Bio-based Materials for Large Wind Turbine Blades

Prepared for: Massachusetts Wind Working Group
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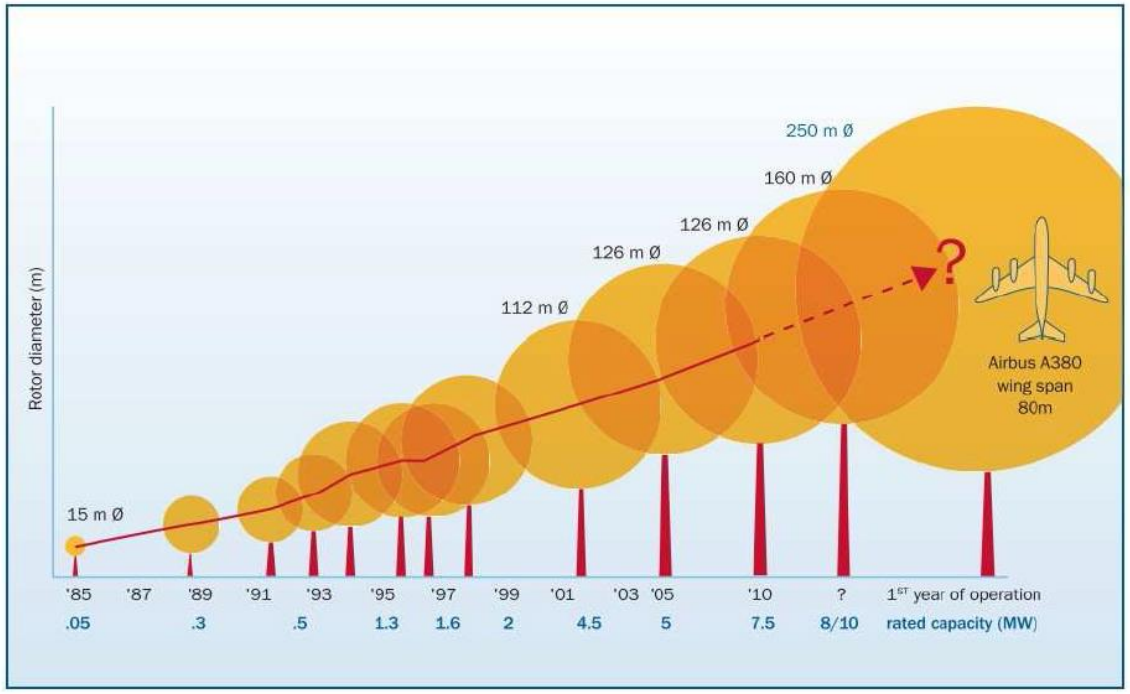
Motivation for Large Wind Energy

- 4.13% of US electricity generated by wind in 2013
- 30% of all new generating capacity from 2009-2014



Wind turbine rotor size trends
from Fichaux (2011), DTU-Riso

$$P = \frac{1}{2}\rho A V^3$$

Basic Considerations for Blade Materials

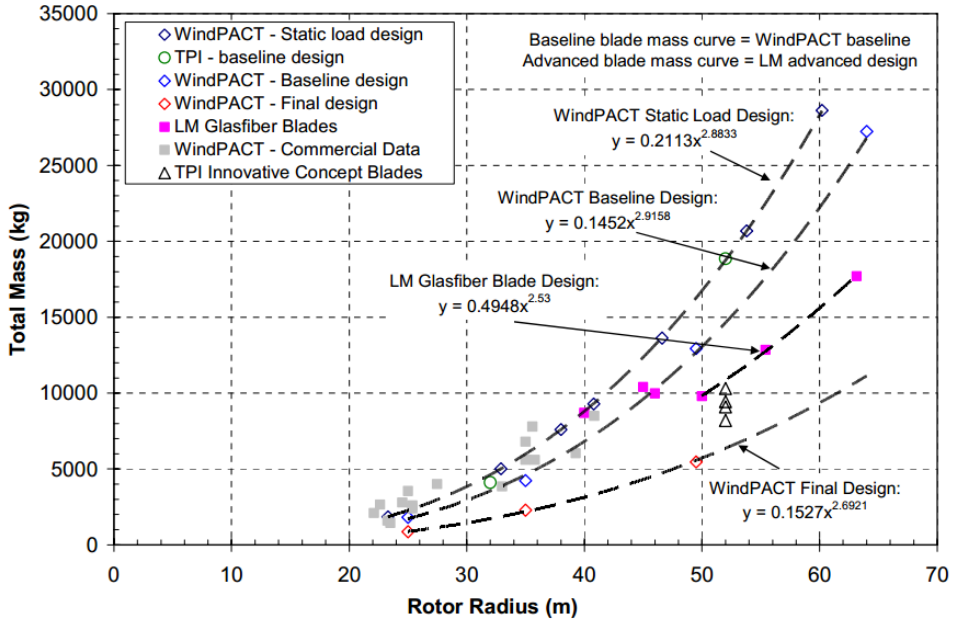
- Stiffness
  - retain airfoil shape
  - tower clearance
- Strength
  - tension, compression, bending
  - fatigue
- Density
  - influences strength requirement

