Natural Fiber Composites

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Introduction

Background and Motivation

Natural fiber composites (NFCs) are a material composed of a natural fiber-reinforced polymer matrix (FRP). NFCs offer a lightweight, sustainable, biodegradable, and versatile alternative to carbon or glass fiber composites.

Current State and Gap Analysis

Current patents filed by Boeing for natural fiber composite materials utilize woven flax to create sustainable, fire-resistance panels for aircraft interiors. The current leader in the field of aerospace composites is carbon fiber, which is expensive and labor and energy intensive to produce, repair, and recycle.

- We aim to test two different natural fibers, one less commonly found and one more commonly found in NFCs:
  - Softwood/hardwood (SW/HW) blended fiber paper (of two different thicknesses), created by students in UW's Bioresource Science and Engineering Dept.
  - 2x2 twill flax mat, externally resourced

Natural fibers – from left to right: flax, thick (0.3 mm) SW/HW, thin (0.1mm) SW/HW

- Comparison of the compatibility of thermoset vs thermoplastic polymer systems:
  - Thermoplastic: Polyetherimide (PEI) sheet
  - Thermoset: CYCOM 977-2A resin sheet

Objectives

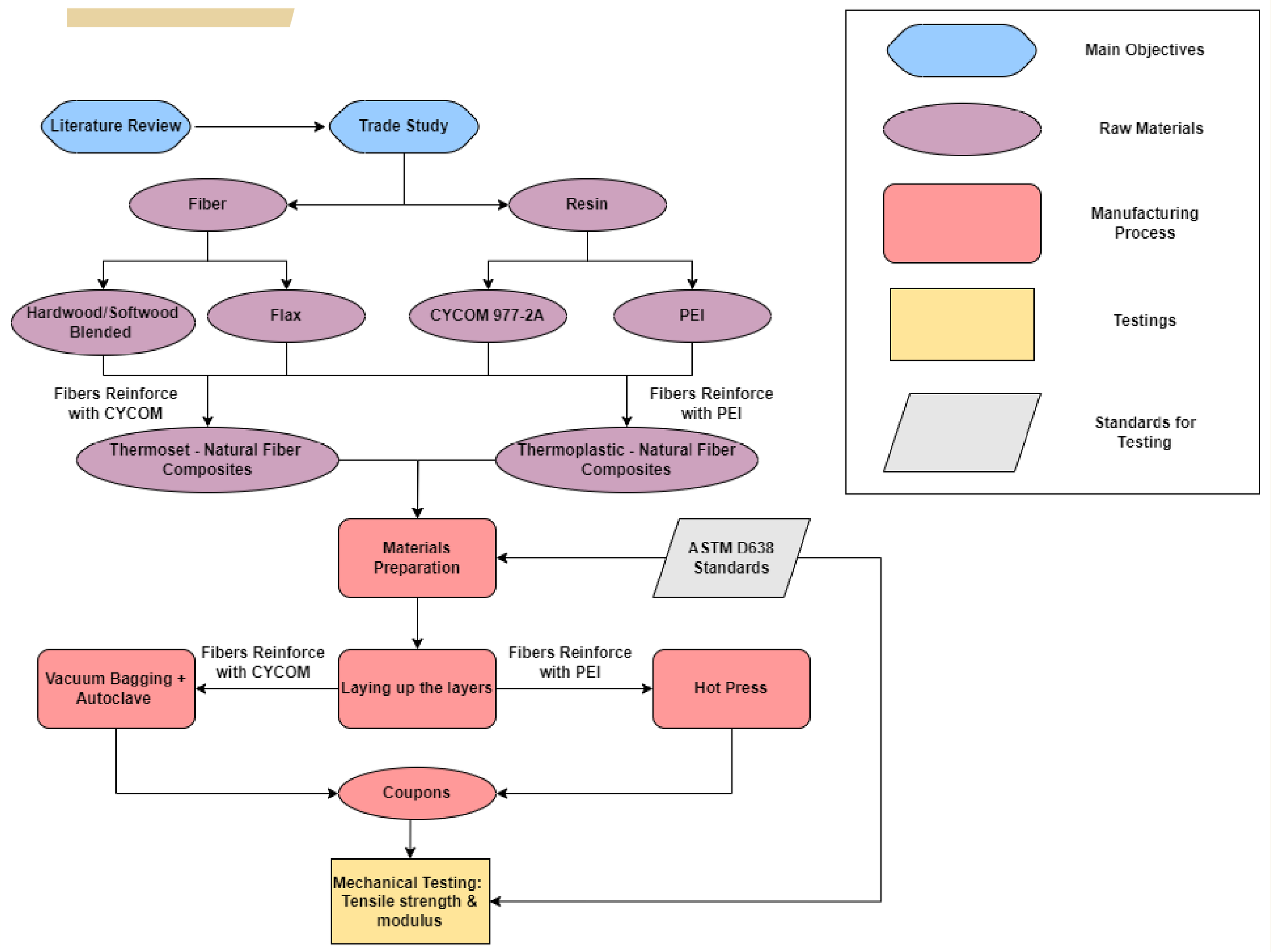
- To research and conduct a trade study to down select natural fibers and polymer matrix systems
- To create panels using different reinforcing natural fiber and thermoset & thermoplastic resin
  - Validate fabrication methods
- To characterize the panels using ASTM D638, type I standard to determine tensile strength and modulus to compare them to each other and to literature values
  - Target Strength: 310. MPa (45 ksi)
  - Target modulus: 19.3 GPa (2.8 Msi)

