Characterizing Early Damage Evolution in CMCs

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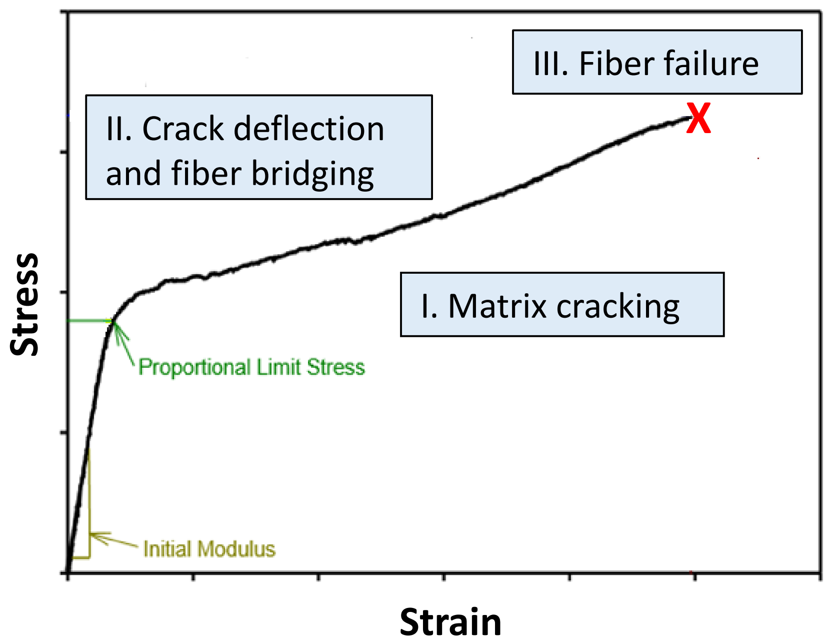
43rd International Conference and Exposition on Advanced Ceramics (ICAAC 2019)
January 27 - February 1, 2019 | Daytona Beach, FL

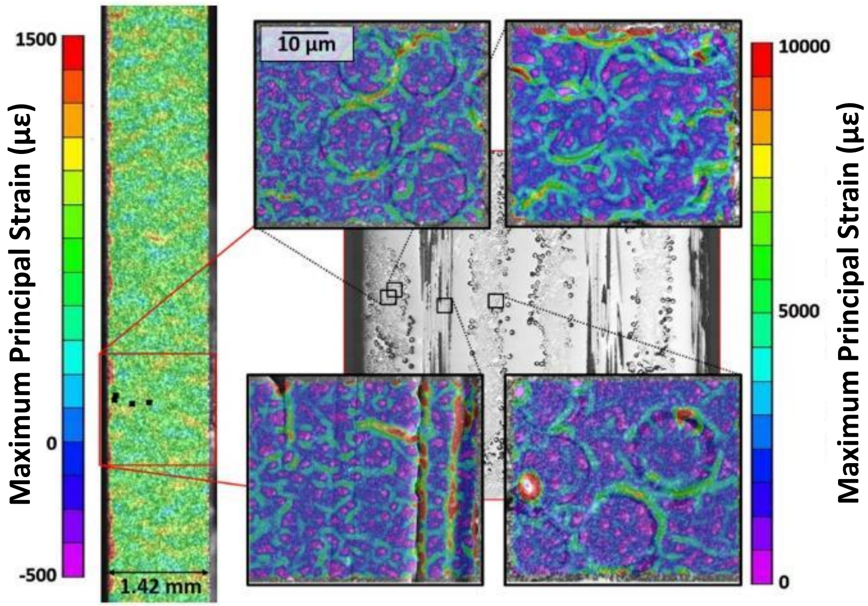
Research Supported by NASA Space Technology Research Fellowship (NSTRF)

Local Composite Landscape and Microstructural Interactions Influence CMC Damage Behavior

GOAL: To correlate the initiation, evolution, and relative activity of surface and subsurface damage mechanisms to constituent landscape in SiC/SiC CMCs

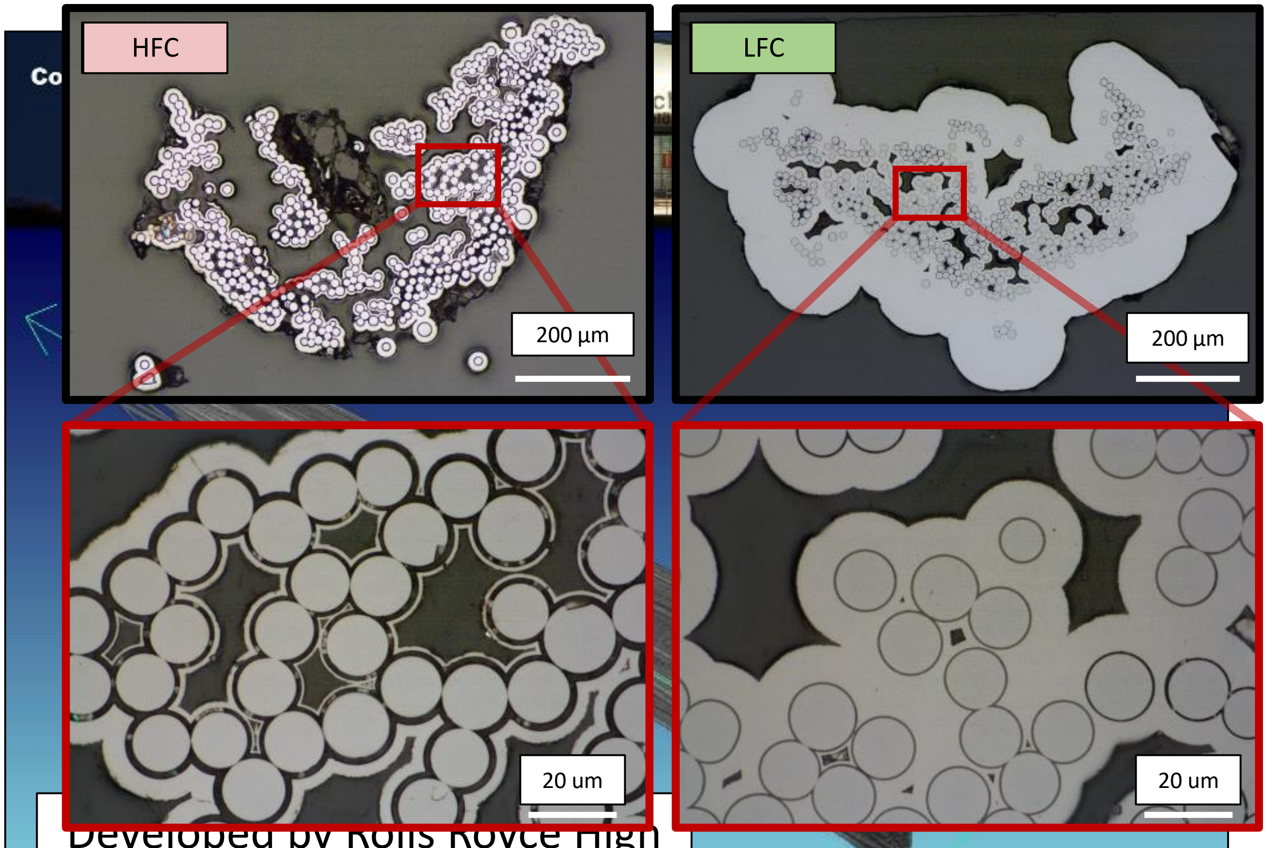


Corman and Luthra, Handbook of Ceramic Composites (2005).