Hull, MA municipal wind turbine
photo: R. Koh

Concerns with fiberglass and carbon fiber

- Fiberglass
  - mass scaling
  - recyclability / end-of-life disposal options
  - global production increase from 5.9 million metric tons in 1999 to 8.7 million in 2011
  - ~10% global fiberglass market share for wind energy and increasing
- Carbon fiber
  - expensive
  - brittle
  - energy intensive production

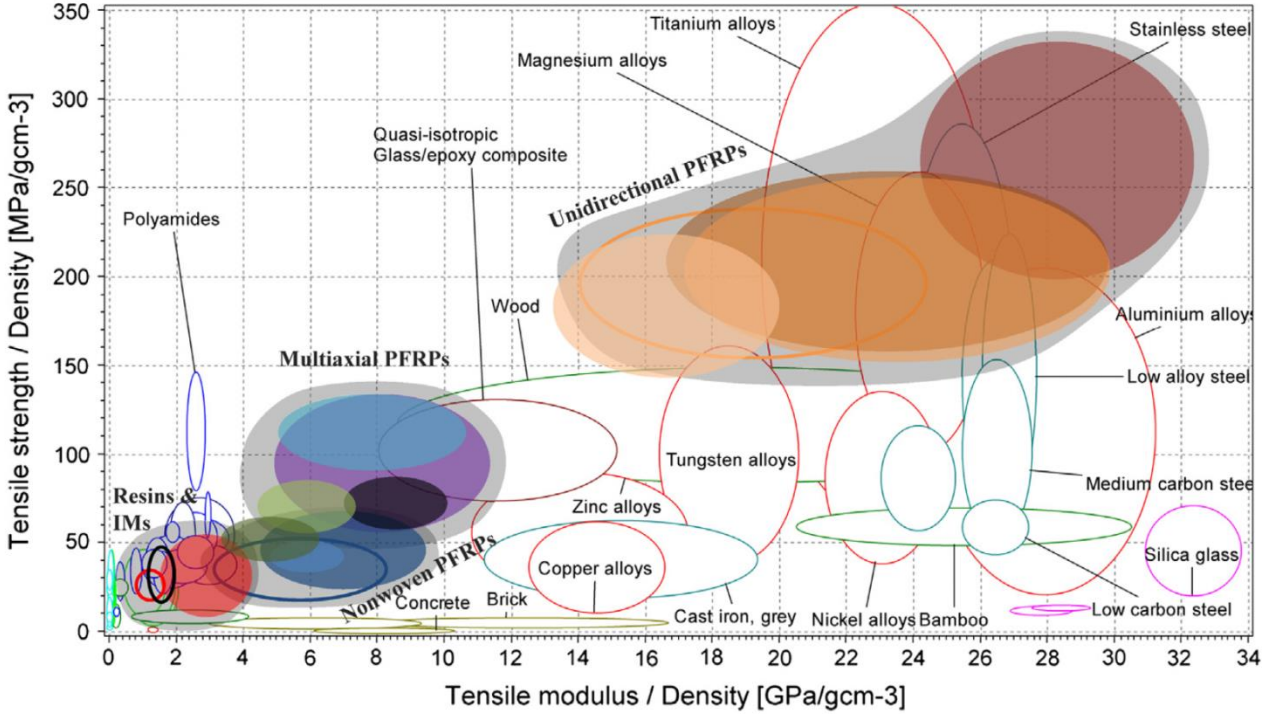
Blade Mass Scaling Relationships
from NREL Cost and Scaling Model



Advantages of Bio-Based Materials

- Competitive specific stiffness and strength
- Competitive fatigue properties

Ashby chart for Plant Fiber Reinforced Polymers
from Shah (2013) at Oxford U.



