Multiscale Mechanics and Failure Analysis of Wind Turbine Composites by Experimental Characterization

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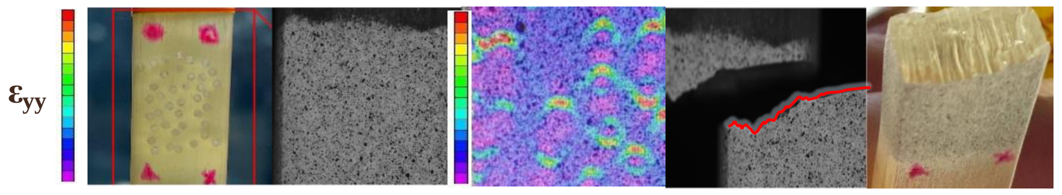
Research Overview

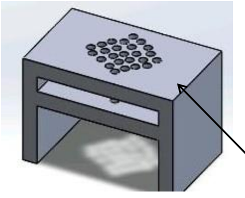
- One of the primary types of damage found in wind turbine blades is macro-scale transverse cracks.
- Fiber-matrix debonding is considered the precursor for transverse cracking and matrix failure in fiber composites subjected to tensile and/or bending loading conditions.
- This study uses an experimental approach to systematically characterize the fiber-matrix interface debonding at different length scales, from single-fiber to RVE scales.

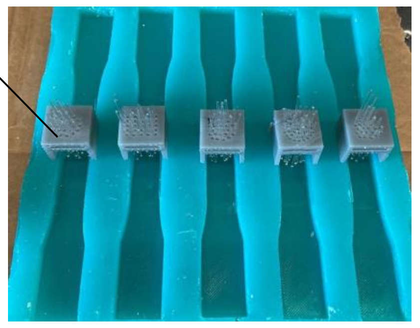


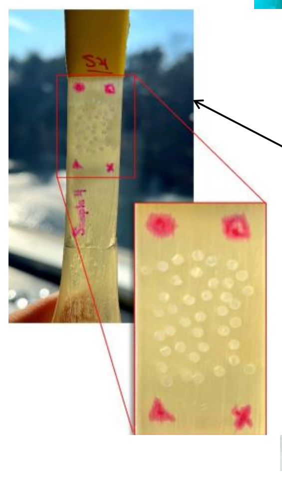
Development of a transverse crack in an epoxy sample with 39 Macro fiber

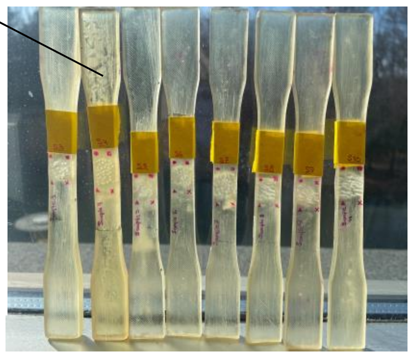
Sample Preparation & Characterization

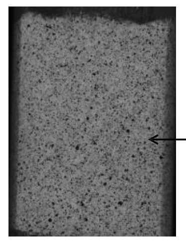
- According to ASTM D638, tensile samples were prepared by embedding >25 glass macro fibers (1mm dia.) in a thermoset epoxy resin to replicate RVEs in transversely loaded fiber composites.
- To prepare the tensile samples, macro glass fibers were held in place over a silicon mold using 3D-printed jigs and cured at room temperature.
- After curing, samples were polished using sandpaper. To better understand debonding shapes were applied on the corner of AOI.
- A speckle pattern was applied on the front (camera-facing) surface for high-magnification DIC measurements.

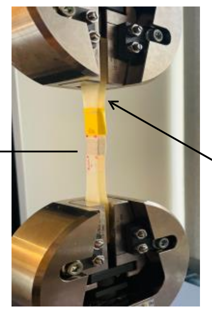

3D printed Jig

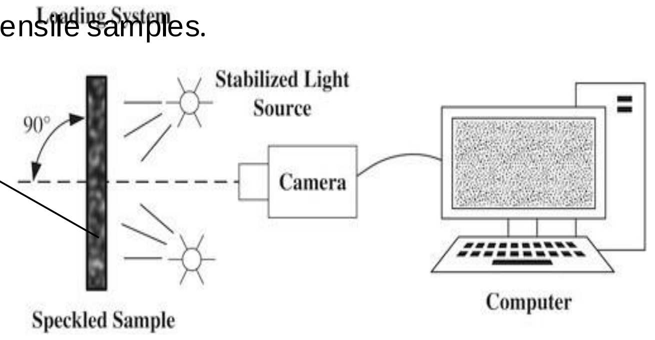

Silicon Mold


AOI of one of the tensile samples.


