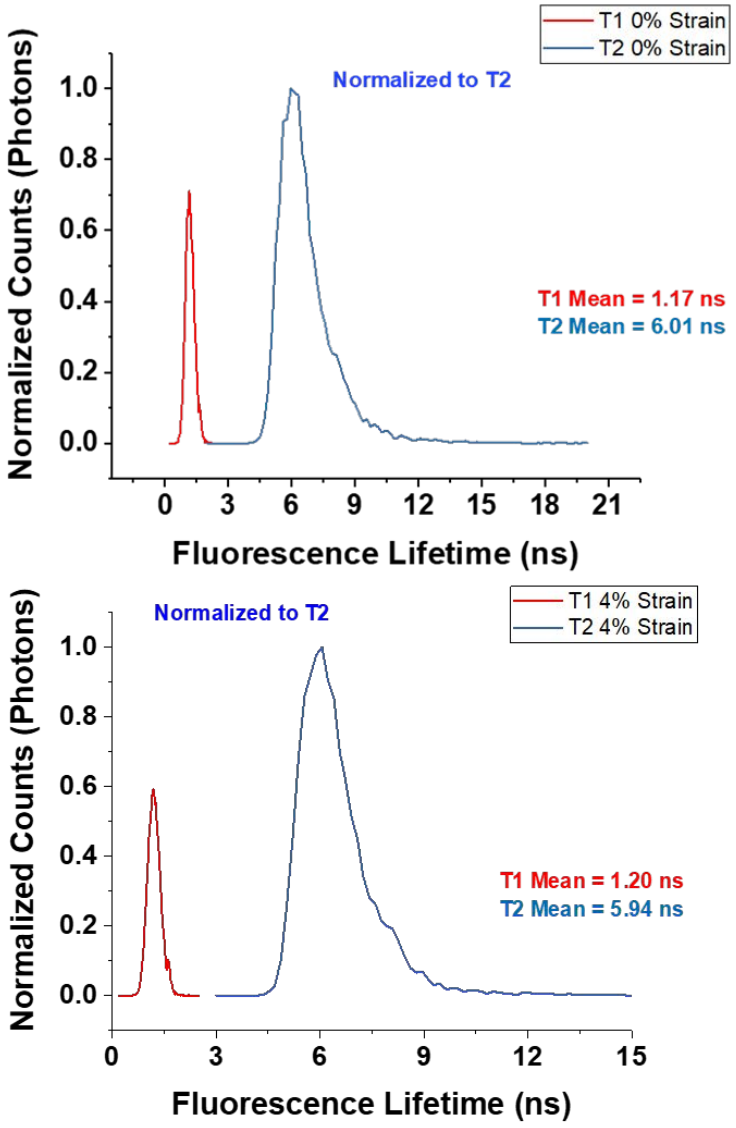




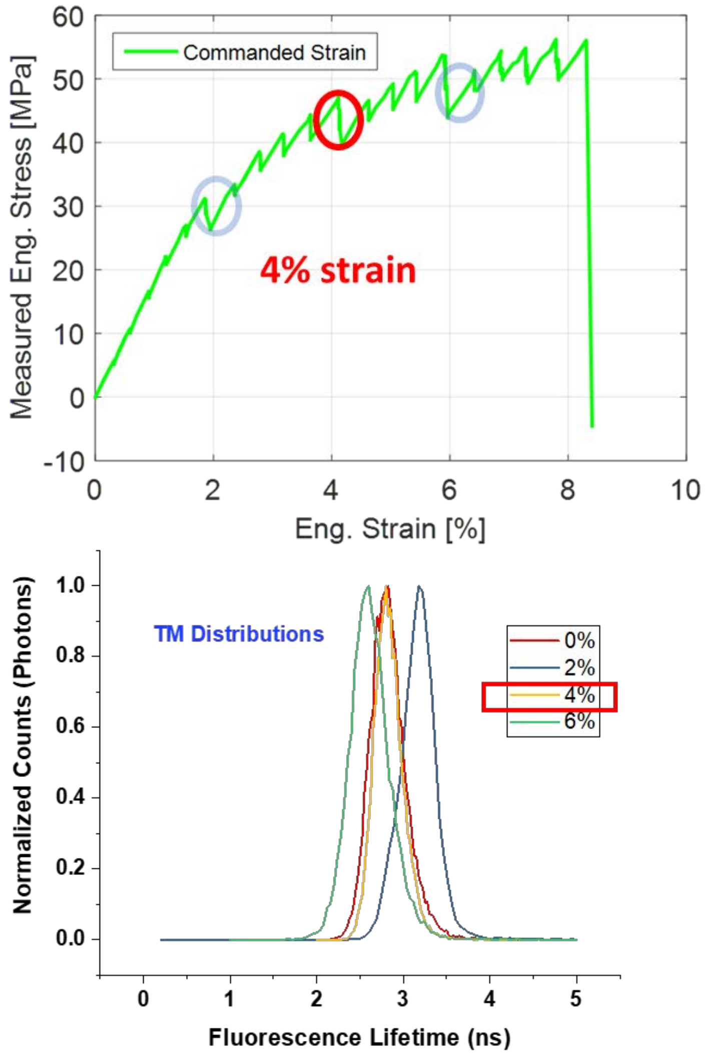


