Bio-based Materials for Offshore Wind Turbine Blades

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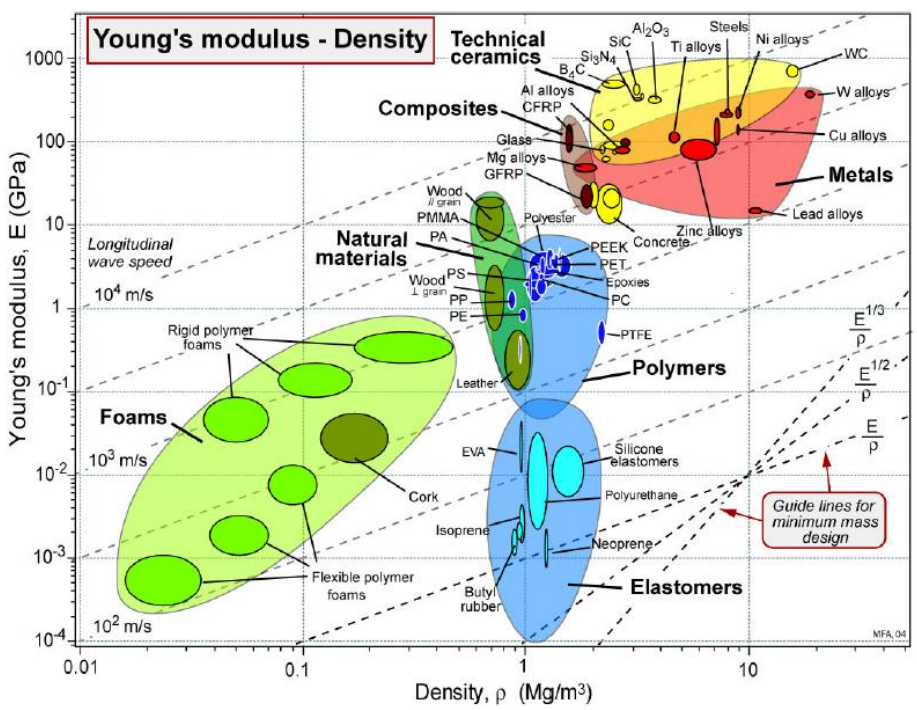
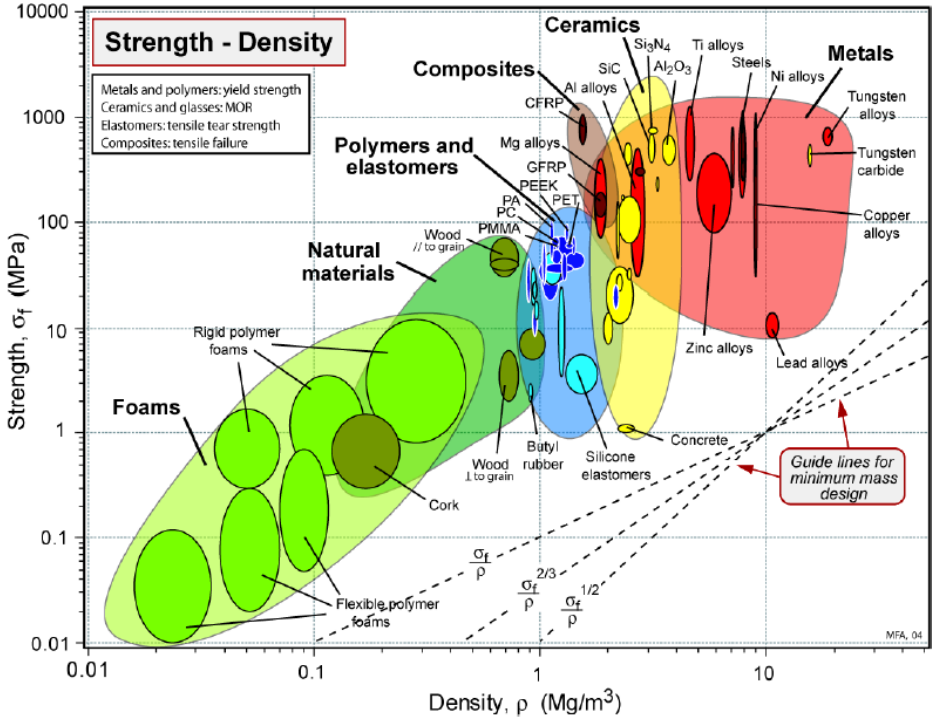
Basic Considerations for Blade Materials