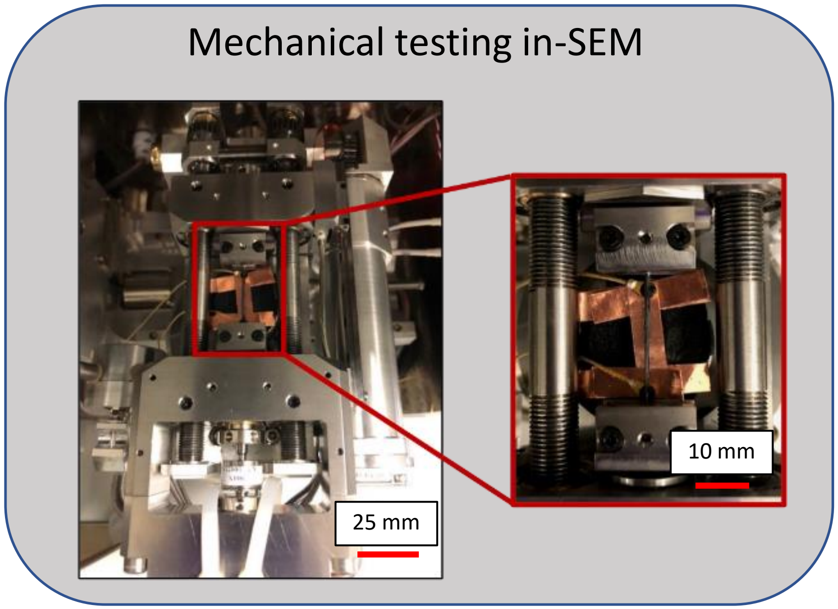
Tracy, Daly, and Sevener (2015).

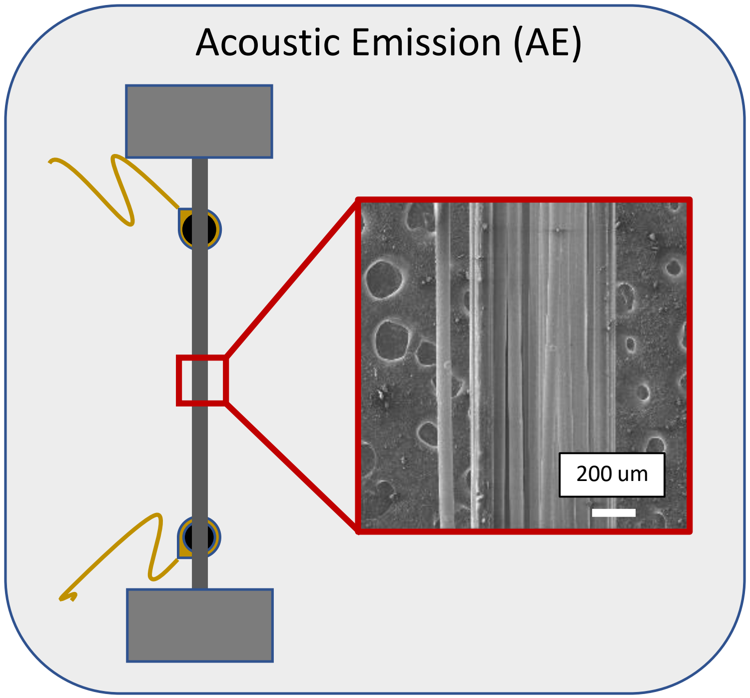
SiC/SiC Minicomposites are Well-Suited for Studying Damage Initiation and Evolution



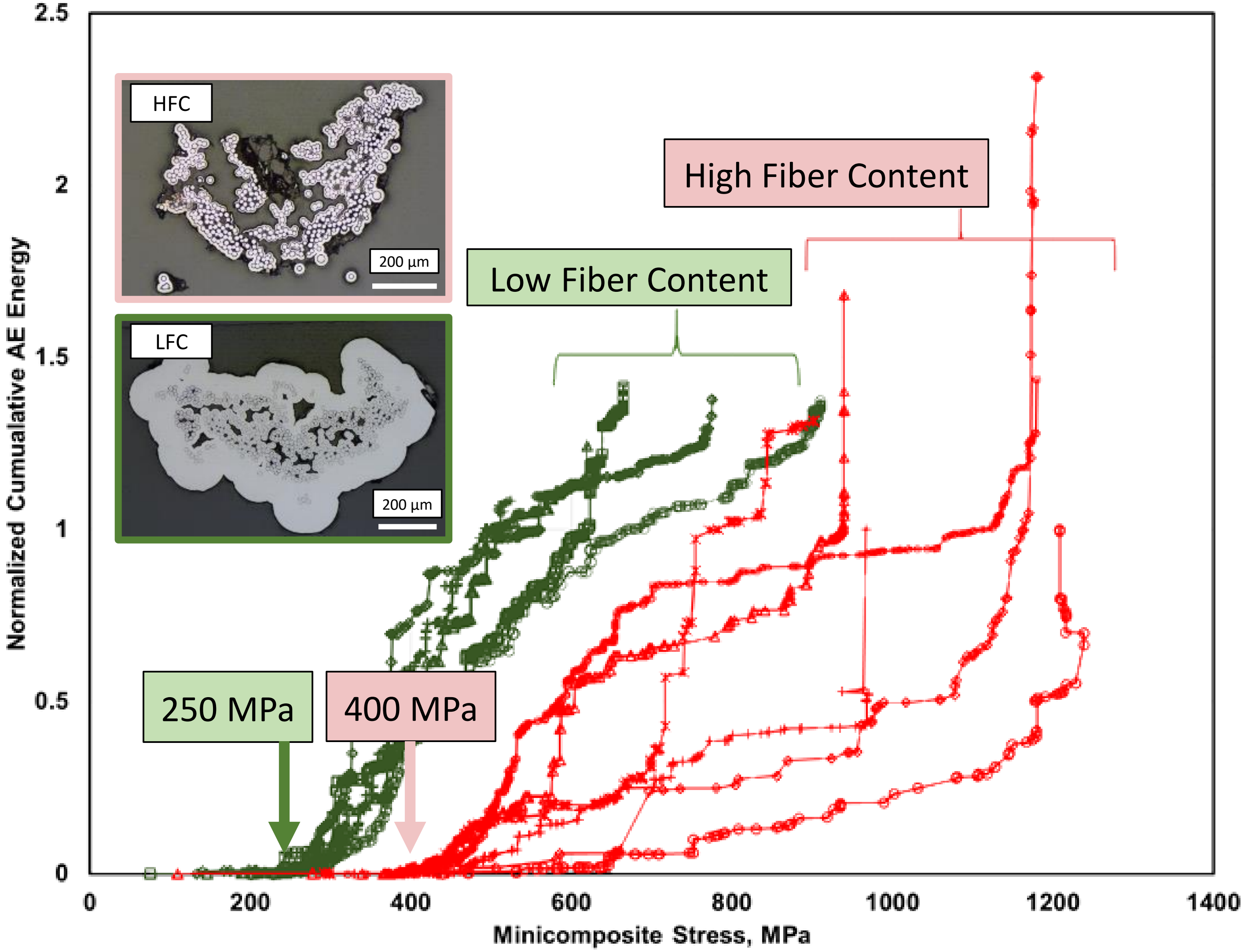
Specimen ID	BN Thickness (µm)	ρ_f	% porosity	ρ_{CVI}	Fiber Volume fraction (%)	BN Volume Fraction (%)	Matrix Volume Fraction (%)	Area (mm^2)
1-1	3	3.2	-	3.2	33.914	27.68	38.406	0.167
2-1	0.4	3.2	10-15	3.2	21.208	2.92	75.87	0.267

