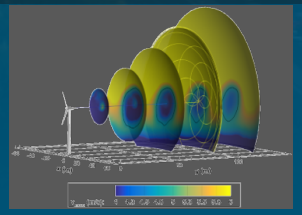
SAND2021-6276C

Sandia National Laboratories

Understanding the Uncertainty in Static Strength Predictions of Composite Laminates in Wind Blades



PRESENTED BY

Ryan Clarke, Ernesto Camarena, and Josh Paquette

U.S. DEPARTMENT OF ENERGY NNSA

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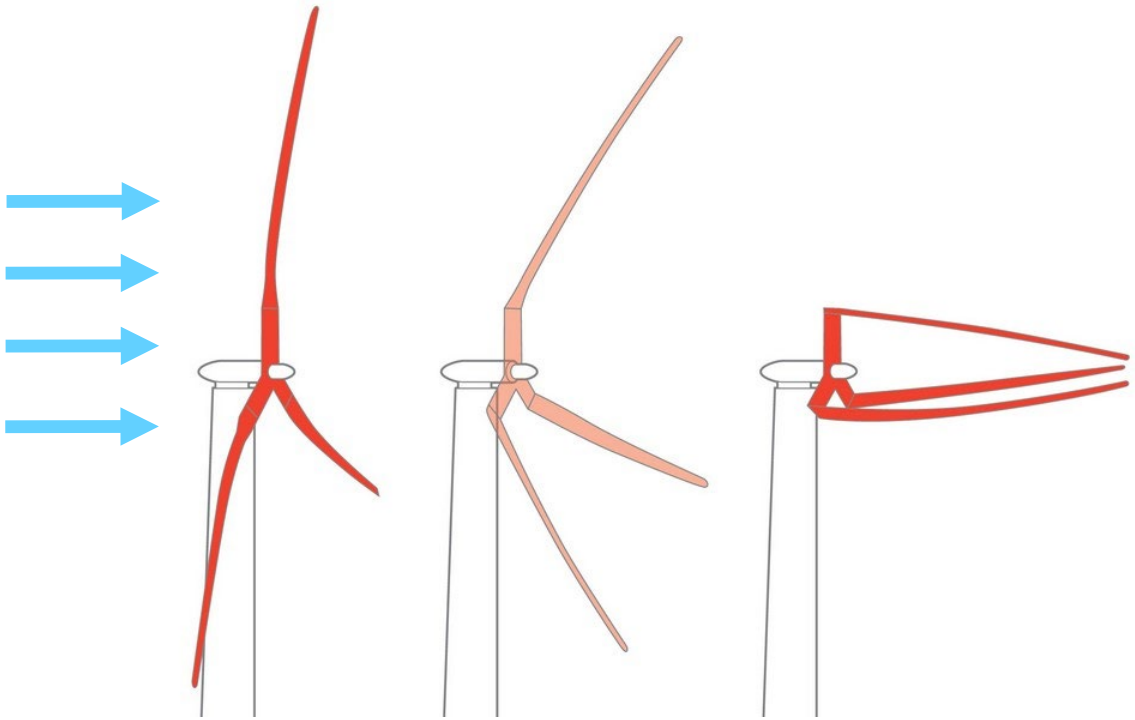
Introduction

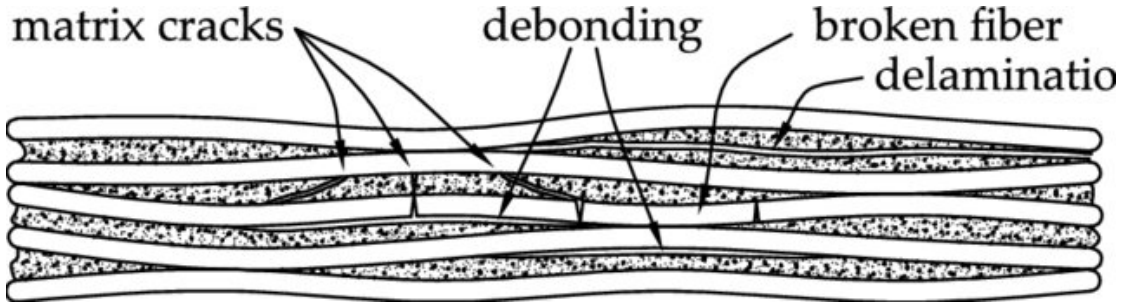
- In recent years highly flexible downwind rotor concepts have been proposed for example the SUMR rotor.
- Highly flexible downwind rotors have the potential to be strength limited design.
- Downwind rotors have been shown to induce higher torsional loads as well as large bending stresses and strains leading to more complex stress states in the wind blade composite structure.