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

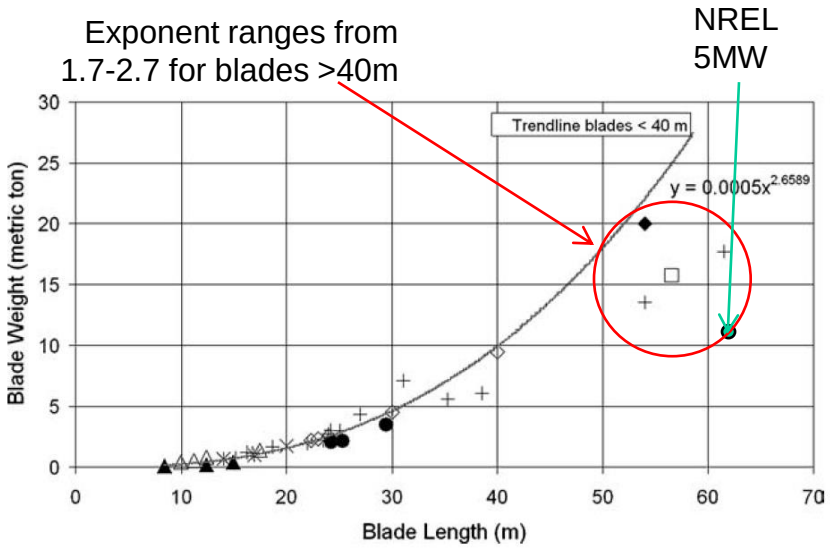
Ashby Materials Selection Charts





Issues with fiberglass and carbon fiber

- Carbon fiber
  - expensive
  - not widely used in industry today
- Fiberglass
  - recyclability/ end-of-life disposal options
  - energy intensive production
  - mass scaling (100m baseline blade > 100 metric tons)
  - global production increase from 5.9 million metric tons in 1999 to 8.7 million in 2011



Political action in Sustainable Materials

- Concern with extraction/processing/ manufacturing emissions and end-of-product-life options has generated:
  - 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
  - USA- Dept. of Energy initiative produced *A Vision to Enhance U.S. Economic Security Through Renewable Plant/Crop-Based Resource Use* and *The Technology Roadmap for Plant/Crop-Based Renewable Resources 2020* which discuss the research and development needs for production, processing, and manufacturing of renewable materials

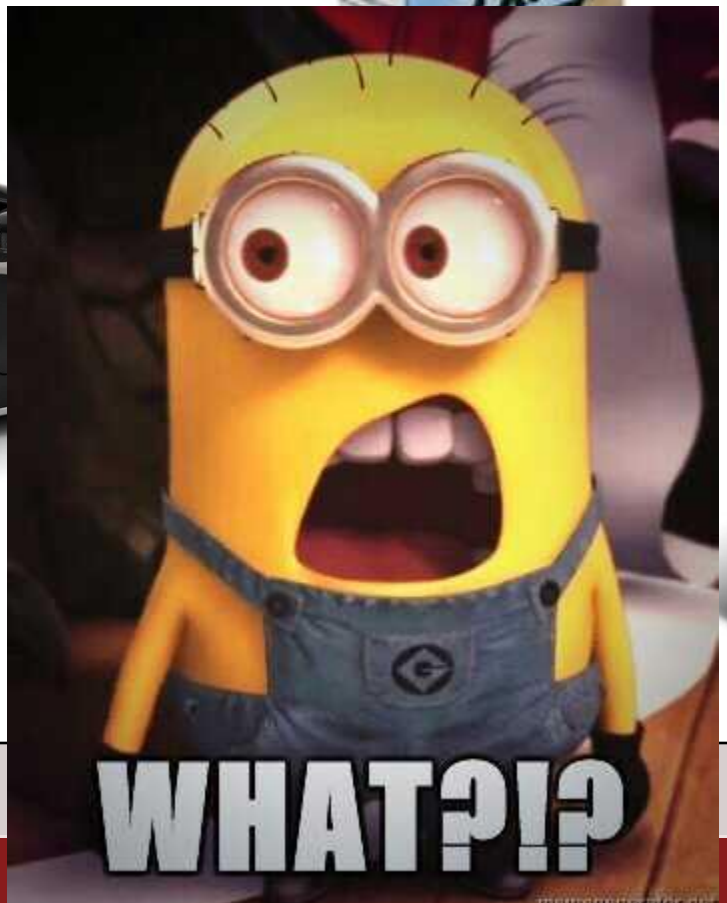
Advantages of Bio-Based Materials

- Competitive specific stiffness and strength
- Competitive fatigue properties
- Renewable
- Biodegradable when triggered
- Low cost raw materials
- Low emissions manufacturing