A Multi-Modal Approach for Damage Characterization in SiC/SiC Minicomposites

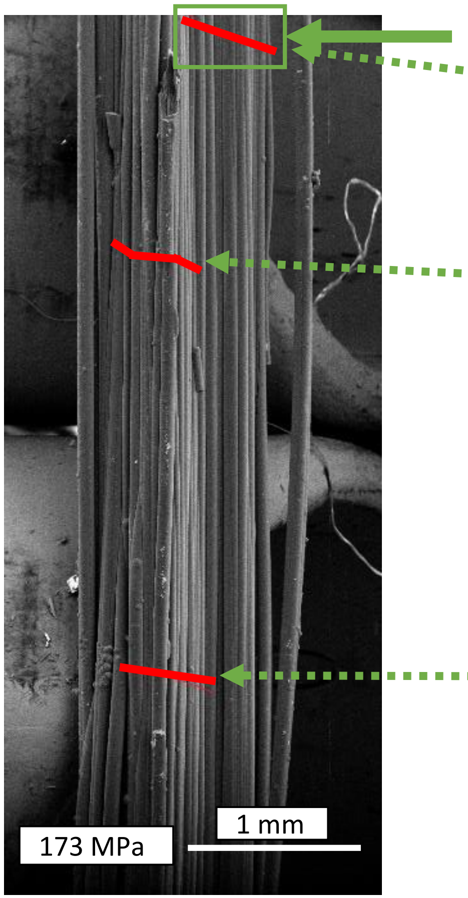


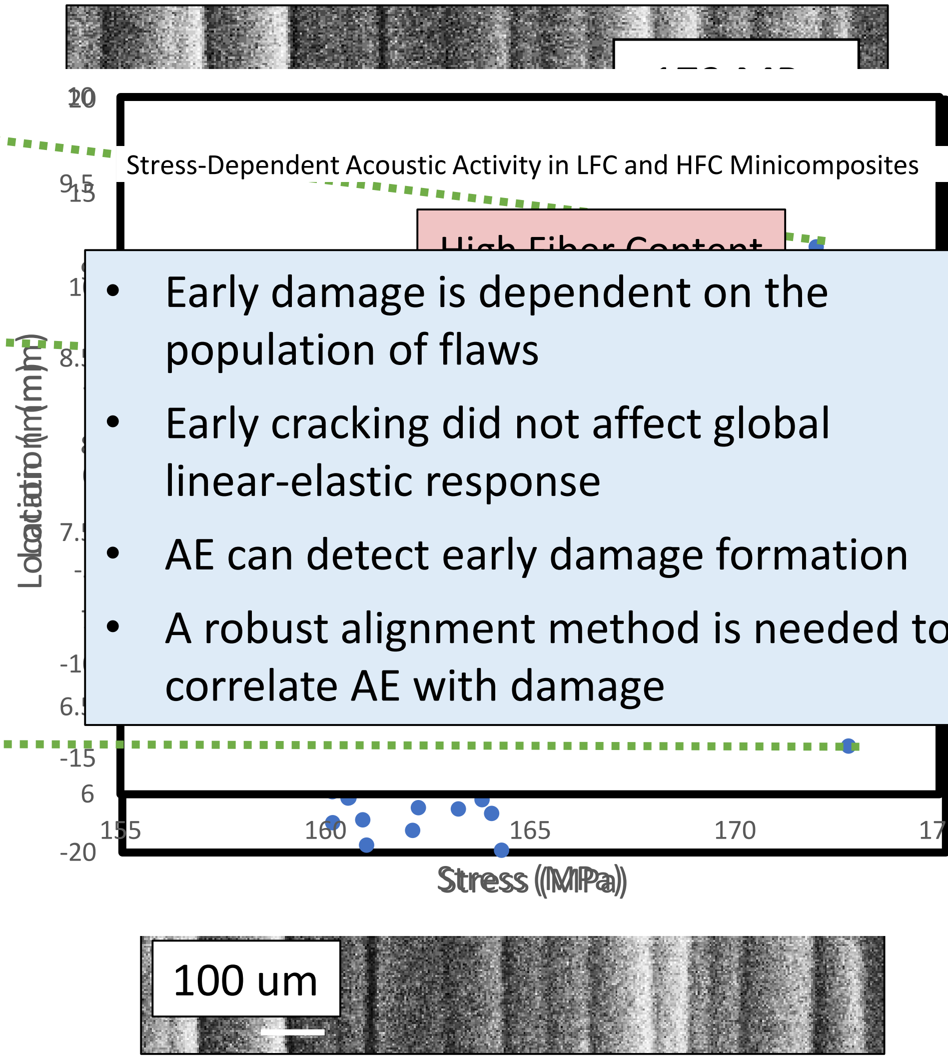


Acoustic Activity Initiates below PL in Tensile Tests



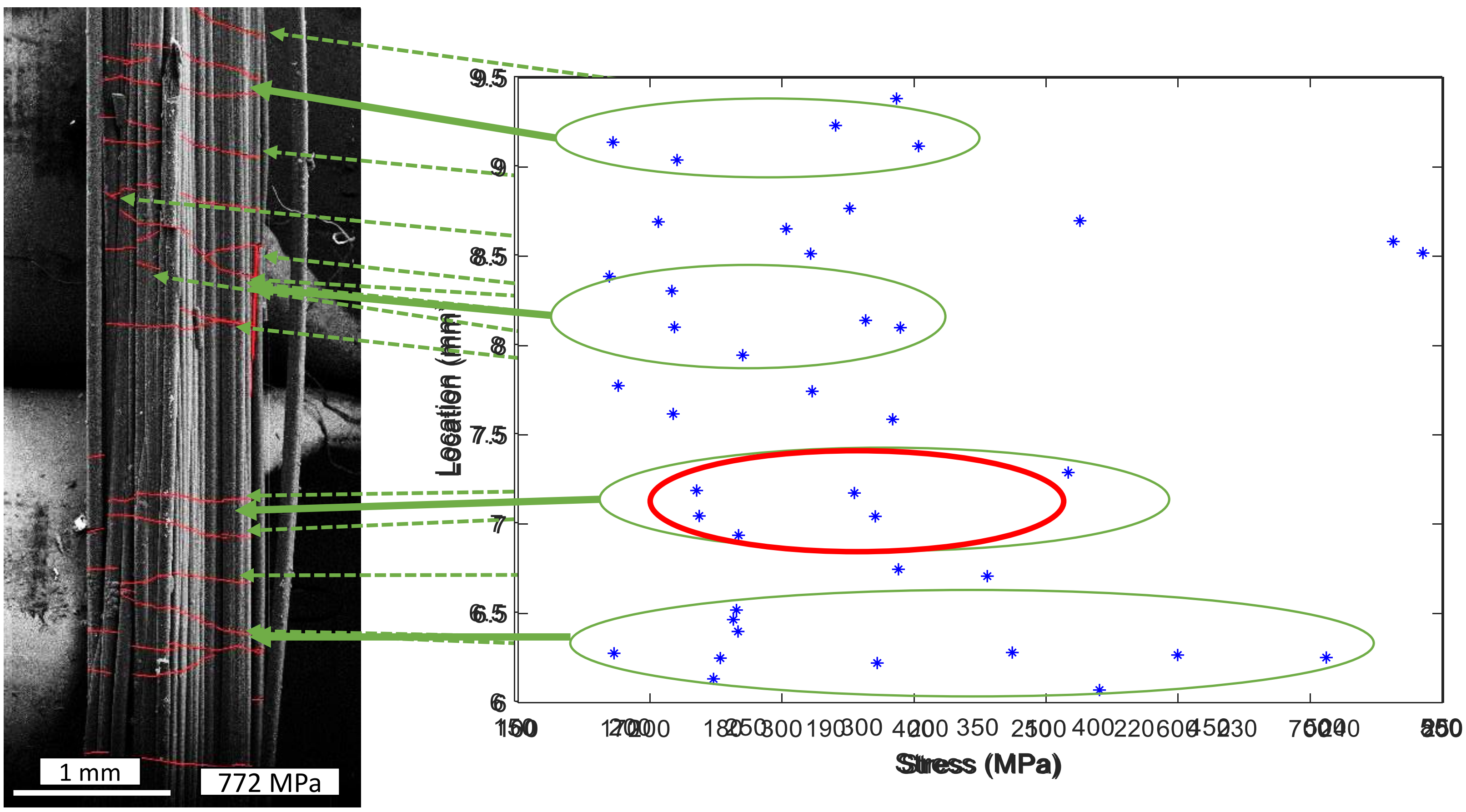
AE Correlates with Crack Formation below PL