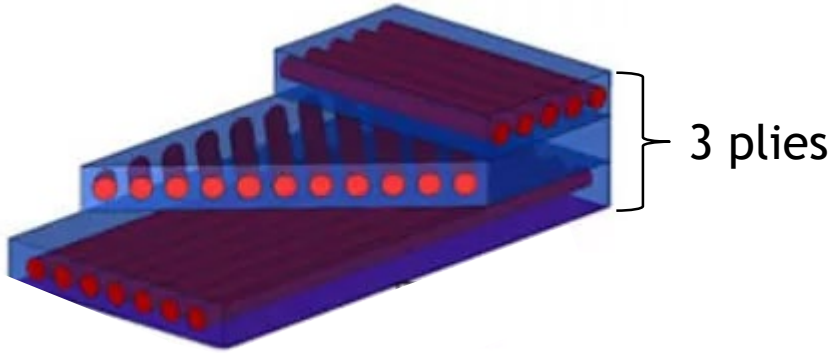
Segmented Ultralight Morphing Rotor (SUMR) – Downwind turbine concept [1]

What are composite failure criteria?

- Damage and failure occur differently in composites compared to more traditional, well-established materials like metals
- Composite failure criteria are based on a ply-by-ply prediction



Different damage mechanisms in fiber-reinforced composite materials [2]



Artist rendering of composite plies that make up a laminate [3]

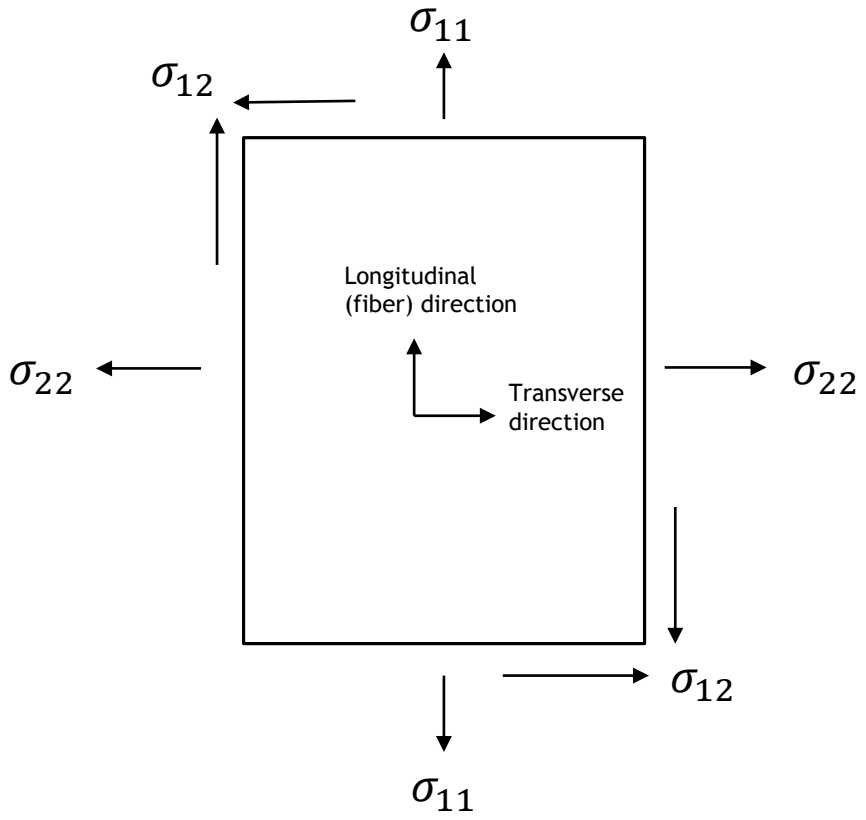
Failure Criteria

- Limit or non-interactive theories:
  - Max Stress
  - Max Strain
- Interactive theories:
  - Tsai-Wu
- Failure mode base or mechanistic theories
  - Puck