Challenges with Bio-Based Materials

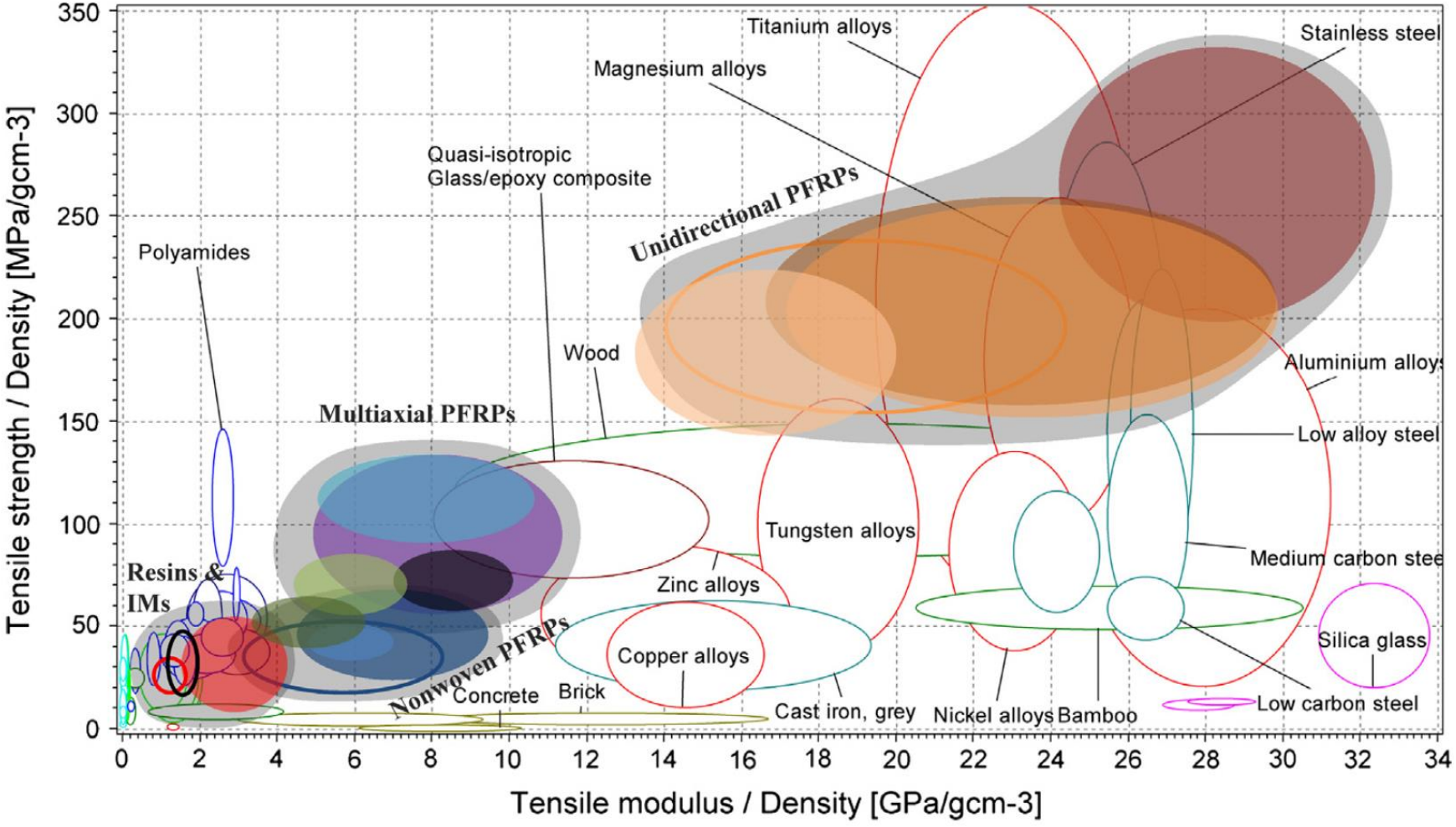
- Variable mechanical properties
- Limited experimental data for atypical loading conditions such as off-axis and multiaxial loading
- High sensitivity to moisture
- Not fully developed modelling techniques
- Not fully developed manufacturing processes
- Perception…

Fiberglass vs. Hemp



Fiberglass vs. Hemp

Magic Trick!