Cured tensile samples


Speckle pattern applied on the AOI of the tensile sample.

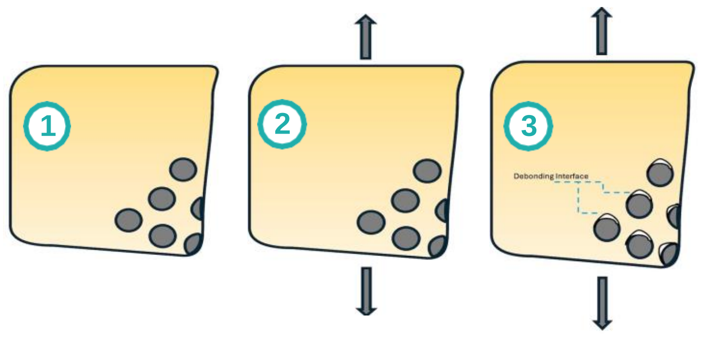

Tensile Sample placed in the grips of a universal testing machine



Schematic of the proposed experimental approach for debonding characterization and crack propagation.

Sample Preparation & Characterization

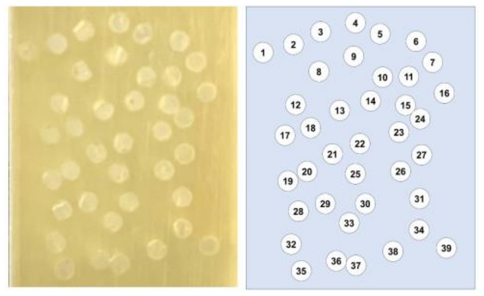
Interpretation of Debonding Mechanism:



1. Initial state
2. After the application of a tensile load and before debonding initiation
3. Upon increasing the tensile load and the formation of a debonded interface

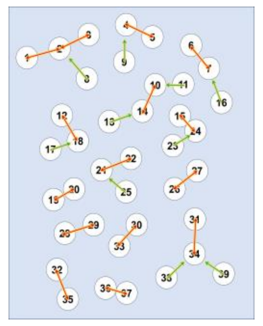
Fiber geometry:

- Epoxy dog bone with 39 randomly distributed glass fibers (1 mm).


Assigning a case number from 1-39 for the 39 fibers.

Results

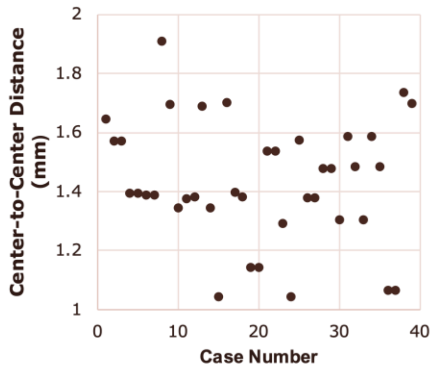
Key Finding 1: Fiber Coordinates for the random fibers (Distance & Angle)

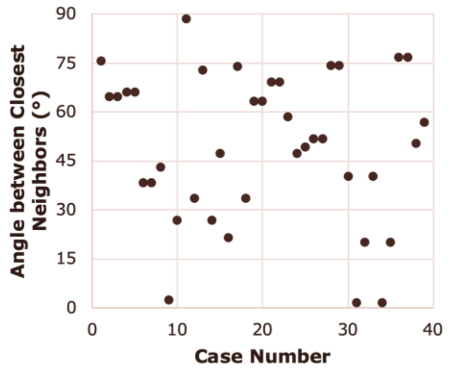

ImageJ was used to find the angle and distance between neighboring fibers.

Fiber distance: "**1**" on the *y*-axis reveals a very close distance between the fibers (almost no gap between them).

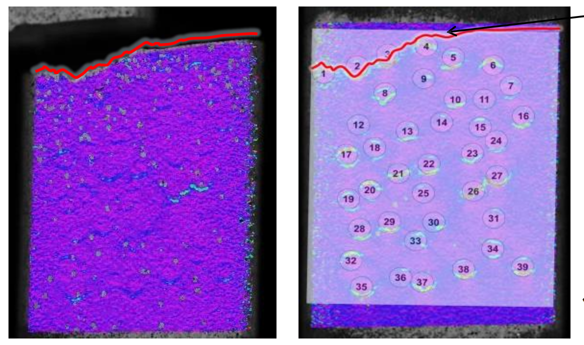
Fiber angle: "0°" reveals that the fiber is completely aligned with the loading direction, while "90°" means the fiber is perpendicular to the loading direction.