    Inclination angle parameters: $p_{\perp\parallel}^{(+)}, p_{\perp\parallel}^{(-)}, p_{\perp\perp}^{(-)}$

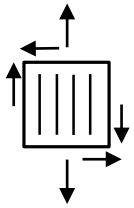
    degradation exponent: n
  - LaRC03

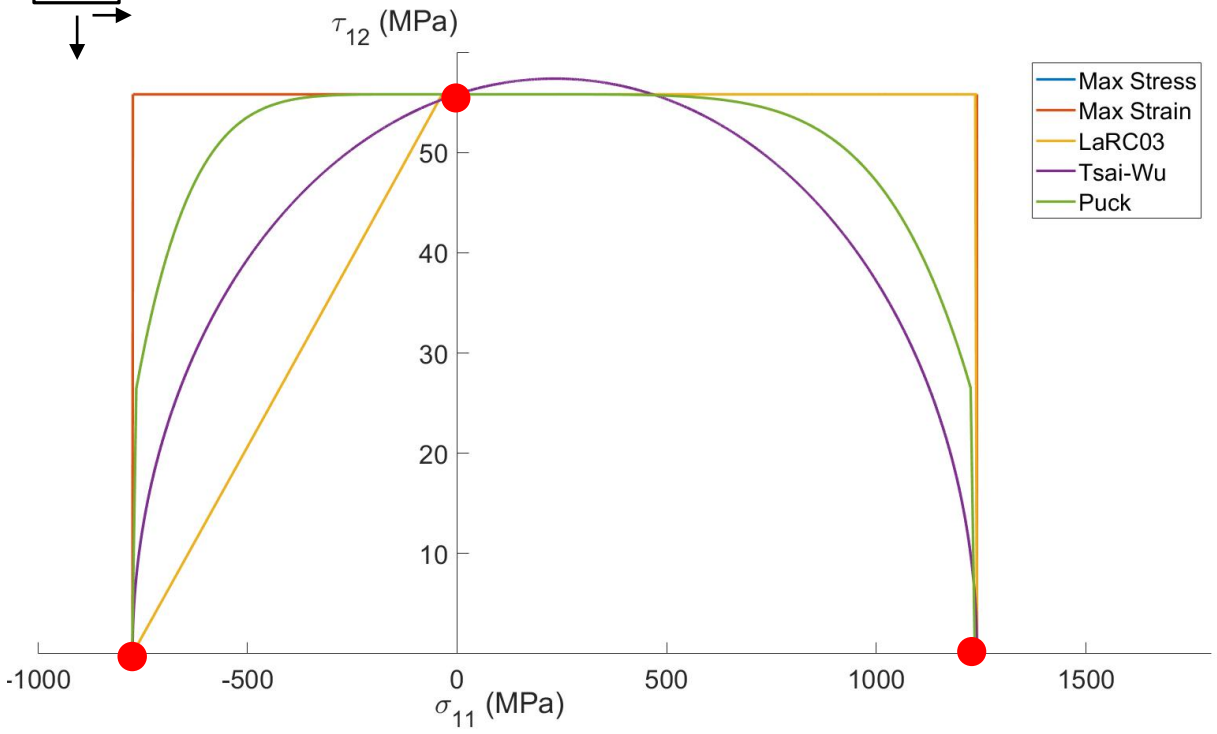
    Maximum fracture angle: α_o