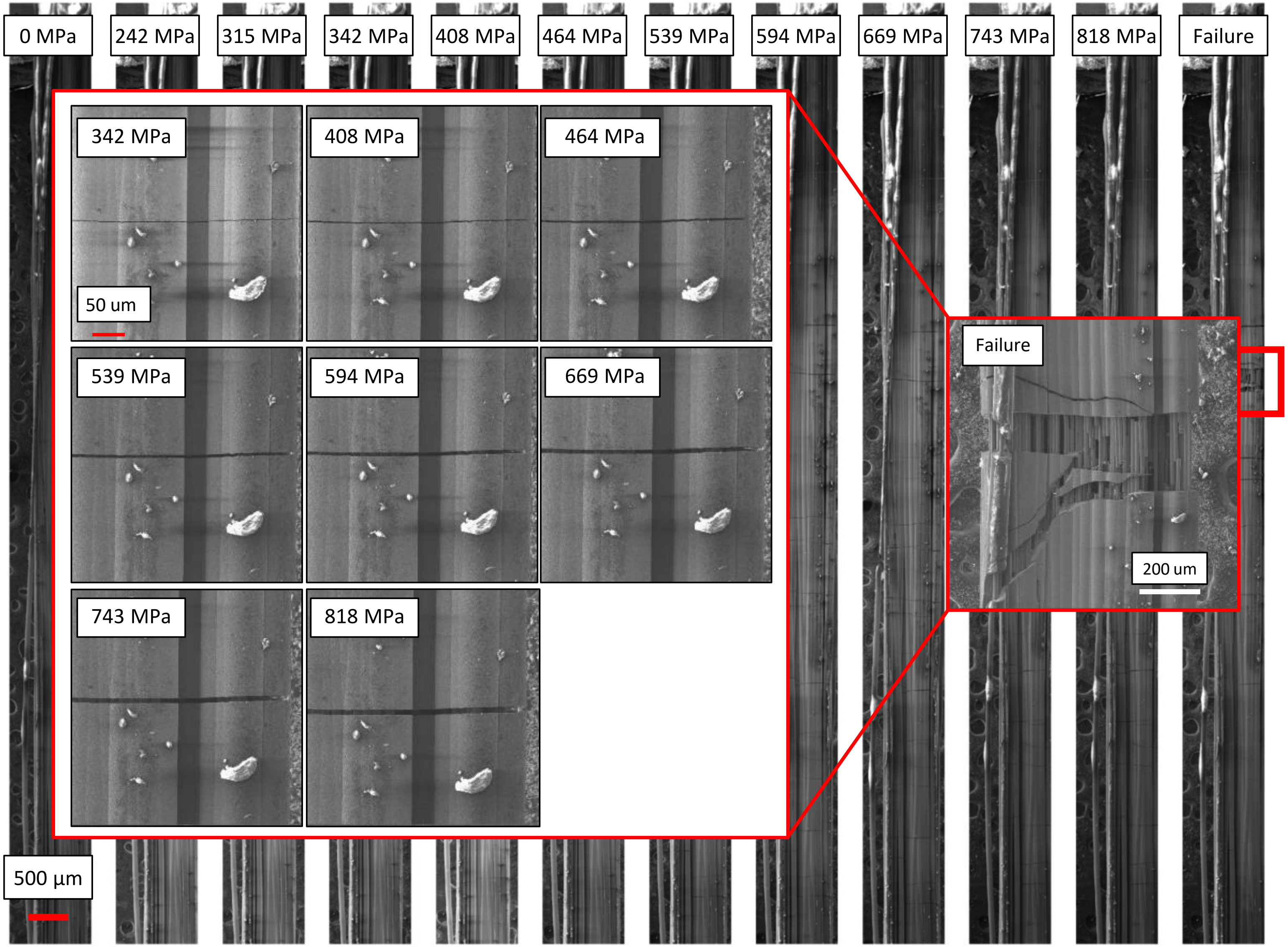


- Early damage is dependent on the population of flaws
- Early cracking did not affect global linear-elastic response
- AE can detect early damage formation
- A robust alignment method is needed to correlate AE with damage