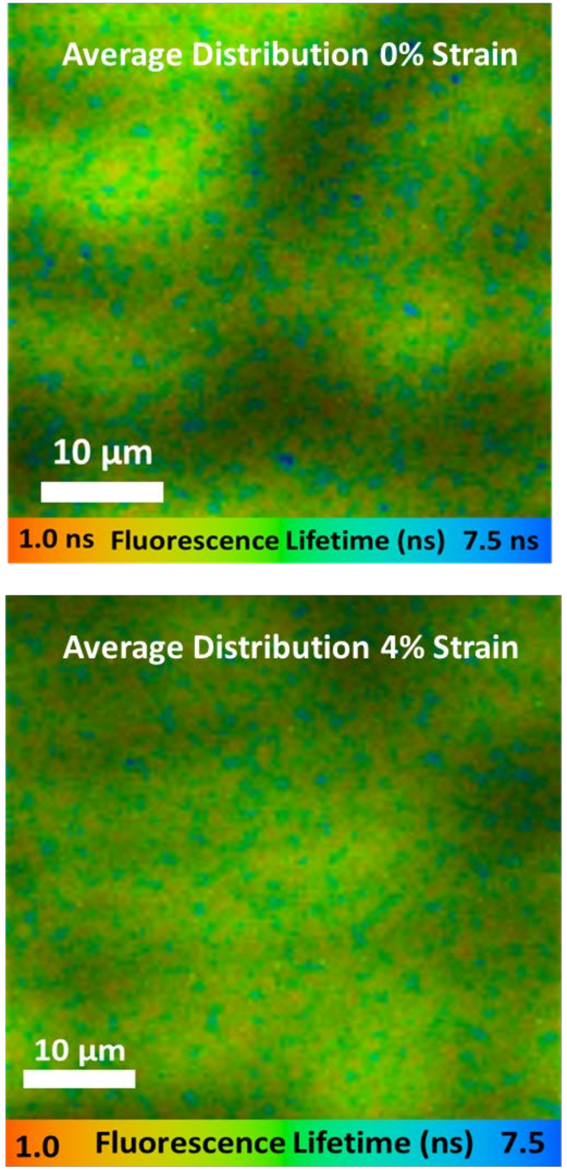


Mechanophores to image matrix damage

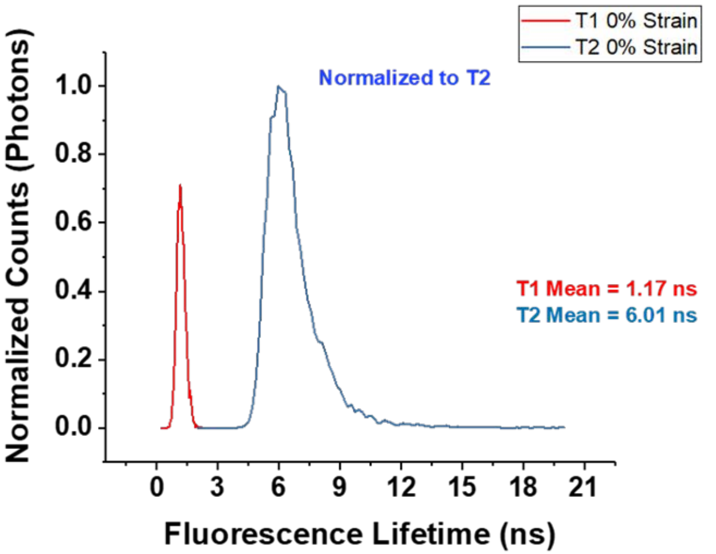