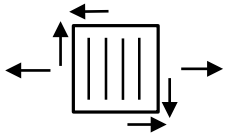


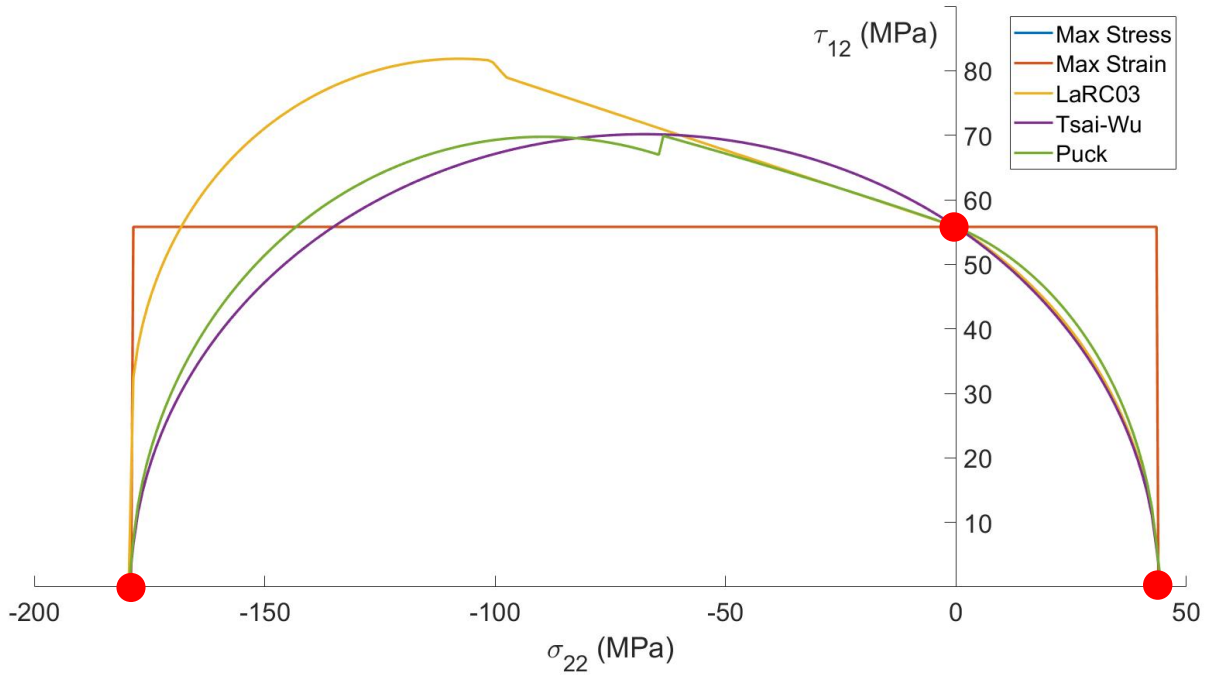
In-plane stress notation

Unidirectional Ply Failure Envelopes



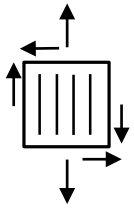


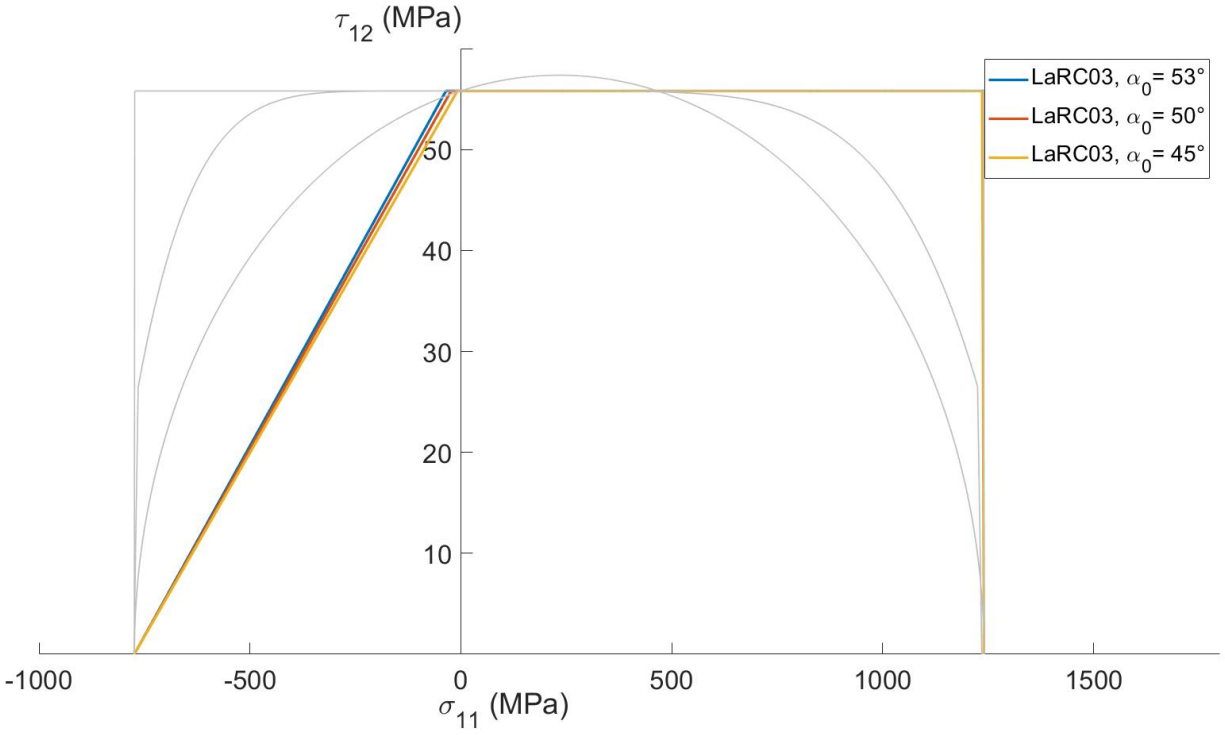


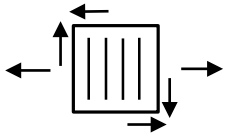