Tensile strength / Density [MPa/gcm-3]
Tensile modulus / Density [GPa/gcm-3]
0
50
100
150
200
250
300
350
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
Titanium alloys
Stainless steel
Magnesium alloys
Quasi-isotropic
Glass/epoxy composite
Unidirectional PFRPs
Polyamides
Wood
Aluminium alloys
Multiaxial PFRPs
Low alloy steel
Tungsten alloys
Medium carbon steel
Resins &
IMs
Zinc alloys
Nonwoven PFRPs
Copper alloys
Silica glass
Concrete
Brick
Cast iron, grey
Nickel alloys
Bamboo
Low carbon steel

Research Objectives

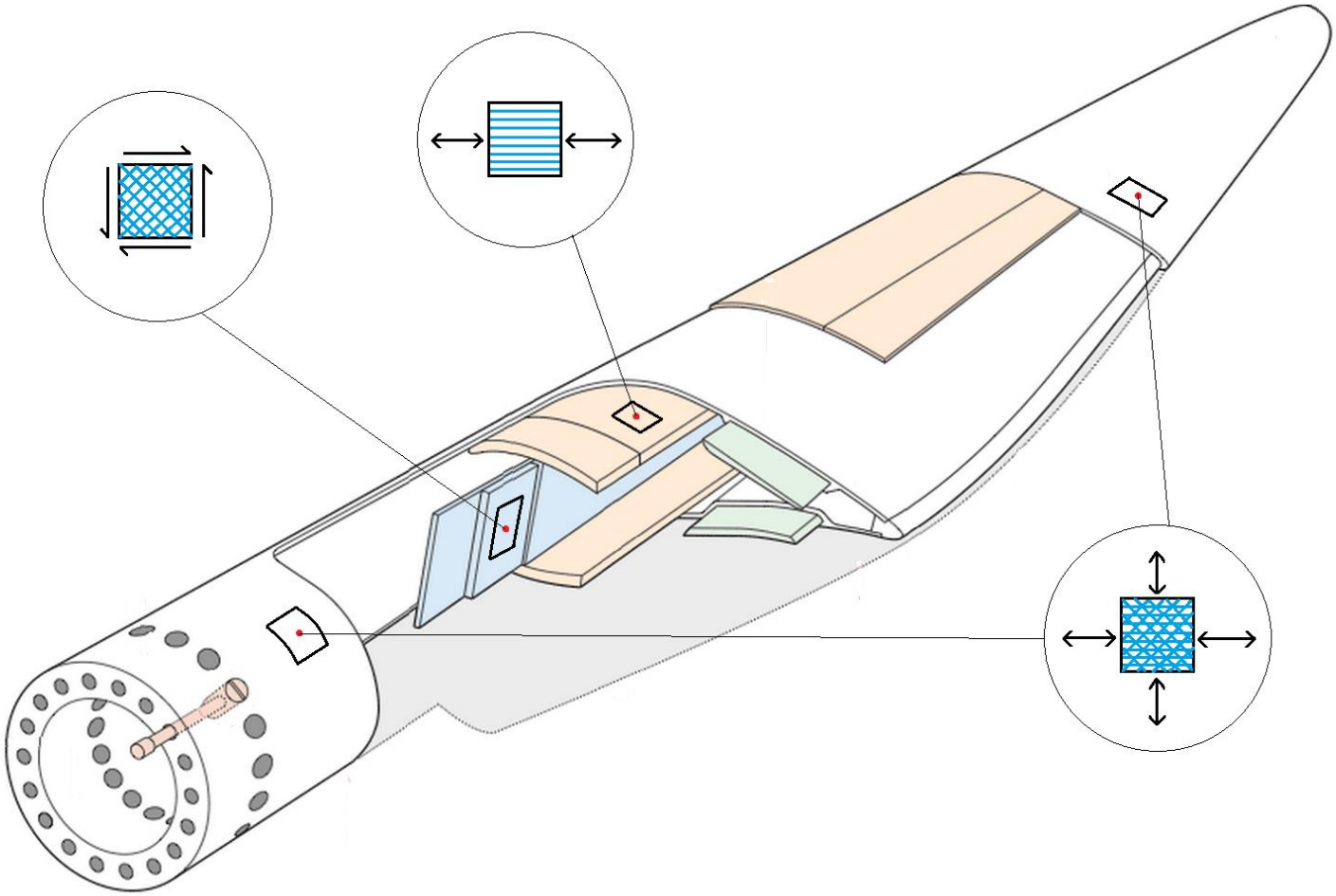
- Generate experimental data for atypical, multiaxial loading situations
- Develop numerical model which aligns with experimental data from ourselves and prior studies
- Incorporate material variability into the design of wind turbine blades
- Propose a design for a bio-based wind turbine blade

BOM for Sandia 100m Fiberglass Blade

Material	Description	Usage	Mass (kg)	Percent Blade Mass
E-LT-5500	uniaxial fiberglass	spar caps, trailing edge reinforcement	25,522	22.0%
SNL Triax	triaxial fiberglass	root build-up, internal and external surfaces	20,050	17.3%
Saertex	double-bias fiberglass	shear webs	2,119	1.8%
EP-3	resin	all fiberglass parts	51,718	44.7%
Foam	foam	core panels, shear webs	15,333	13.3%
Gelcoat	coating	coating	920	0.8%