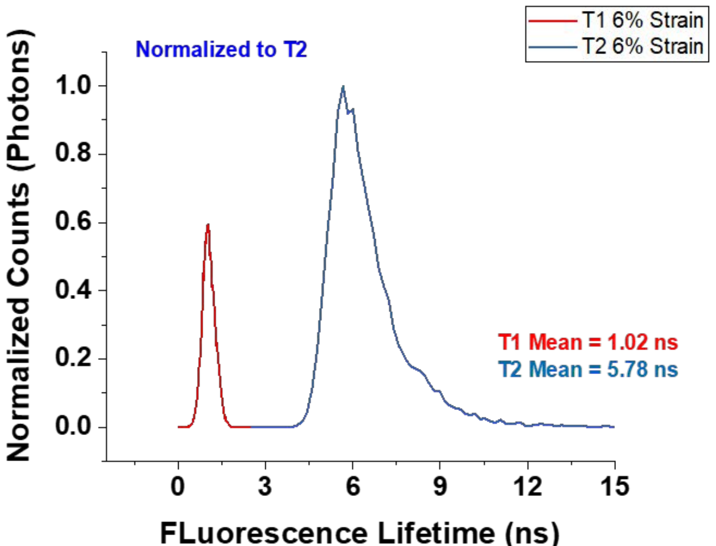
Observed Lifetime with Strain (0 and 4% Strain)