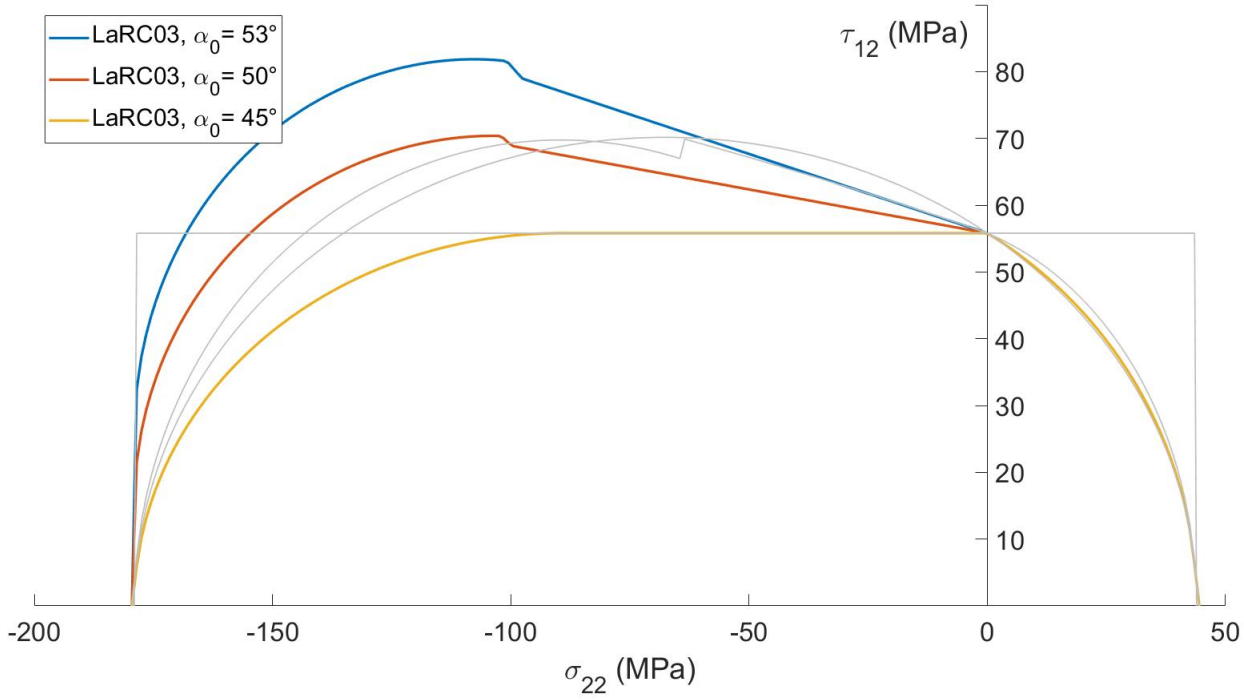
- Have wind composite test data for

Variability in LaRC03 Failure Envelope

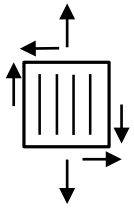


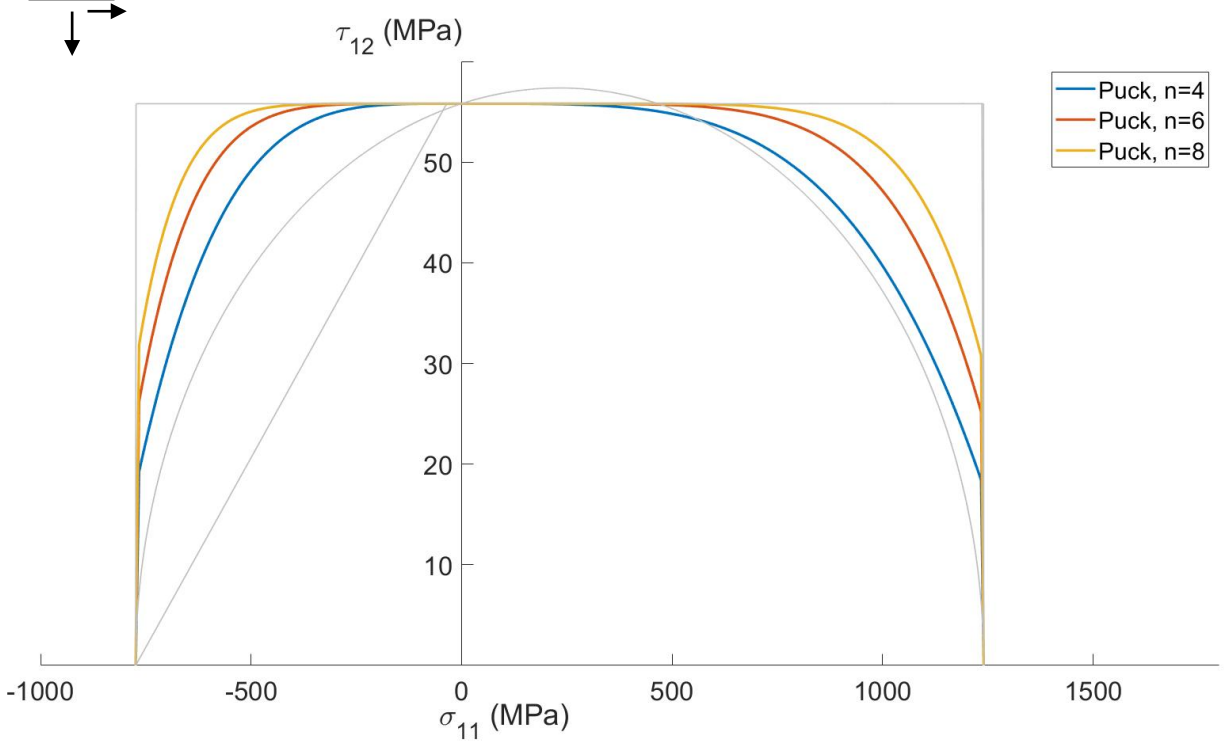


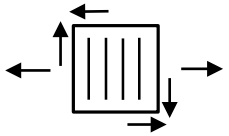