Advantages of Bio-Based Materials (cont'd)

- Renewable (unlimited resource)
- Biodegradable when triggered
- Low emissions manufacturing
  - EU- *Directive on Landfill of Waste* and *End-of-life Vehicle Directive* are seen as barriers for development and continued use of glass and carbon in some markets
- Low cost raw materials
- "Bio-inspired" and "Biomimicry" engineering

Challenges with Bio-Based Materials

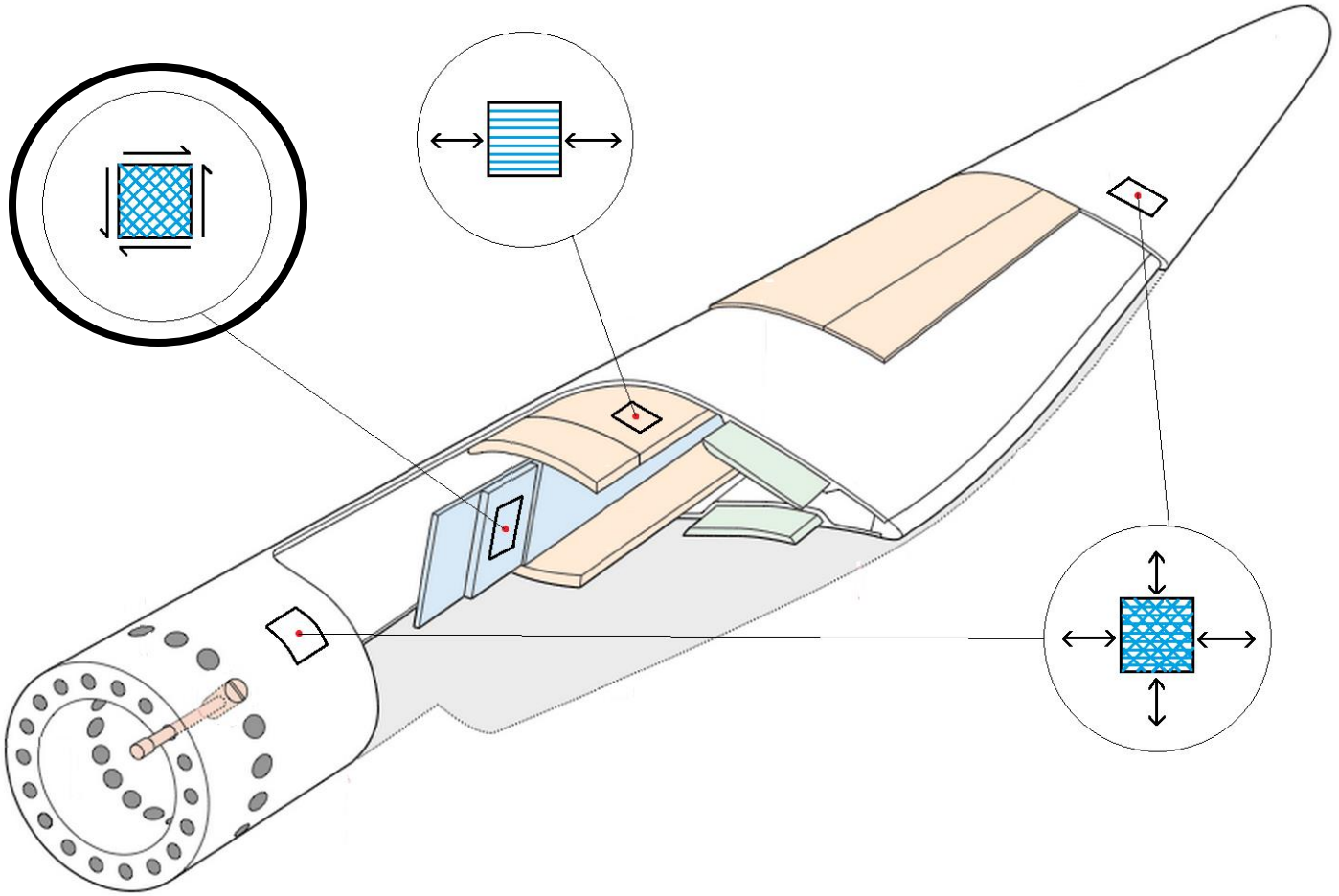
- Variable mechanical properties
- Limited experimental data for complex loading conditions such as off-axis and multiaxial loading
- High sensitivity to moisture
- Not fully developed manufacturing processes

Current Projects

- Shear Properties and Failure Mechanics of Angle-Ply Wood Laminate Beams
- Yield Criteria Assessment for Multiaxial Wood Laminate and Flax Fiber Reinforced Composites
- FEA of Wind Turbine Blades with Material Property Variability using Probabilistic Design