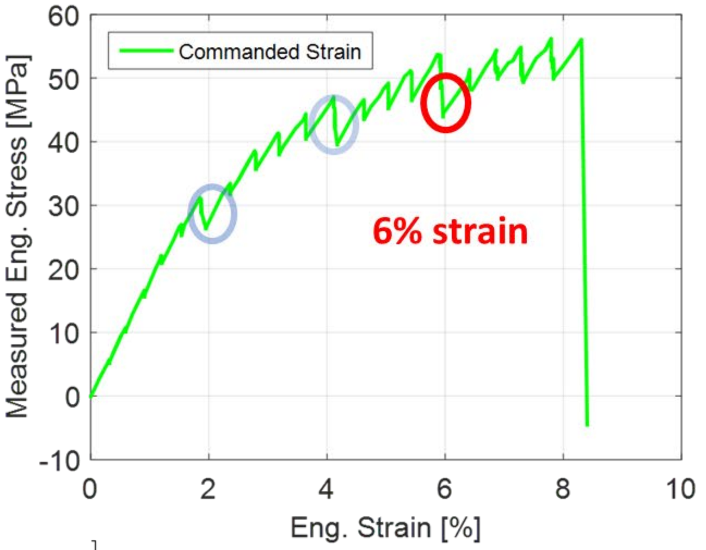


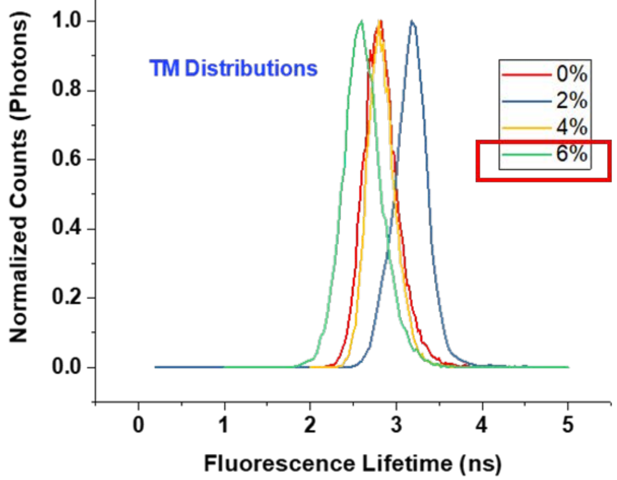
Mechanophores to image matrix damage

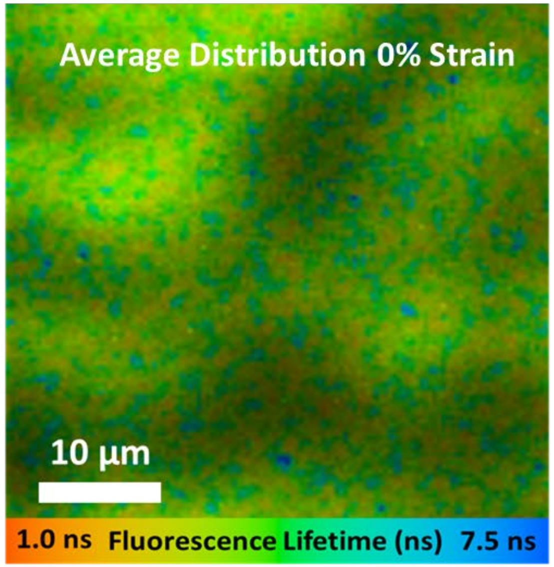


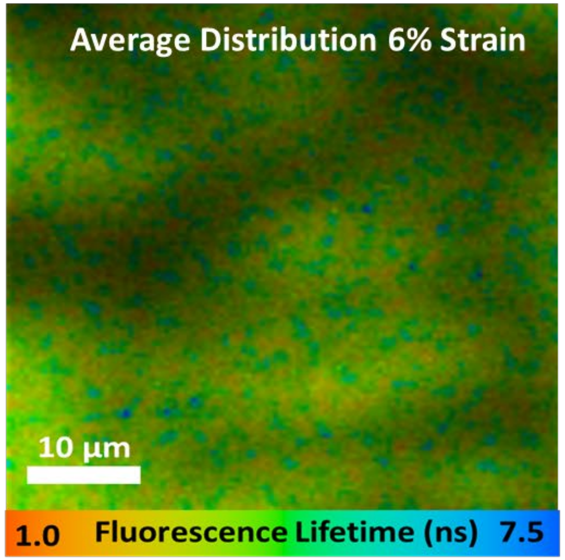


Observed Lifetime with Strain (0 and 6% Strain)