Scope of Project/Timeline

- Given a budget of $2000
- Completed over a 5-month period, starting in January

Literature Review (1/28) → Design Approach (2/22) → Development and Validation (4/24) → Laminate Creation (4/26) → Laminate Testing (5/17) → Final Report (5/30)

Design Process Flow Diagram



Methodology

Testing Matrix

- Target fiber-to-resin volume ratio = 60:40
- Target dimensions:
  - 15.24 cm x 17.78 cm x 0.2 cm (SW/HW samples)
  - 17.78 cm x 20.32 cm x 0.2 cm (flax is larger to account for fraying and warping)
- Stacked fiber and resin layers to allow for even distribution and symmetry about the mid-point

		Fiber (F)		
		Flax	Thick SW/HW	Thin SW/HW
Resin (R)	PEI	2 layers F 16 layers R	3 layers F 16 layers R	12 layers F 16 layers R
	CYCOM 977-2A	2 layers F 31 layers R	4 layers F 31 layers R	13 layers F 31 layers R

Testing matrix showing the combinations of fibers and resin investigated and the respective amounts of each material used

PEI Laminates – Hot Pressing

- Heat and pressure applied simultaneously to allow melting of plastic and impregnation into fibers
- Set temperature: 450 ˚F
- Set Pressure: 50 ton-force
- Duration: 20 minutes for SW/HW samples, 40 minutes for flax samples

CYCOM 977-2A Resin Laminates – Vacuum Bagging + Autoclave

- Prior to autoclave cure, vacuum bagged to remove air and ensure complete contact between layers
- Autoclave applies pressure and heat necessary for the resin to cure
- Set temperature: 350 ˚F
- Set Pressure: 7 bar
- Duration: 3 hours

Results – Fabrication

Thermoplastic: PEI

- Conclusion: PEI and chosen fibers and methods were incompatible
  - Melting point of PEI is approx. the same at the burning points of our fibers
    - Melting point of PEI: 450 ˚F
    - Burning point of flax ≈ SW/HW blend: 450 ˚F – 460 ˚F
  - Fibers began to burn as the plastic was melting
  - PEI failed to impregnate into fibers

Thermoset: CYCOM 977-2A Resin

- Conclusion: CYCOM was compatible with our chosen fibers
  - Able to create laminates that could be cut into coupons and tested

Thermoplastic PEI Laminates - from left to right: flax/PEI, thick SW/HW/PEI, thin SW/HW/PEI.

Thermoset CYCOM Laminates - from left to right: flax/CYCOM, thick SW/HW/CYCOM, thin SW/HW/CYCOM.

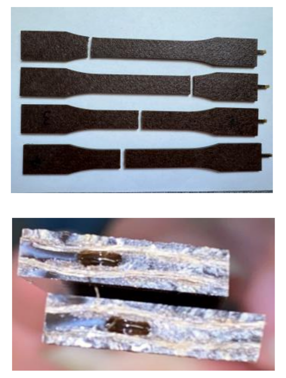
Results – Testing via ASTM D638, Type I

Flax/CYCOM

- Average tensile strength: 58.6 MPa
- Average tensile modulus: 2.36 GPa
- Flax gives the best tensile modulus
- Air bubbles trapped within the laminate during production cause the variation of the results.

$$Stress\left(\frac{N}{mm^2}[=]MPa\right) = \frac{Force\ (N)}{Cross-sectional\ Area\ (mm^2)}$$

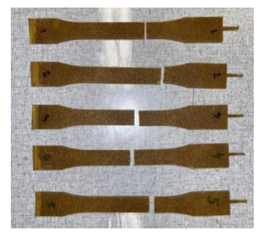
$$Tensile\ Modulus\ (GPa) = \frac{Stress\ (MPa)}{Strain} * \frac{1\ GPa}{1000\ MPa}$$



Top: Flax/CYCOM coupons after testing
Bottom: Cross section at fracture point of a flax/CYCOM sample showing air pocket

Thick SW/HW Blend and CYCOM Laminate

- Average tensile strength: 67.0 MPa
- Average tensile modulus: 2.16 GPa
- All sample performed consistently during the mechanical testing
- SW/HW fiber exhibits stronger internal adhesion compared to flax leading to higher tensile strength of the corresponding composite.