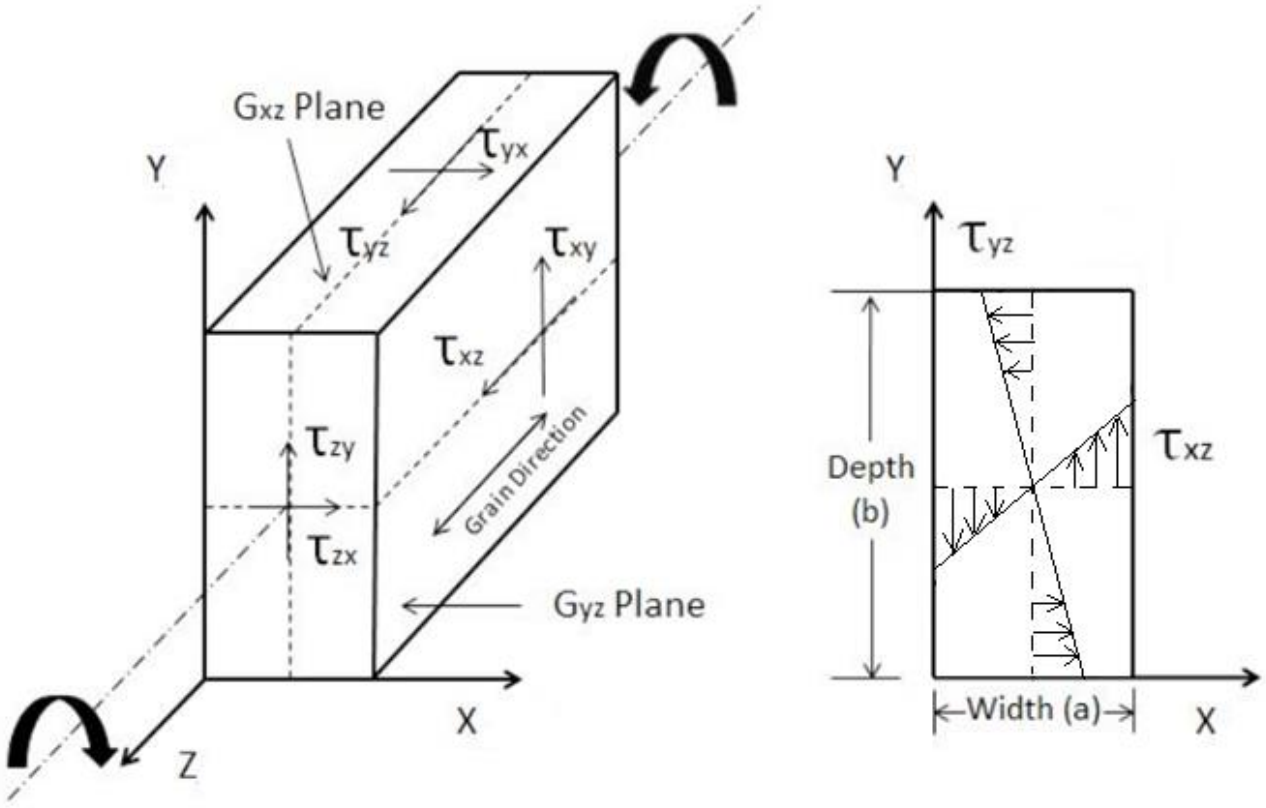
Shear Properties and Failure Mechanics of Angle-Ply Wood Laminate Beams

Multidirectional Materials in Wind Turbine Blades



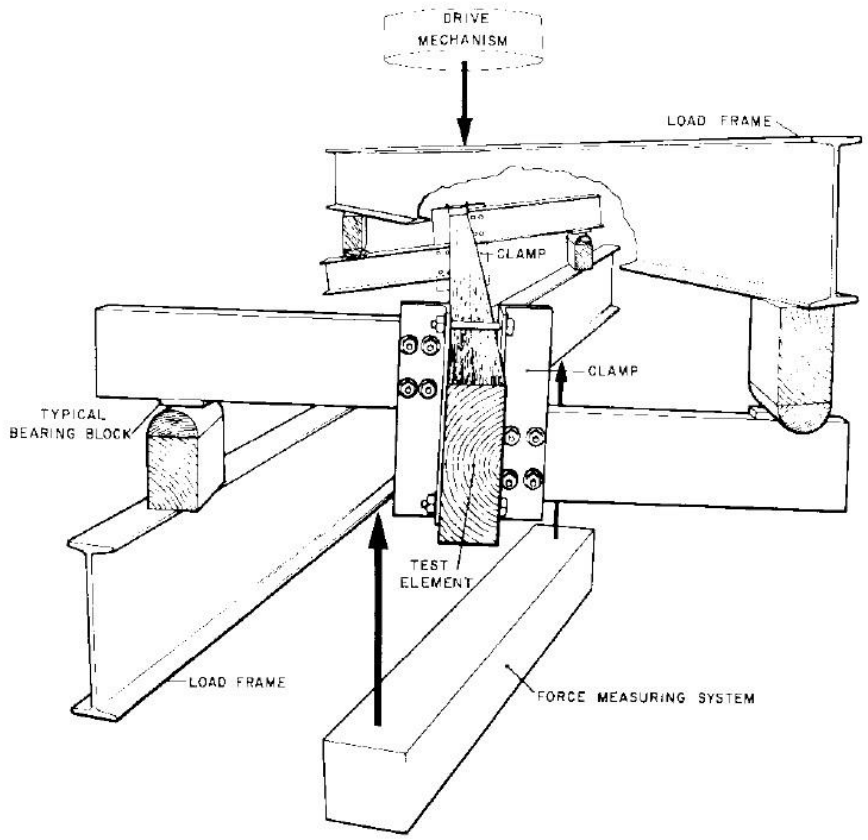
Adapted from Gurit Corporation (2014).