Composites at NIST

NIST

National Fire Research Laboratory

Accelerated Environmental Service Life Prediction

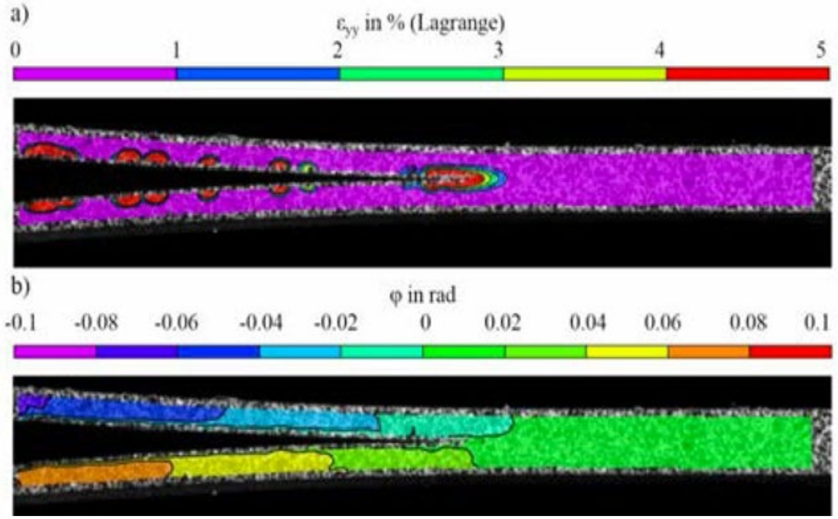
UV, water, temp, load, ……

NIST Center for Automotive Lightweighting

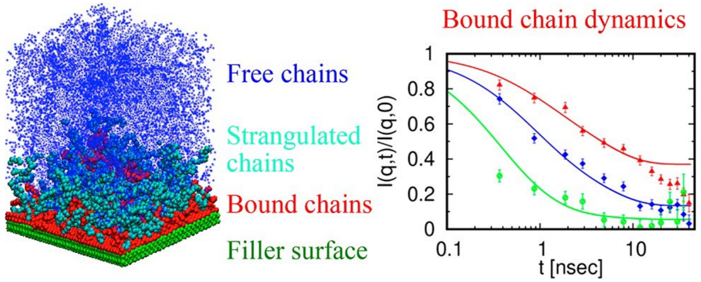
Dow

Ford

Interlaminar Failure in CFRP

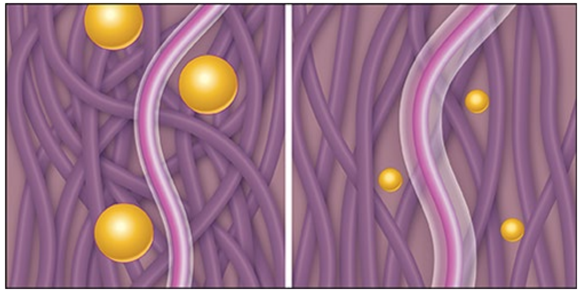


NIST Center for Neutron Research



Polymer dynamics near a carbon filler

https://doi.org/10.1021/acsmacrolett.5b00368



Polymer entanglement near a filler particle

Phys. Rev. Lett. 118, 147801 (2017)

NIST

Center for Automotive Lightweighting

Academic Partners

- Northwestern University 1851
- Ohio State
- Michigan
- 東京農工大学 Tokyo University of Agriculture & Technology
- UNH Manchester
- POSTECH GIFT 철강대학원 Graduate Institute of Ferrous Technology
- University of Maryland
- KIT Karlsruhe Institute of Technology
- University of Windsor Ontario Canada
- MIT Massachusetts Institute of Technology
- Carnegie Mellon
- tu technische universität dortmund
- Clemson University
- PennState

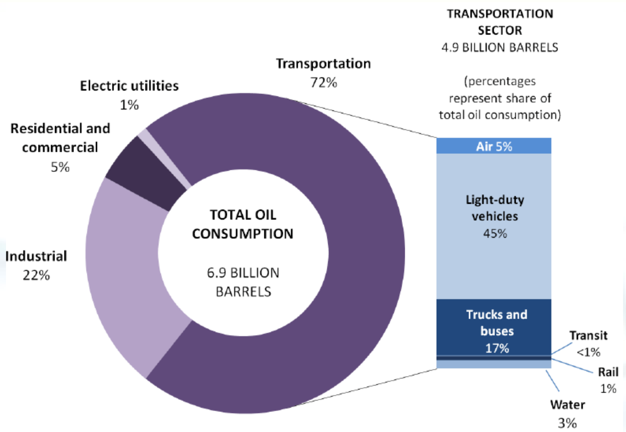
Organizations

- ISO International Organization for Standardization
- USCAR United States Council for Automotive Research
- lift Lightweight Innovations for Tomorrow
- ASTM International Standards Worldwide
- U.S. Army
- A/S P
- American Iron and Steel Institute
- TARDEC
- ornl Oak Ridge National Laboratory
- U.S. Department of Energy Office of Science

Industrial Partners

- Toyota
- CAT
- Dow
- Aditya Birla Novelis
- ThyssenKrupp
- PPG
- Ford
- GM
- EWI We Manufacture Innovation
- Dofasco Our product is steel. Our strength is people.
- Alcan
- FCA Fiat Chrysler Automobiles
- BASF The Chemical Company
- USS
- Honda
- Volvo
- ExxonMobil
- ArcelorMittal
- Alcoa