AE Show Single Crack Information and Directionality of Local Crack Networks



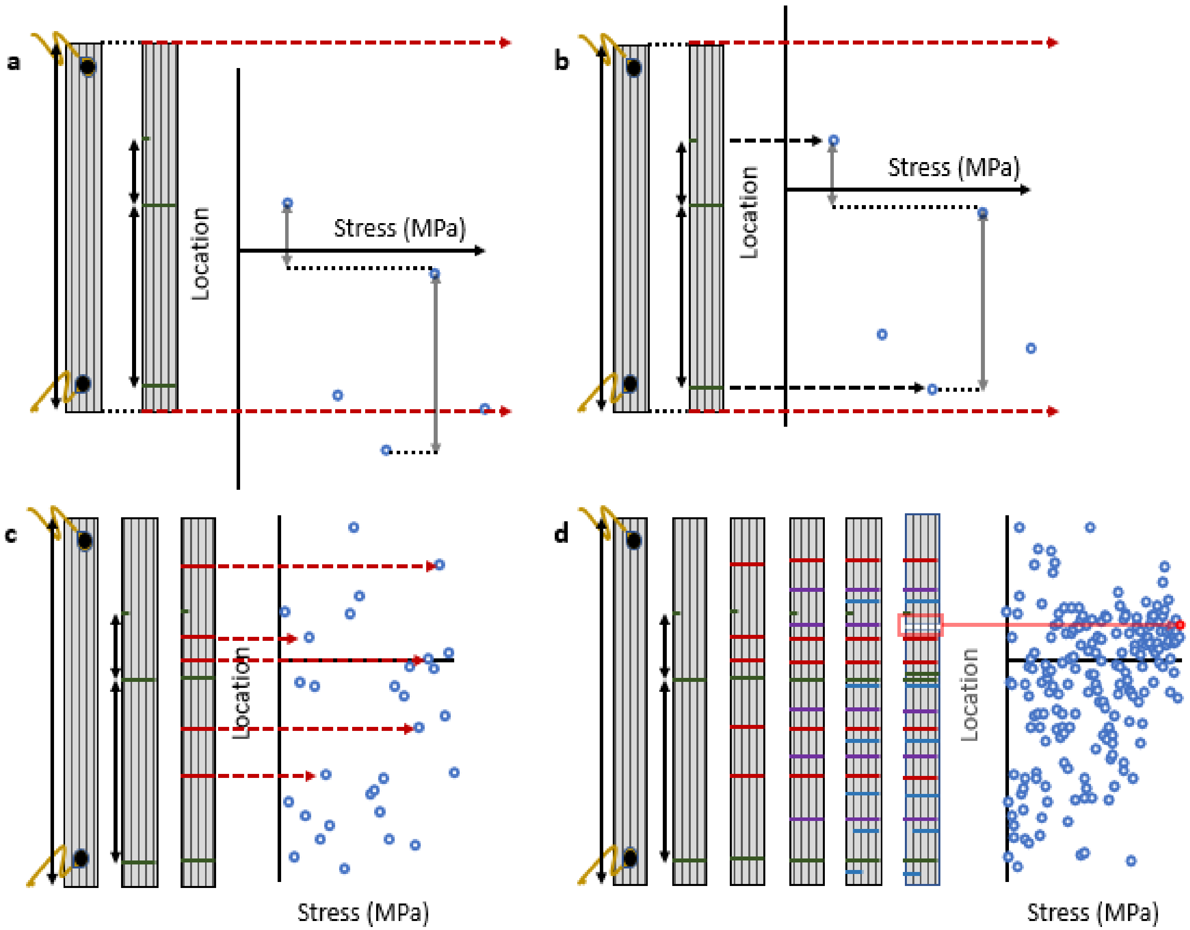
Incremental Loading Used to Capture Damage Progression in Minicomposites



Improved Alignment Scheme to Correlate Damage Mechanisms with Local AE Activity

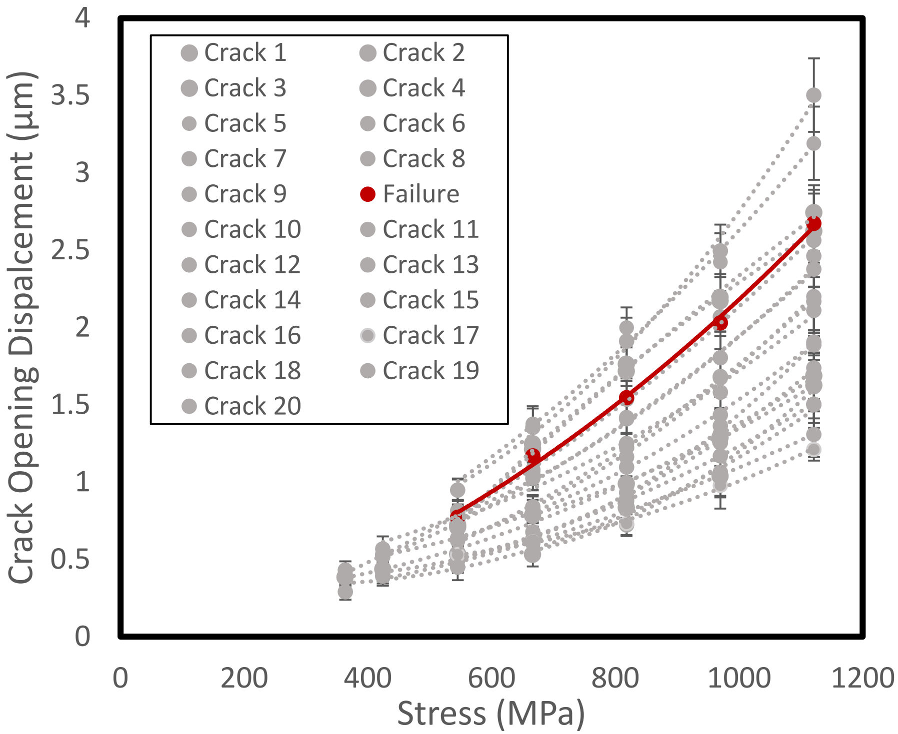
$$Location = \frac{x}{2} \cdot \left[\frac{\Delta t}{\Delta t_x}\right]$$

x = sensor separation
Δt = arrival time difference
Δt_x = difference in arrival times from events outside of the gage

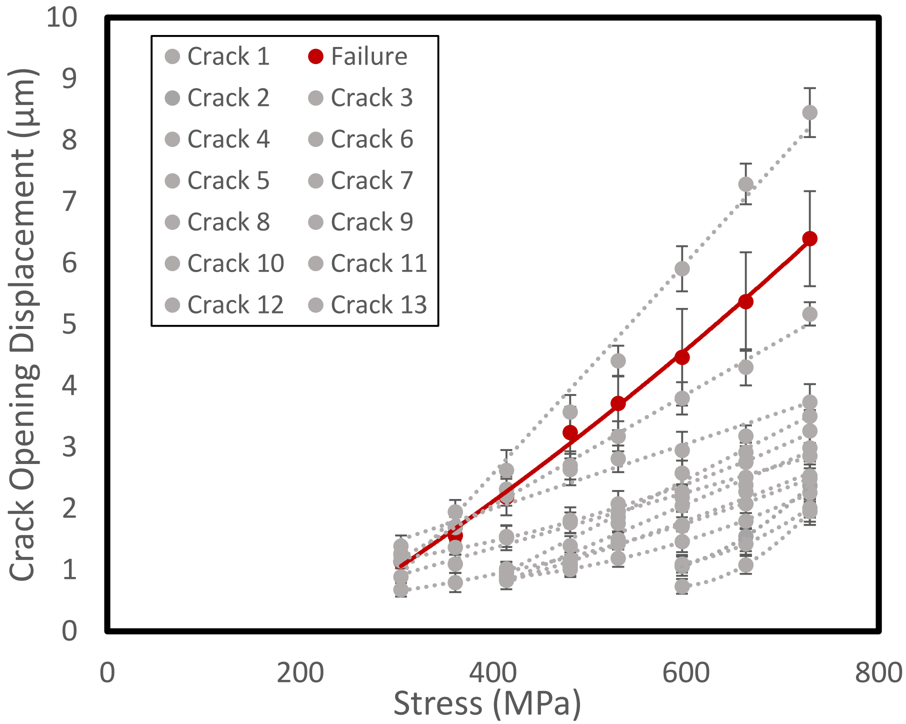


Fiber Content Drives Variation in Crack Opening Displacements (CODs) Between Batches