Torsion Test for Shear Strength and Stiffness

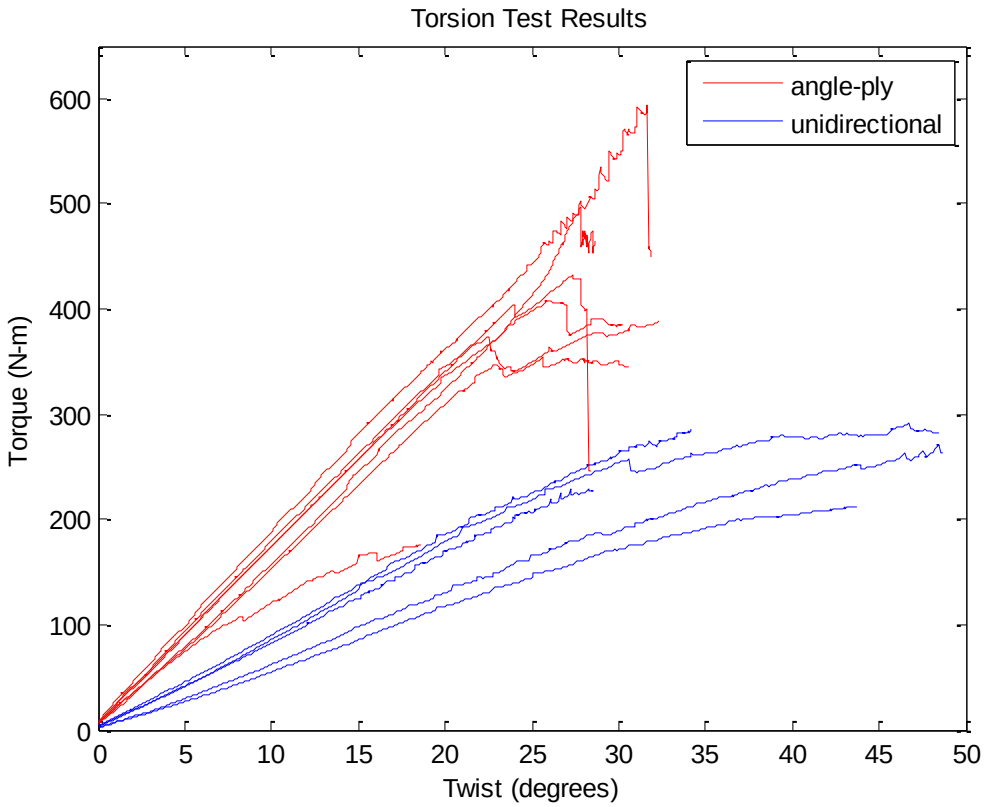


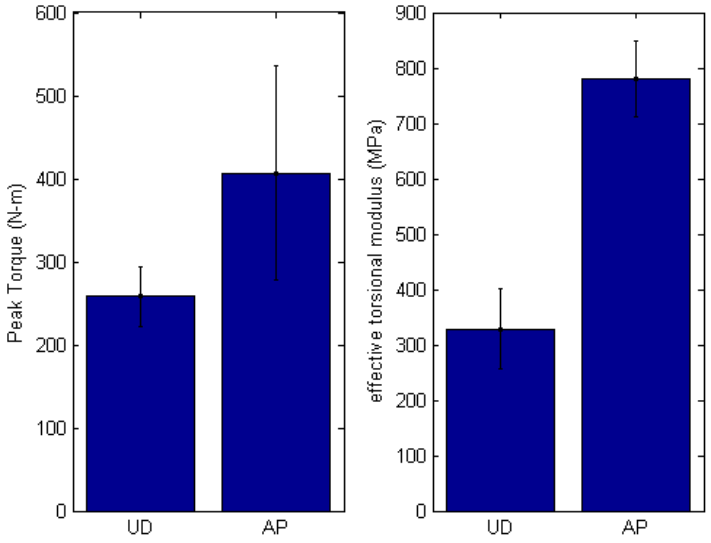
Adapted with permission from Yang (2012).