Automotive Lightweighting



Motivation

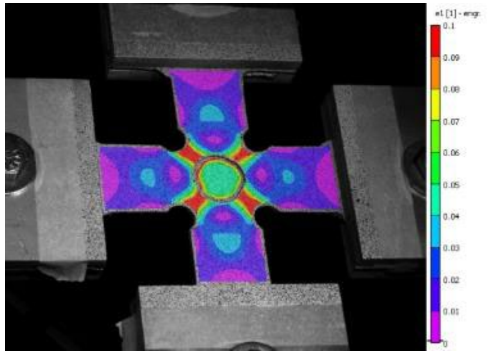
The US auto industry lacks the tools to quickly and inexpensively adopt new, lightweight materials

Objective

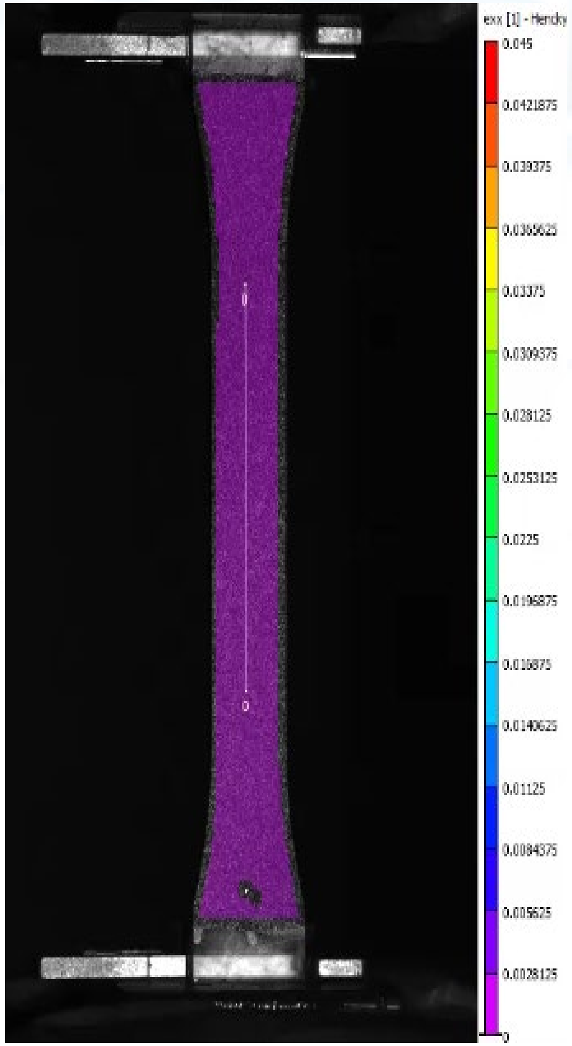
Develop new metrology, data and models to help them achieve these goals

Accomplishments

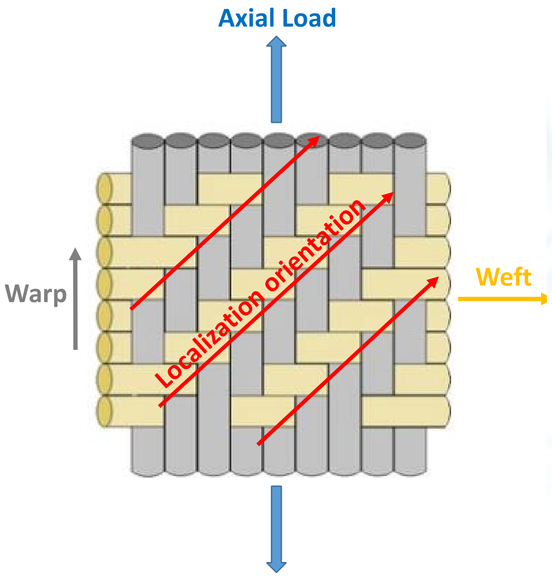
- Providing high rate and complex stress state data on CFRPs and developed new mechanical tests
- New instrumented tension/compression testing system developed
- Formation of new society for DIC and launched new standards activities
- New insights into best practices for interpreting texture data for accurate mathematical representation
- Our data on evolving yield surface in aluminum used by Ford to save development time and cost for aluminum bodied F-150 pickup
- Provided guidance and leadership to manufacturing center LIFT on project selection and review
- Active and pending research agreements: LIFT, Novelis, GM, Caterpillar, Auto/Steel Partnership, Ford, Dow