High fiber content

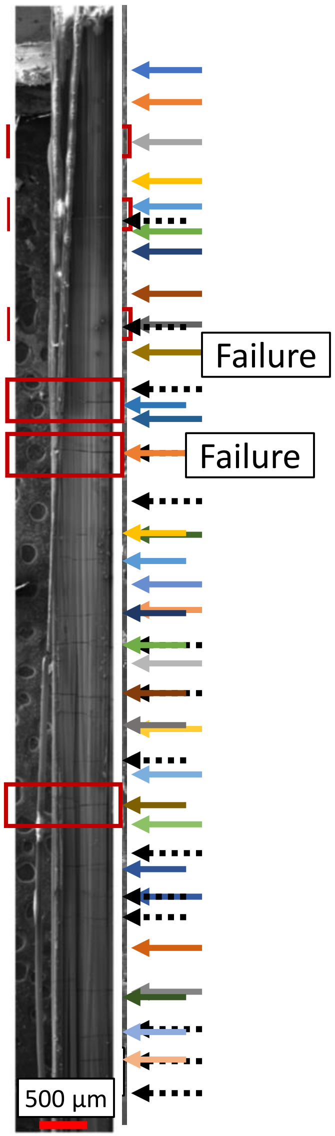


Low fiber content

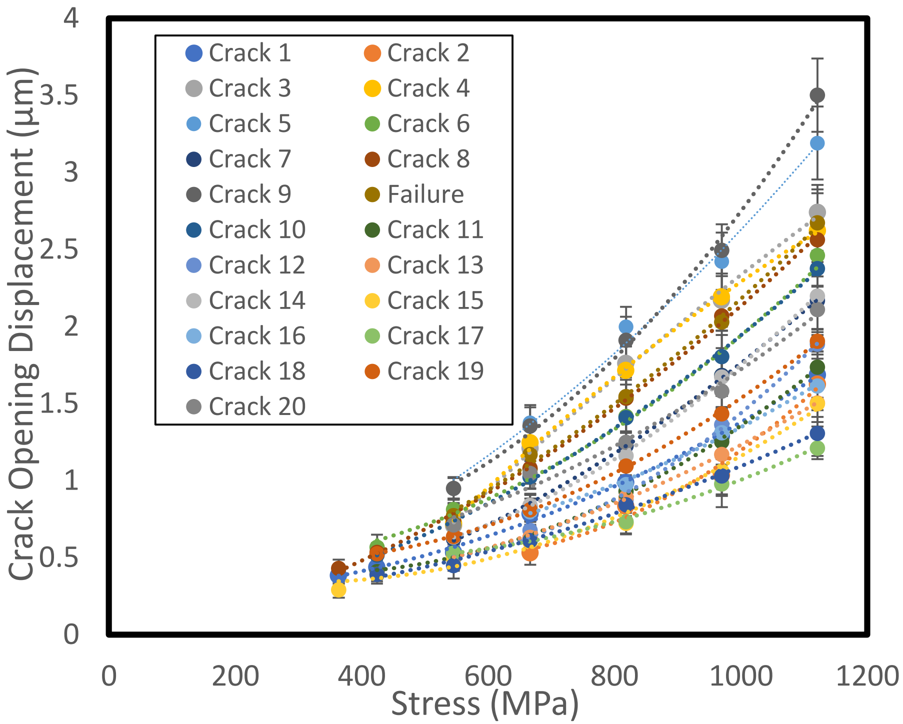


Local interfacial changes may be responsible for variations from predicted parabolic relationship of stress and crack opening displacements (COD)

Microstructural Interactions and Local Stresses Drive Variations in Crack Spacing