- Fiber distance and angle can help us determine how a crack starts and propagates.





Key Finding 2: Transverse crack path

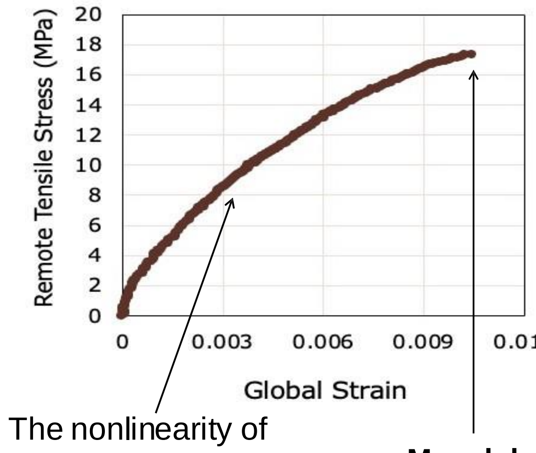


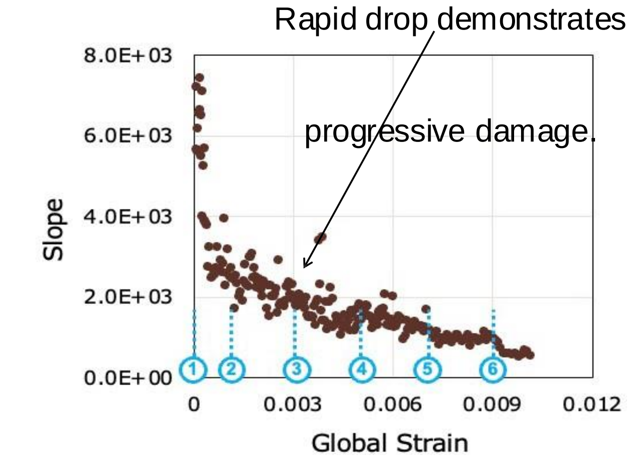
Appearance of transverse crack.
Overlay of the crack path & just before the sample breaks.

- Upon applying tensile stress, the fiber-matrix interface undergoes locally high stresses, initiating an interface opening at the upper/lowermost region along the interface.
- Crack development starts from case fiber 1 and quickly merges to 2,3 and 4.

Results

Key Finding 3: Global Stress-Strain



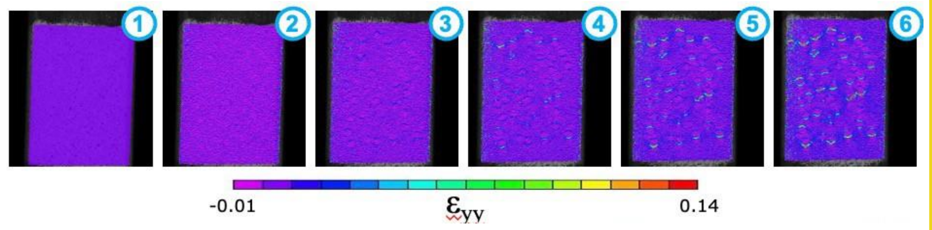


Rapid drop demonstrates progressive damage.

The nonlinearity of the curve due to damage evolution.

Max debonding

- Global strain measured by optical extensometer.
- The intensity is higher where the fibers are located. It is also highest at the top (forming red bands).



Strain development in y Direction

Conclusion

- DIC enabled accurate and high-resolution characterization of the strain fields.
- The strain evolution can effectively indicate the interface debonding initiation transverse matrix failures in fiber composites.
- The fiber coordinates and the relation between angle and distance can determine how the transverse crack develops and propagates.

Future Work

- Employ electrospray deposition to coat fibers with nanomaterials (e.g., carbon nanotubes) to improve damage/fracture resistance and delay crack propagation.
- Hybridizing fiber composite (e.g., glass and carbon). Although carbon and glass fiber composites are quasi-brittle materials, they can show pseudo-ductility when they are hybridized intelligently.
- Extract the local strain between the fibers and plot based on global strain to predict precisely the location of the transverse crack based on local strain.
- Using hybrid approaches, DIC analysis & finite element models to cross-verify.

Acknowledgements

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