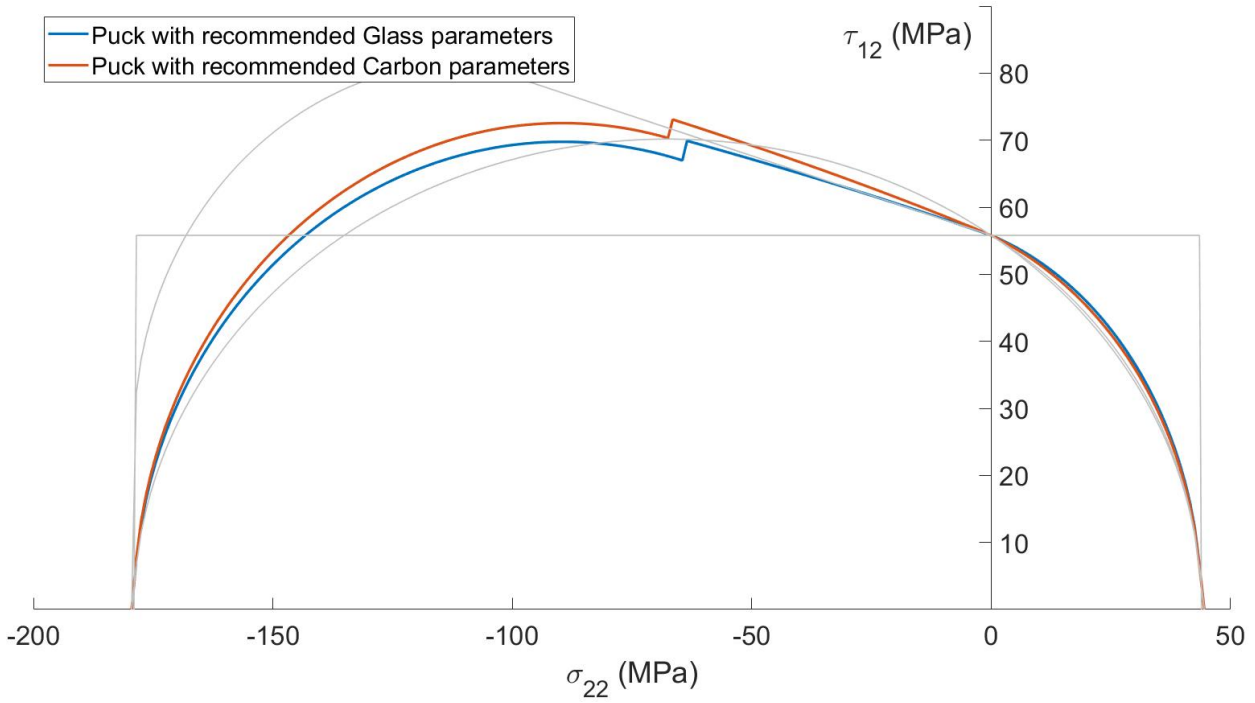


Variability in Puck Failure Envelope









Stitched fabrics and failure

- Wind blades are mainly manufactured using multidirectional stitched fabrics and not individual unidirectional thin plies (i.e. prepregs)
- It has been shown that Classical Lamination Theory with thin individual ply assumption can still accurately predict the elastic behavior of stitched fabrics, however there are key differences in the strength between the two systems.
- The assumption of transverse isotropy no longer holds [5]