Table compiled with data from:
Griffith, D. T. & Ashwill, T. D. (2011). The Sandia 100-meter All-glass Baseline Wind Turbine Blade: SNL100-00. *Sandia National Laboratories Technical Report*

Multidirectional Materials in Wind Turbine Blades



Shear Strength of an Angle-Ply Wood Laminate

Torsion Test

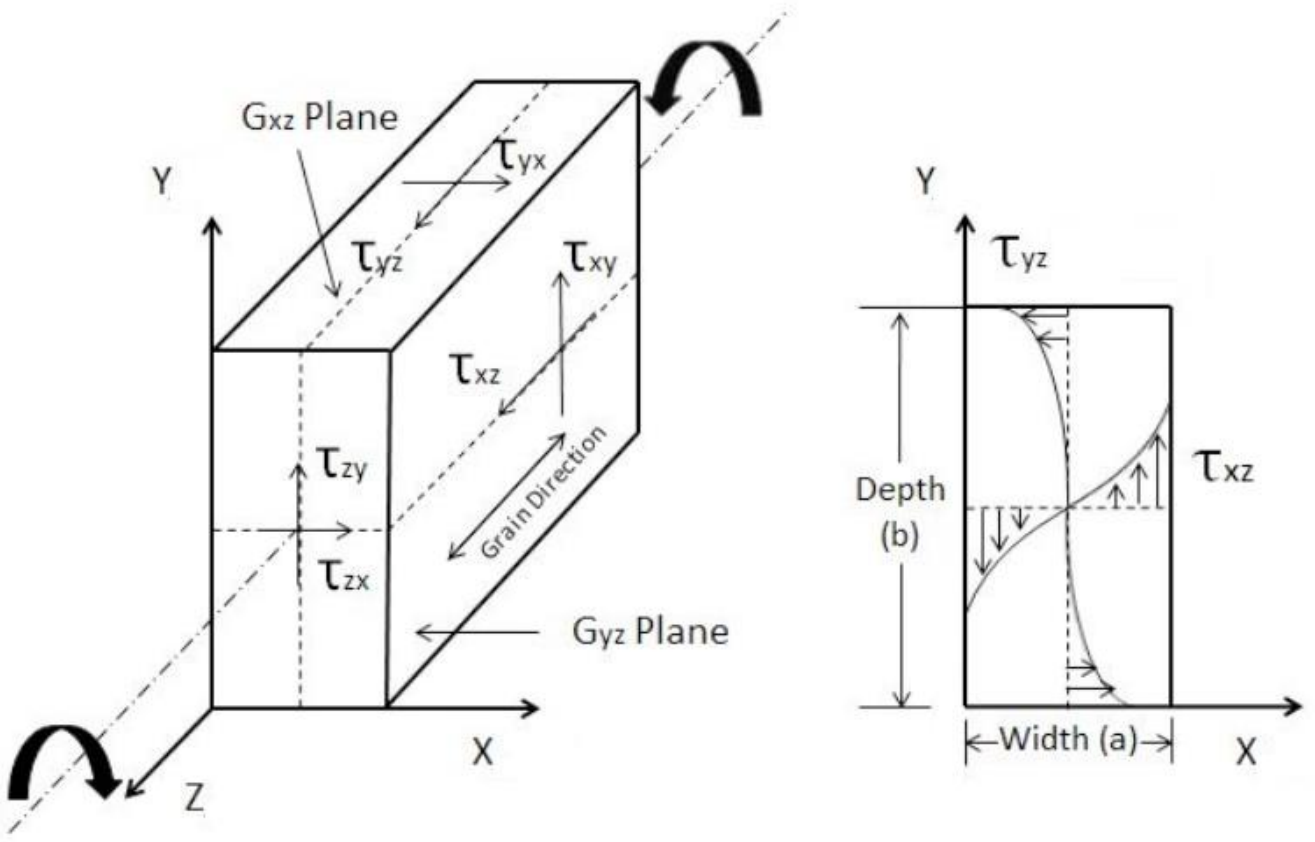
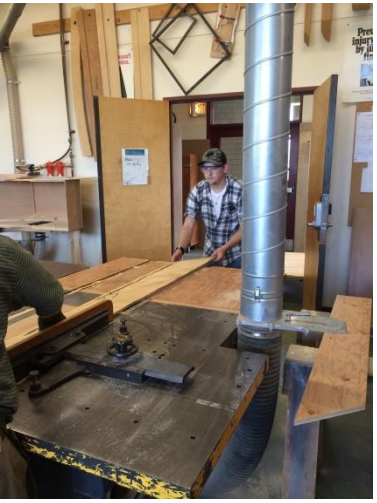