Torsion Test Configuration (ASTM D198)

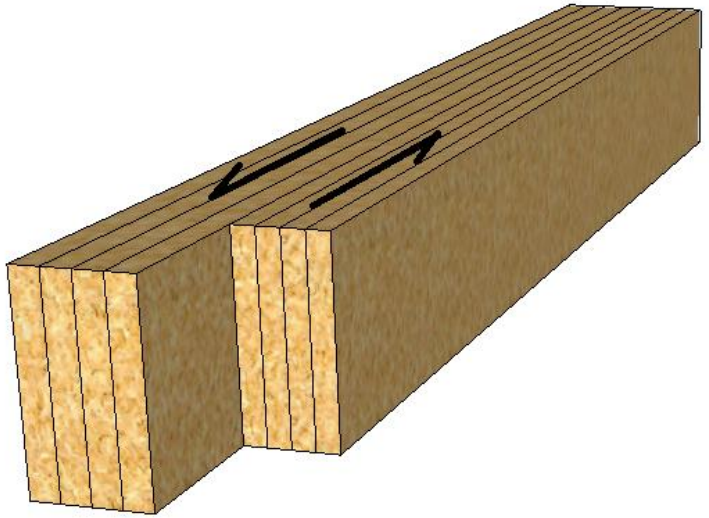


Preliminary Torsion Test Results





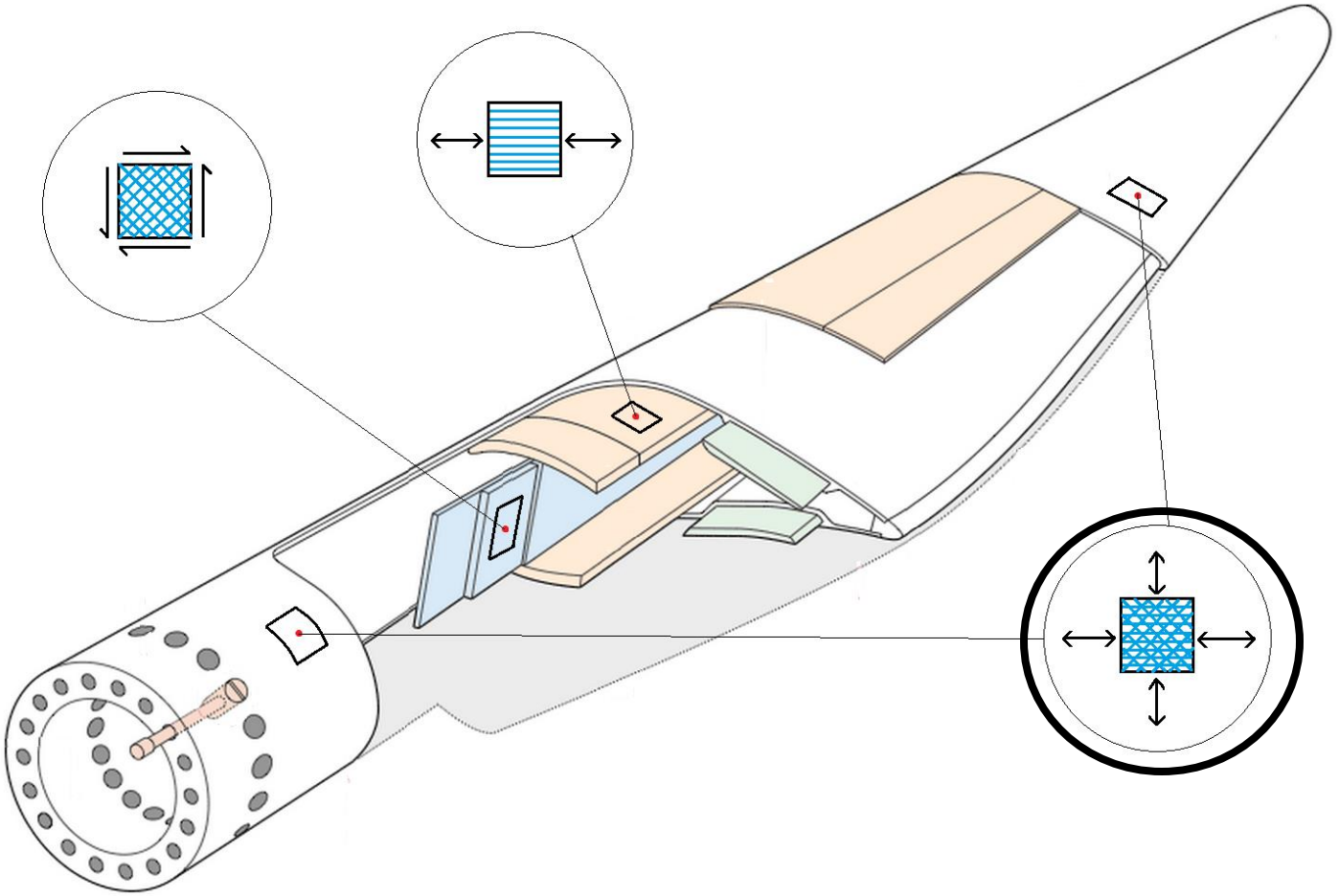
Possible failure modes under torsional loading