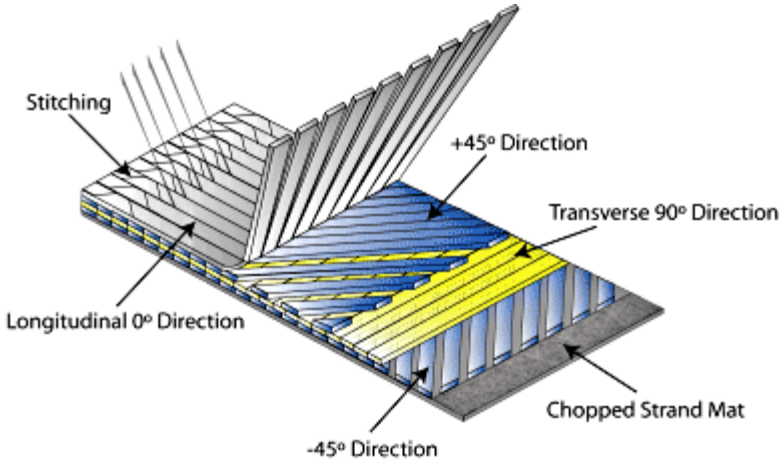
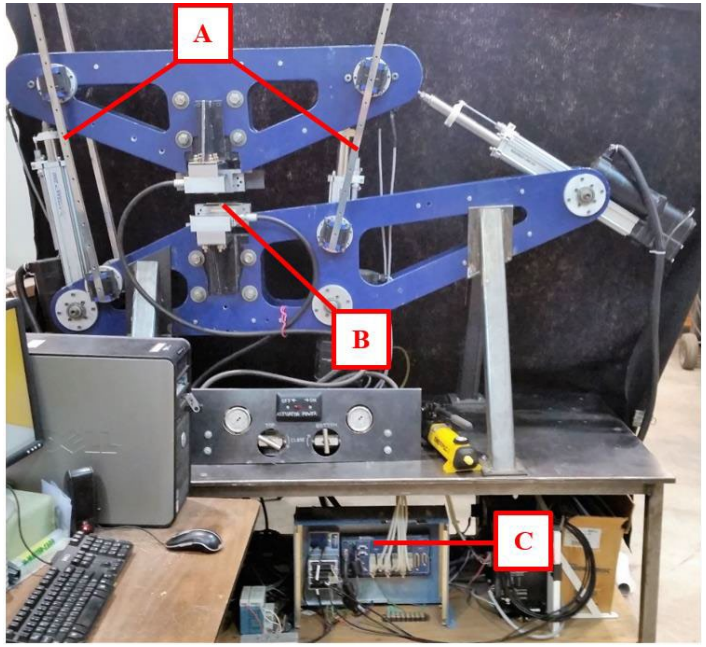


Diagram of a stitched fabric [4]

Need for multiaxial testing

- Having multiaxial test data can be used to calibrate and validate failure models
  - Can be used as a method for indirect determination of composite material parameters such as fracture angle for LaRC03, inclination parameters and degradation exponent for Puck,
  - Calibration, and validation of progressive failure models for multi-ply laminates



Montana State University's In-Plane Loader [6]

Navy Research Laboratories 6 DOF NRL 66.3 Load Frame [7]

Conclusions

- Failure criteria are only as good as their inputs
- There is no best failure criteria just the most suitable for your case
- There are key differences between stitched multidirectional fabrics and the unidirectional ply composites that composite theory is based on.
- Multiaxial test data can reduce uncertainty in composite laminate strength predictions and decrease conservancy of wind blade strength design.

References

[1] "Segmented Ultralight Morphing Rotor." https://www.eurekalert.org/multimedia/pub/107749.php?from=317568 (accessed May 19th, 2021, 2021).

[2] R. J. Unnborsson, M.T.; Runarsson, T.P., "NDT Methods for Evaluating Carbon Fiber Composites," pp. 1-17, 21-23 September 2004 2004.

[3] "Composites 101." https://www.quartus.com/composites-101 (accessed May 18 2021, 2021).

[4] "Stitched-Bonded Reinforcements." Vectorply. https://vectorply.com/stitch-bonded-reinforcements/ (accessed May 18,2021, 2021).

[5] D. Samborsky, J. Mandell, and P. Agastra, "3-D Static Elastic Constants and Strength Properties of a Glass/Epoxy Unidirectional Laminate," p. 26.

[6] J. Jette, "Damage Characterization of Fiber-Reinforced Composite Materials by means of Multiaxial Testing and Digital Image Correlation," Masters of Science, Mechanical and Industrial Engineering, Montana State University, 2017.

[7] J. G. I. Michopoulos, A.P.; Steuben, J.C.; Hermanson, J.C., "Multiaxial and Multiscale Implications of Dissipative Behavior of Composites," in *39th Riso International Symposium on Materials Science*, 2018: IOP Publishing.

Thank you

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