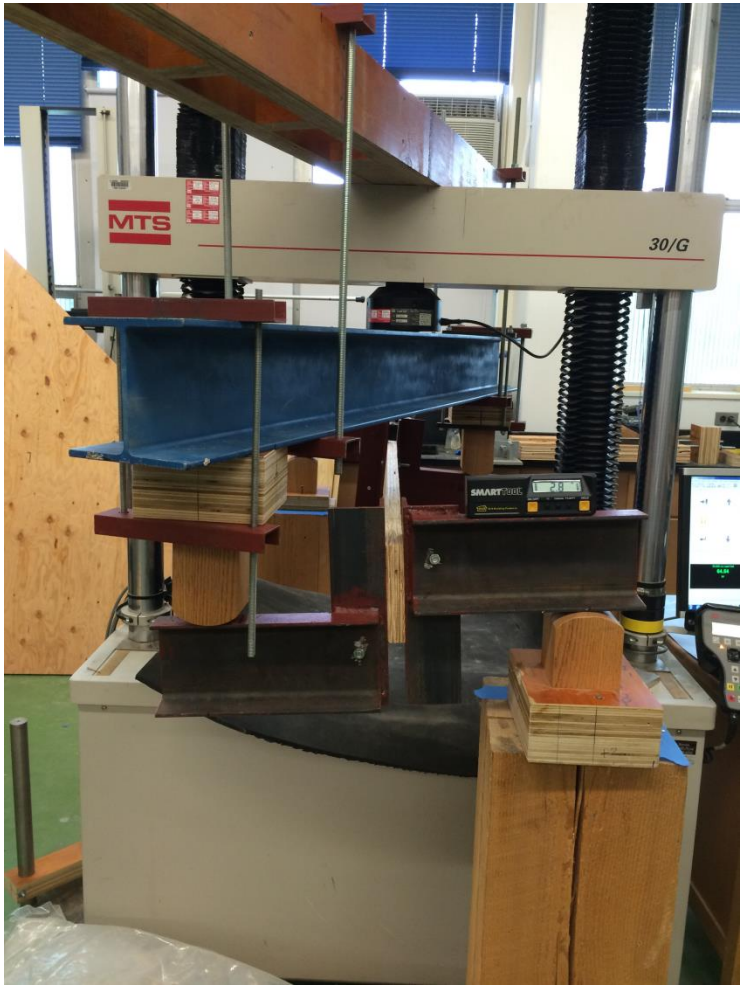
Figure from:
Yang (2012) Torsional Shear Strength and Size Effect in Structural Composite Lumber. Master's Thesis. Univ. of Mass. Amherst.