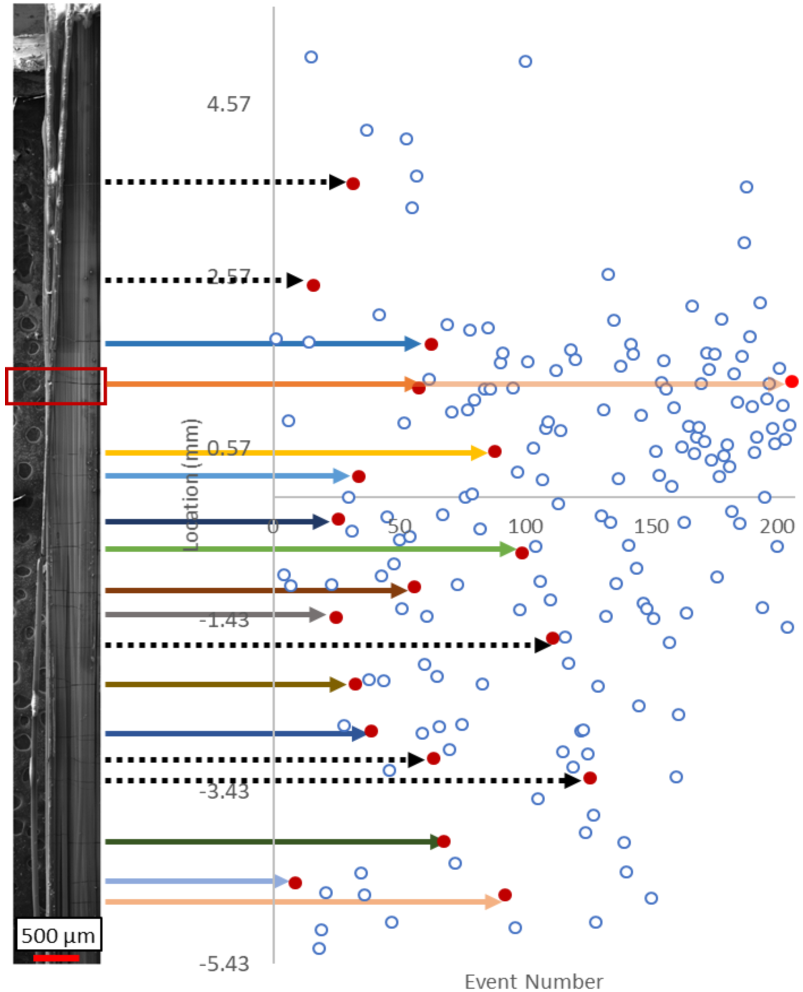


High fiber content

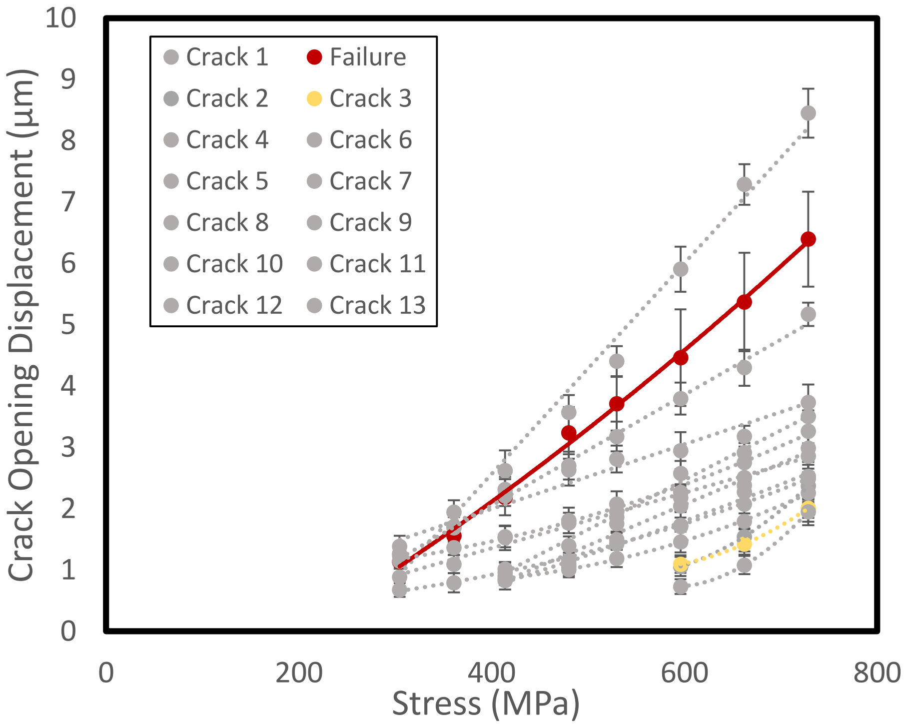


Variations in matrix pathway relative to loading direction, porosity, interfacial properties, interactions of cracks with fiber surfaces, subsurface differences in crack morphology

Global AE Activity Shows Prediction of Failure Region in Advance of Failure State



Low fiber content

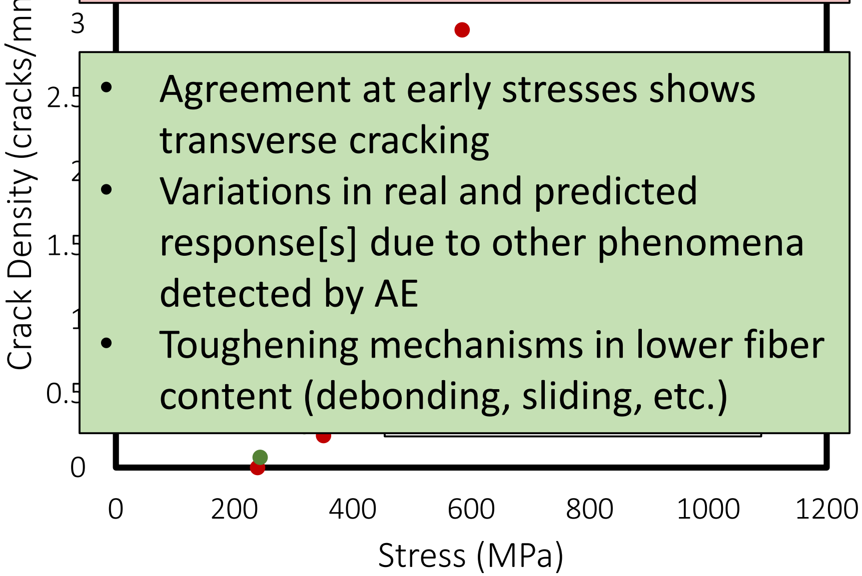


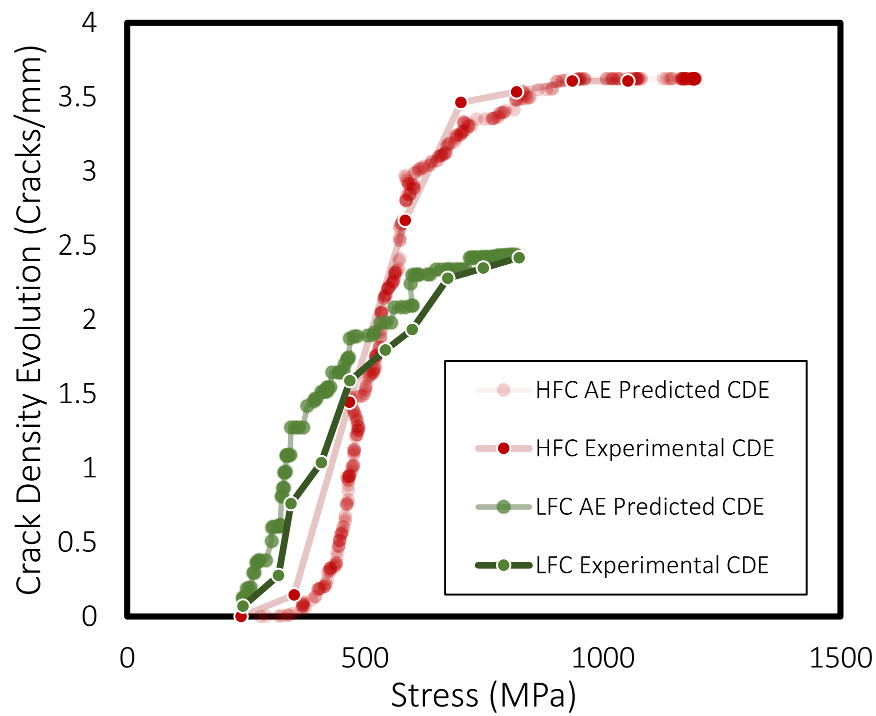
In-SEM Crack Density Evolution (CDE) Validates AE-Predicted Evolution

$$CDE(N) = \mathrm{CD}_{\mathrm{rupture}} \cdot \frac{\text{Cumulative AE(N)}}{\text{Cumulative AE at crack saturation}}$$

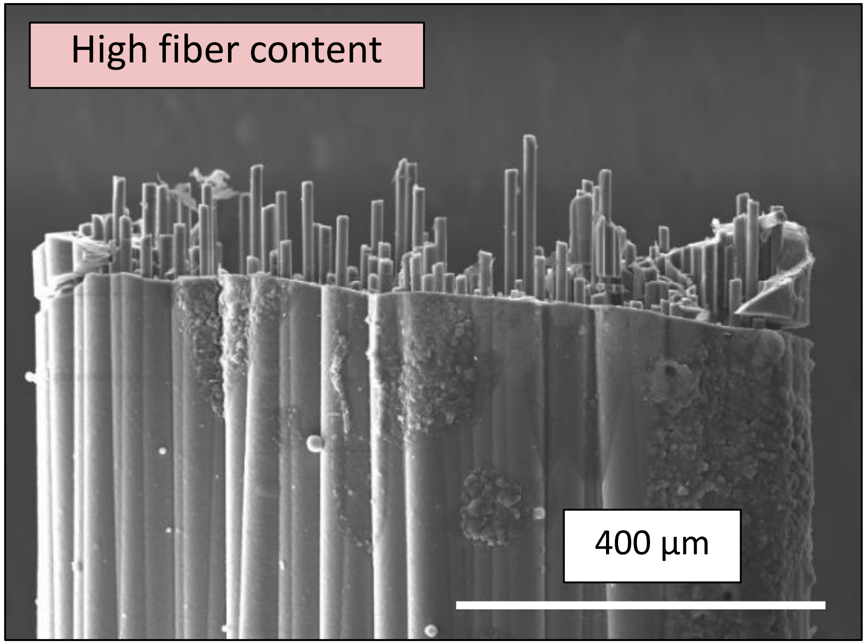
- Agreement at early and intermediate stresses shows transverse matrix cracking dominance