longitudinal-tangential (LT)
failure plane (τ_{yx})

Yield Criteria Assessment for Multiaxial Wood Laminate and Flax Fiber Reinforced Composites

Multidirectional Materials in Wind Turbine Blades



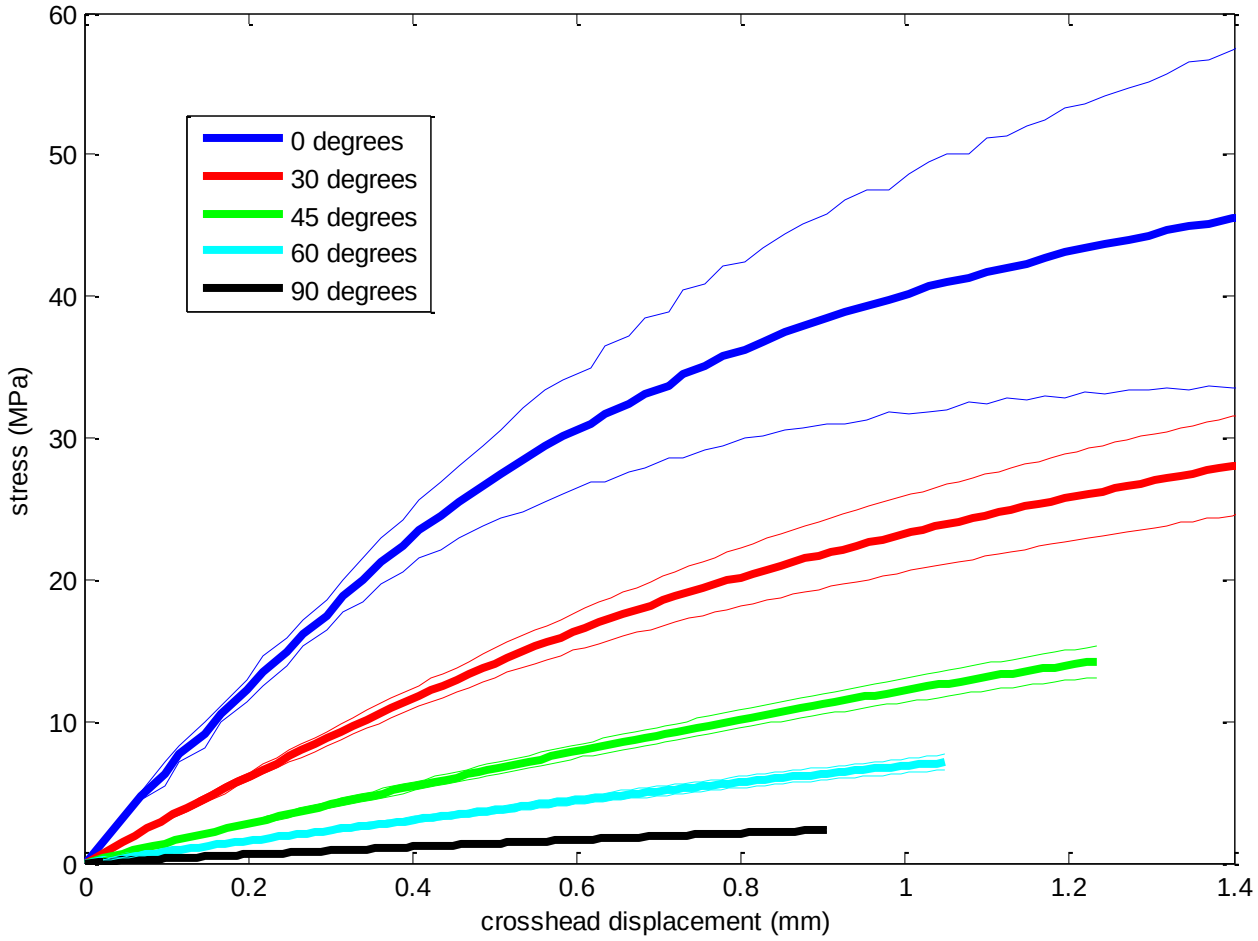
Adapted with permission from Gurit Corporation (2014).