Angle-Ply Laminate Fabrication

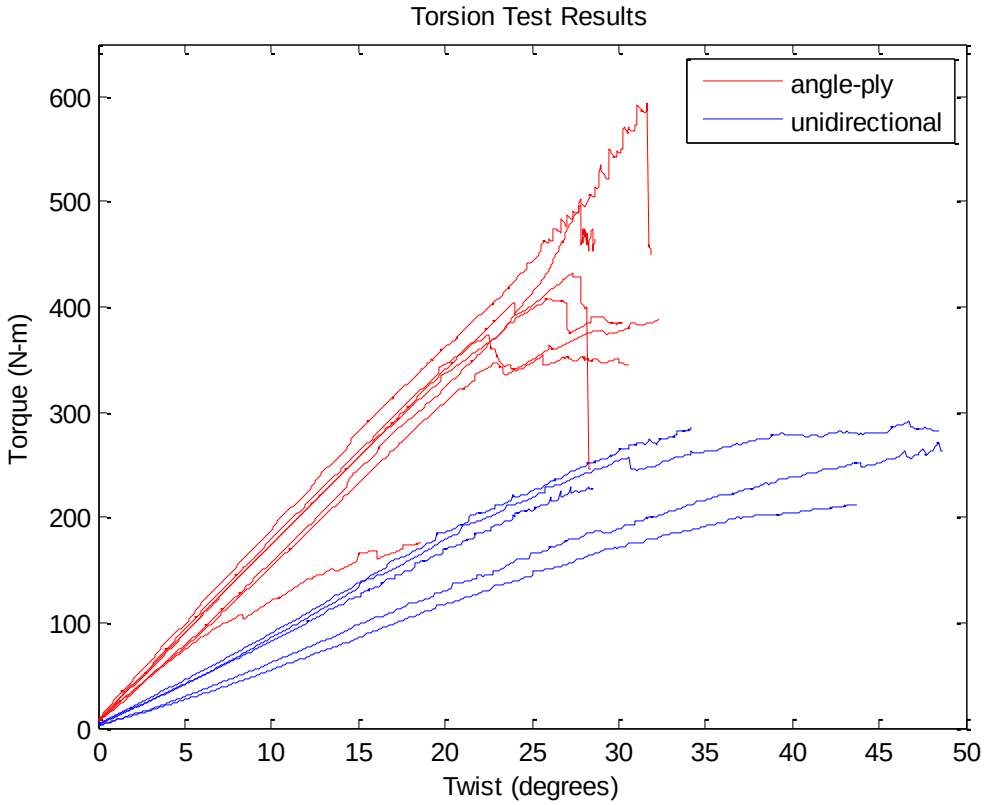


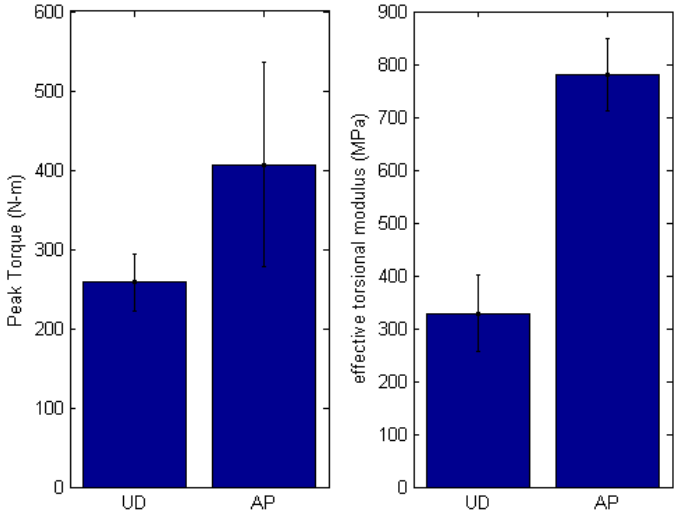


Torsion test set-up

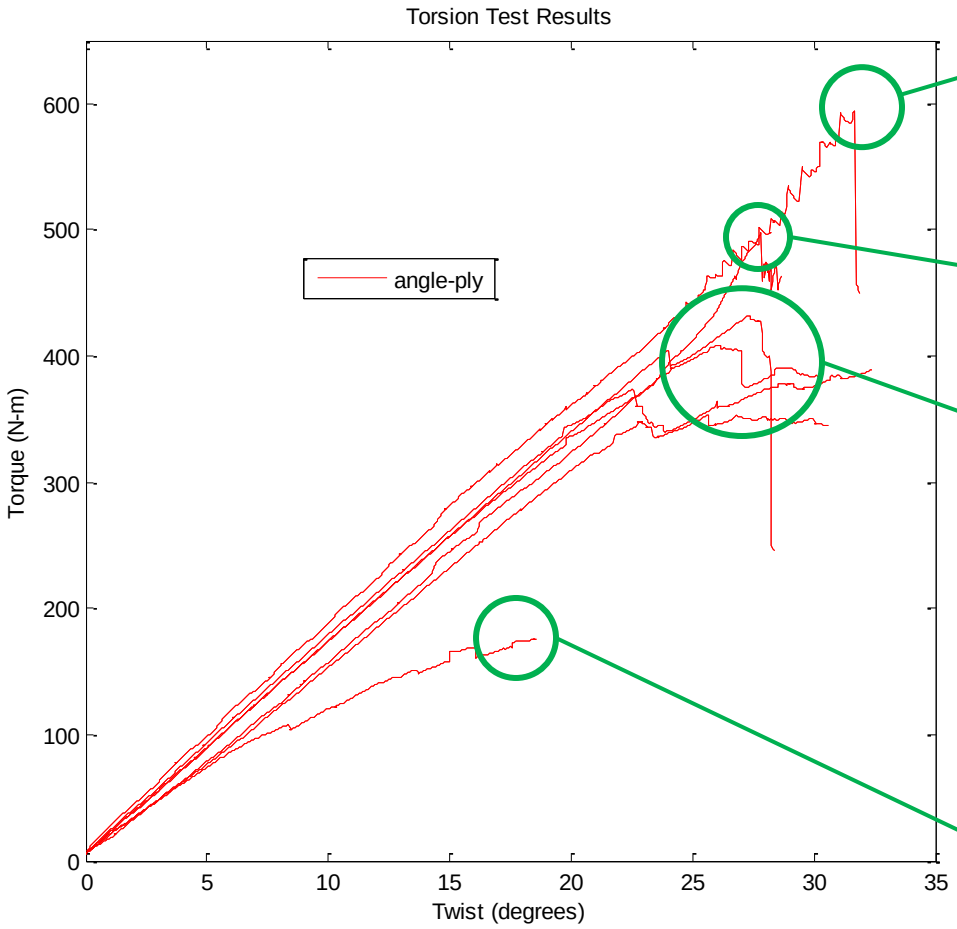


Preliminary Results

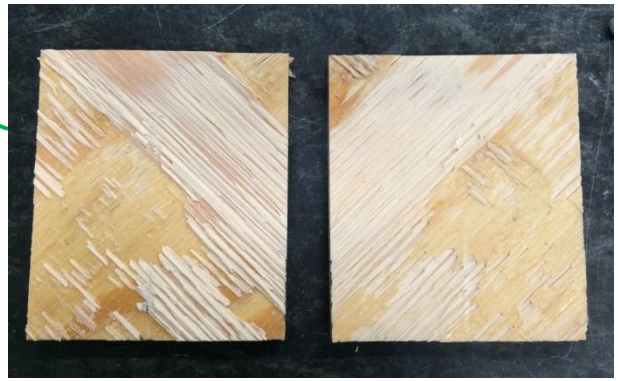




Preliminary Results



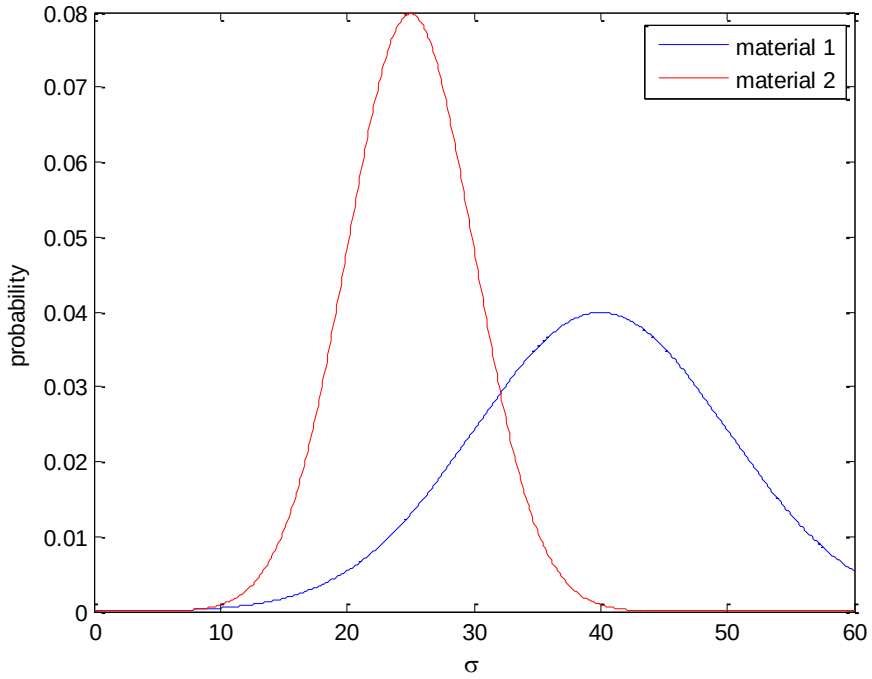
Bracket interference

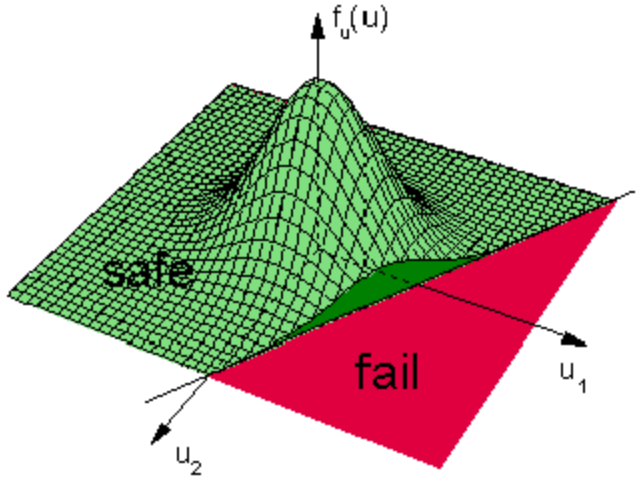


Future work

- Experiment limitations
  - Adhesive spreading
  - Clamping mechanism
  - Test apparatus limitations
  - Edge effects
- Model
  - Interaction between plies
  - Non-catastrophic failure

Probabilistic Design





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- Mom
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