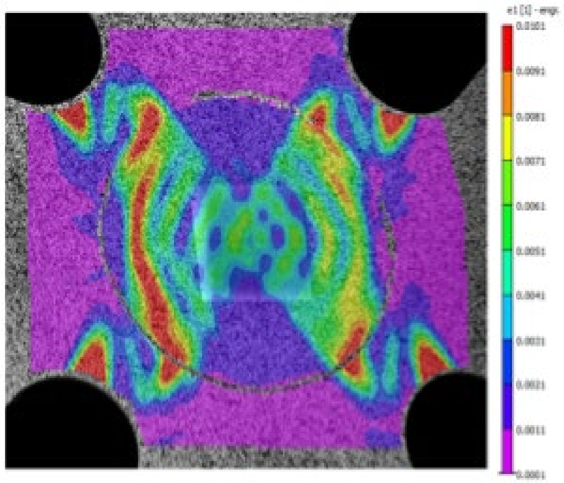


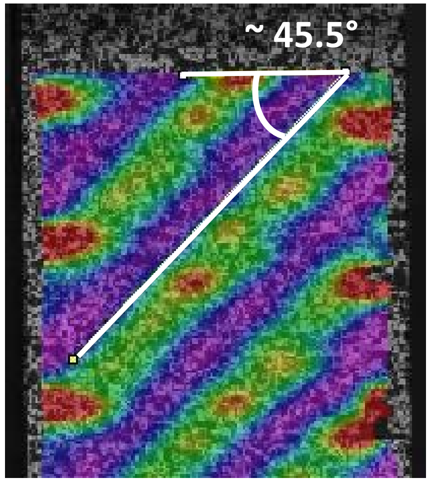
Digital Image Correlation (DIC) Standards



- Calculates deformation in 3D with high resolution
- Shows details previously unobserved
- Problem: "Garbage In, Garbage Out"
- **NCAL Role**:
  - Standards Development
  - Best Practices
  - Dissemination to Industrial Partners



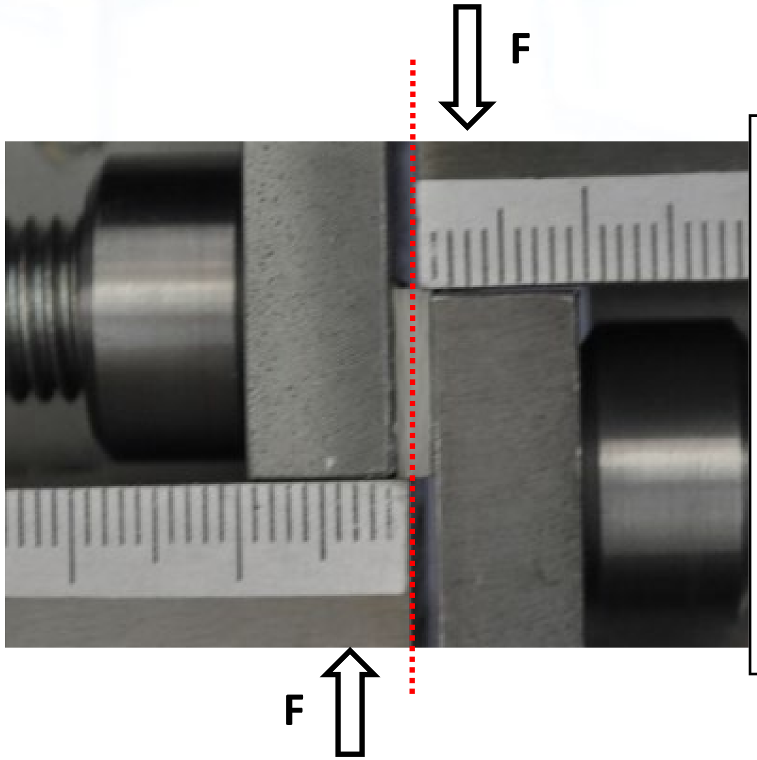




Industrial Interactions: Carbon Fiber Composites

“Smart” models to design w/ CFRPs for structural components. We measure complex behaviors that include:

- High rate for crashworthiness (w/T)
- Interfacial strength
- Single fiber adhesion to epoxy