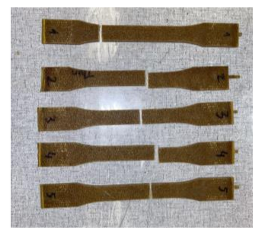


Thick SW/HW/CYCOM coupons after testing

Note: Flax has fiber orientation, but SW/HW doesn't

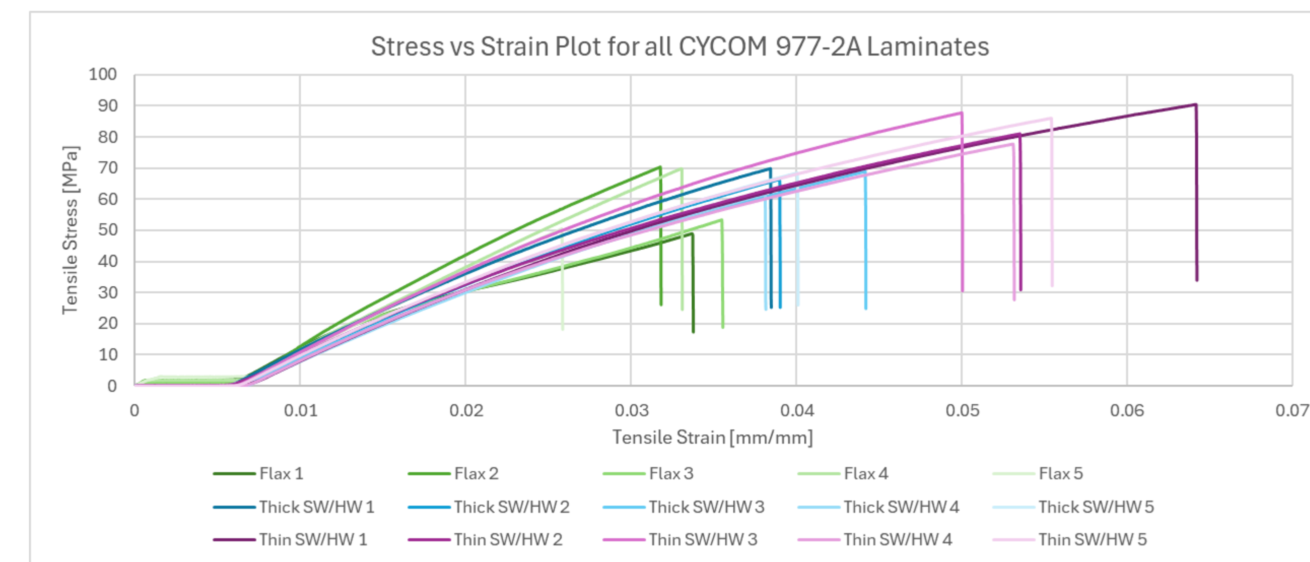
Thin SW/HW Blend and CYCOM Laminates

- Average tensile strength: 84.6 MPa
- Average tensile modulus: 2.21 GPa
- Has the best tensile strength performance due to the more even and thinner fiber-resin layers arrangement -> Better resin impregnation & less defects



Thin SWHW/CYCOM coupons after testing

Results – Consolidated Data



Stress versus strain plots for all CYCOM samples: flax is green, thick SW/HW is blue, and thin SW/HW is purple.

	Target	Flax	Thick SW/HW	Thin SW/HW
Average Tensile Strength (MPa)	310.	58.6	67.0	84.6
Average Tensile Modulus (GPa)	19.3	2.36	2.16	2.21

Consolidation of tensile properties of all CYCOM laminates, compared to our target values

Conclusion

- Although none of the composites meet the specified targets, there is promise noted in the Thin SW/HW reinforced with CYCOM composites for the best tensile strength and average modulus overall
- Flax-CYCOM composite is also a promising candidate for the highest modulus.

Future Work

For continuing to iterate with CYCOM or other thermoset sheet resins it is recommended to:
- Use thin SW/HW sheets and reiterate the process for optimization.

For research into better compatibility with PEI and other thermoplastic resins it is recommended to:
- Pretreat already researched fibers like flax or the SW/HW blend to achieve a greater heat resistance
- Research new fibers that can withstand the temperatures needed to melt thermoplastic resins
- Search other methods of melting the thermoplastic that may be less harmful to the fiber in use

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