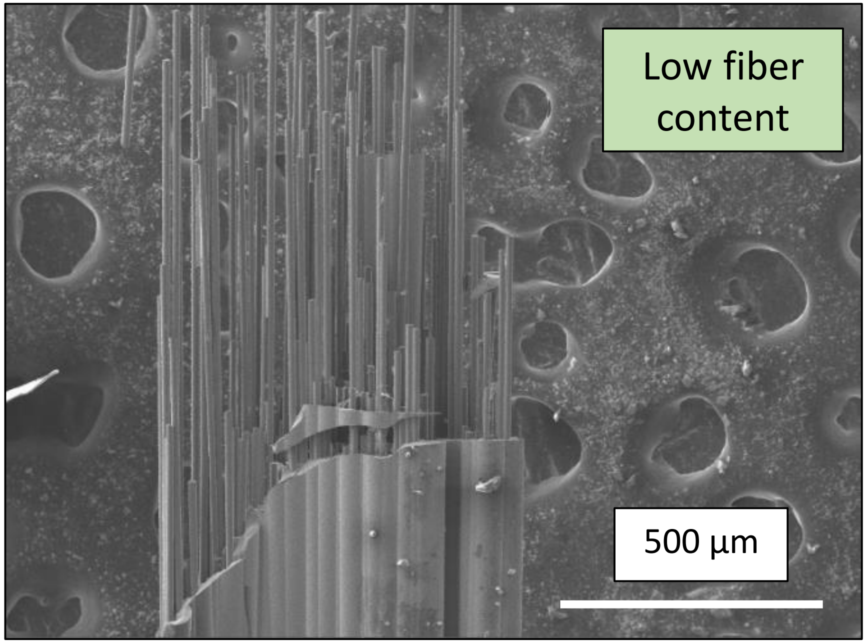
- Agreement at early stresses shows transverse cracking
- Variations in real and predicted response[s] due to other phenomena detected by AE
- Toughening mechanisms in lower fiber content (debonding, sliding, etc.)





Differences in Fiber Pullout Indicate Relative Activation of Toughening Phenomena





Limited fiber pullout

Extensive fiber pullout

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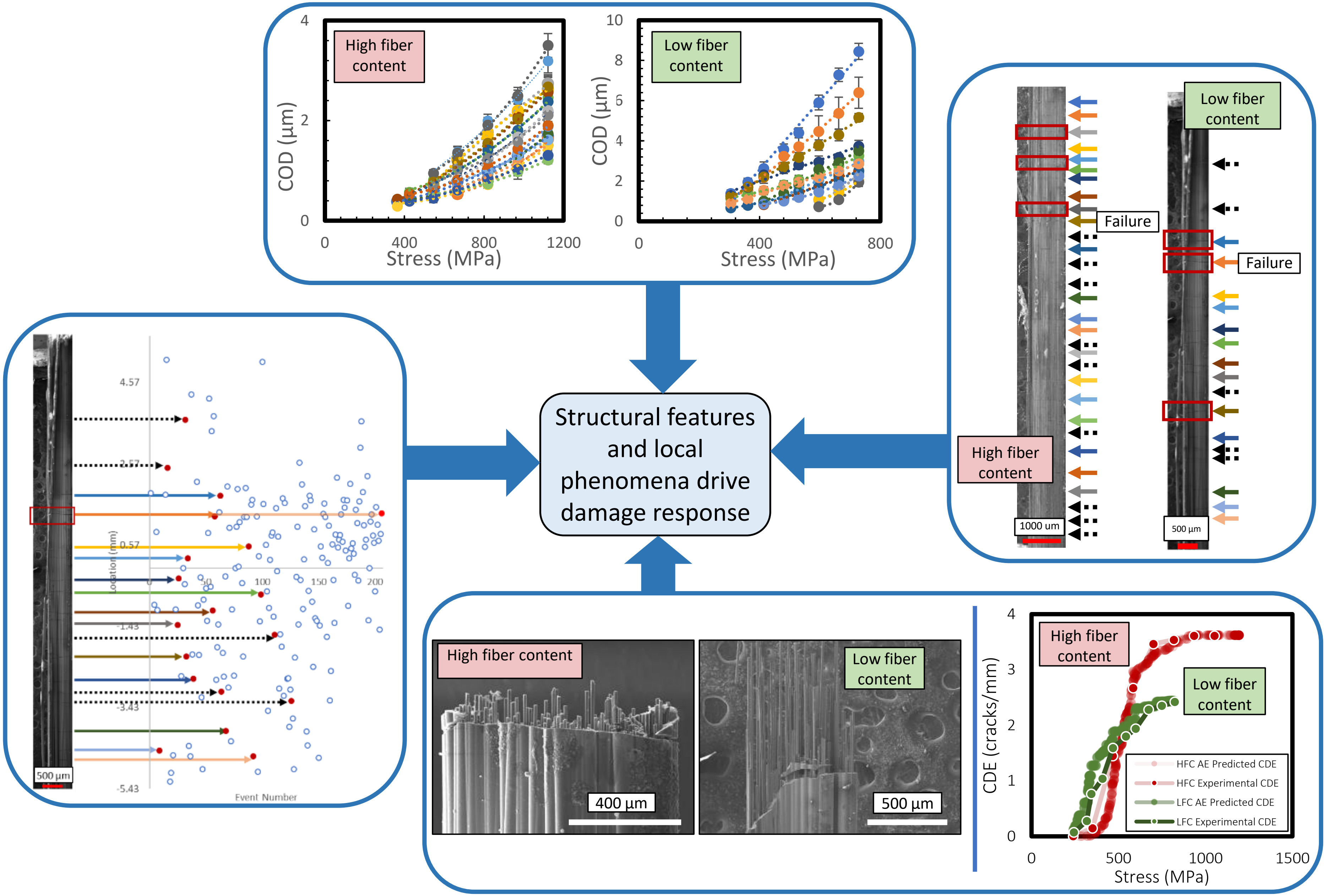

Acknowledgements

Collaborators at UCSB

- Daly Group
- Dr. Zhe Chen
- Mr. Ben Callaway
- Mr. Kirk Fields
- Mr. Mark Cornish
- Mr. Chris Torbet

Collaborators at GRC

- Mr. Pete Bonacuse
- Dr. Wayne Jennings
- Dr. Craig Smith
- Dr. Richard Rauser
- Mr. Aaron Thompson

We gratefully acknowledge funding provided by the
NASA Space Technology Research Fellowship Program

Future efforts

Goal: To quantitatively characterize the interactions between constituent landscape and the early accumulation and evolution of surface/sub-surface damage in CMCs.

- Characterization of CVI SiC/SiC minicomposites
- Interpreting signal-specific AE features associated with damage modes

- Modeling the mechanical response of CMCs
- Characterization of damage at laminate length-scale
- Characterization of damage under thermo-mechanical / environmental conditions
- Statistical framework to interpret extremely large data sets

Results will yield insights on the relationships between temperature, environment, stress, and damage