COMPOSITES FOR INFRASTRUCTURE ROADMAP

NIST Special Publication 1218

ROAD MAPPING WORKSHOP REPORT ON OVERCOMING BARRIERS TO ADOPTION OF COMPOSITES IN SUSTAINABLE INFRASTRUCTURE

Richard Sheridan
Northwestern University

John P. Busel, Daniel Coughlin
American Composites Manufacturers Association

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National Institute of Standards and Technology

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Antonio Nanni
University of Miami

Ellen Lackey
University of Mississippi

William R. O'Donnell
DeSimone Consulting Engineers

Dustin Troutman
Creative Pultrusions, Inc.

Robert W. Harris
National Rural Electric Cooperative Association

Jim Gutierrez
California Department of Transportation

Charles Bakis
Penn State University

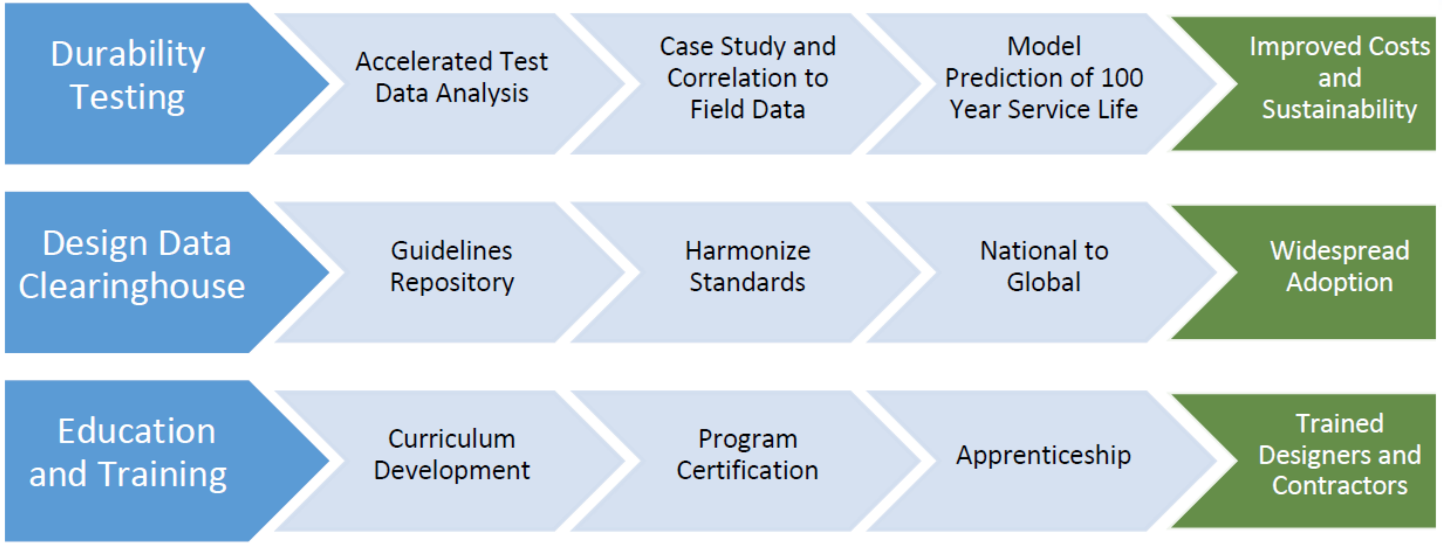
Scott Holmes
Highland Composites

Robert Moser
US Army Engineer Research and Development Center

This publication is available free of charge from:
https://doi.org/10.6028/NIST.SP.1218

December 2017

Workshop Report makes three key recommendation to overcome barriers to commercialization



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December 2017

Resounding support from our stakeholders!
Variations on the recommendations appear in many bills

Year	Number	Sponsor
2018	S.3765	Capito
	H.R.6229	Comstock
2019	S.384	Capito
	H.R.2393	Webster
	H.R.1159	Cicilline
	S.403	Whitehouse
2020	H.R.5685	Lucas
	H.R.6898	Cicilline
2021	S.451	Capito

To date, none of these bills have been enacted into law