Fabrication Process (90% of research)

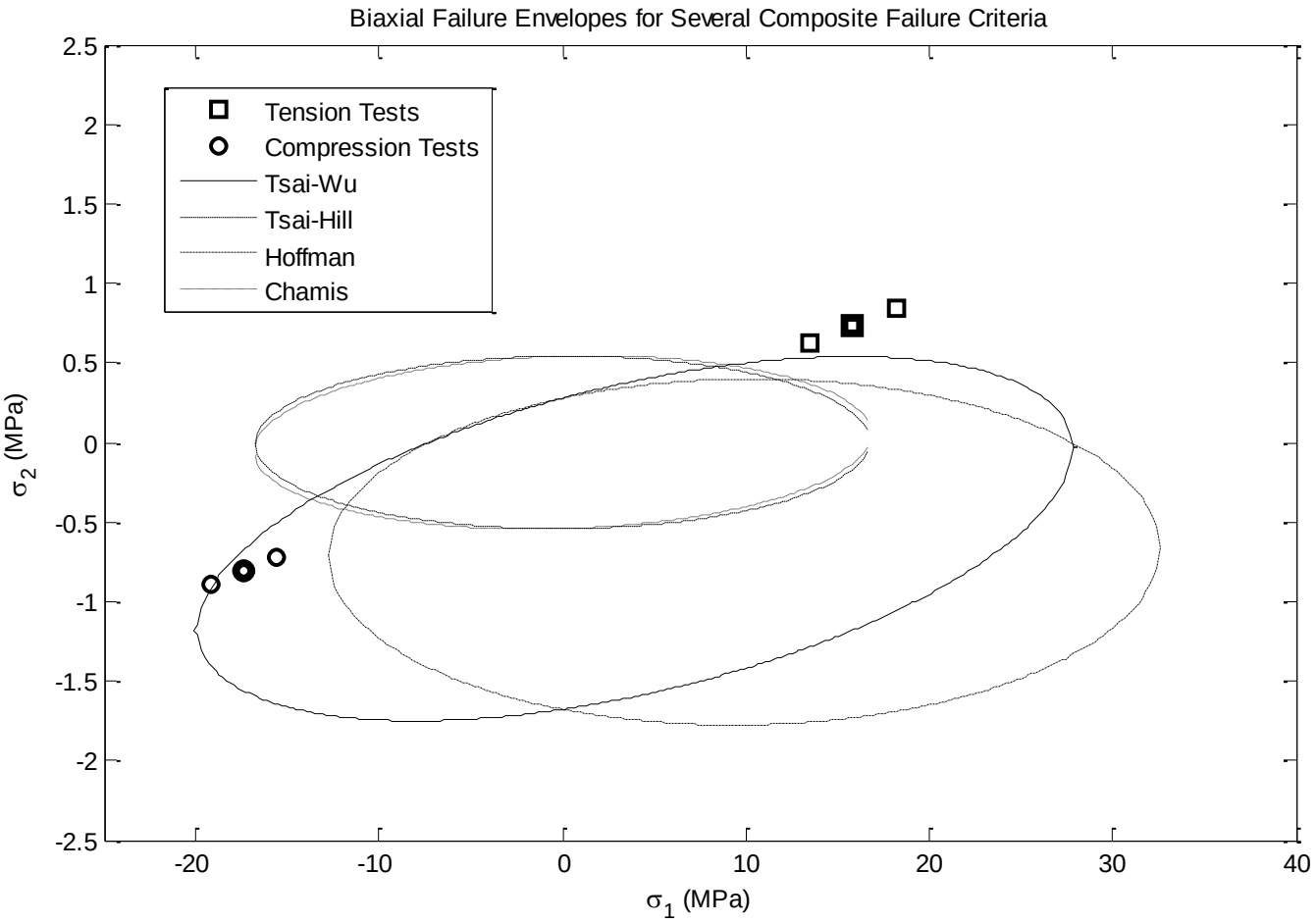



Mechanical Testing

Preliminary Results



Preliminary Results (cont'd)



Future Tasks

- multiaxial flax composite tests
- develop finite element material model to reflect multiaxial test data
- finite element design of hybrid bio-based 5MW blades

Acknowledgements

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