Hybrid Polylactic Acid (PLA) Composites: Impact of Varying the Cellulose Material (CM) Source

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Hub & Spoke Program

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Bio-based Composites

BioHome3D

- Printed at the Advanced Structures and Composites Center (ASCC) at the University of Maine
  - Revealed November 2022
- Natural Fiber Composites for Additive Manufacturing
  - Reduced Coefficient of Thermal Expansion (CTE)
  - Increased Heat Deflection Temperature (HDT)

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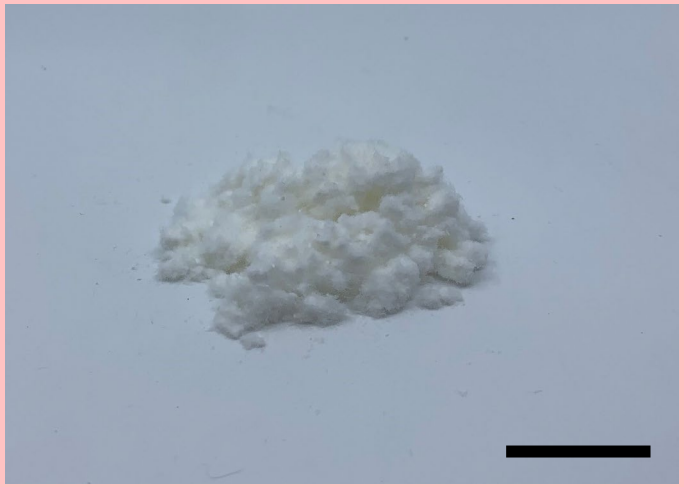
ADVANCED STRUCTURES & composites center

Creafill



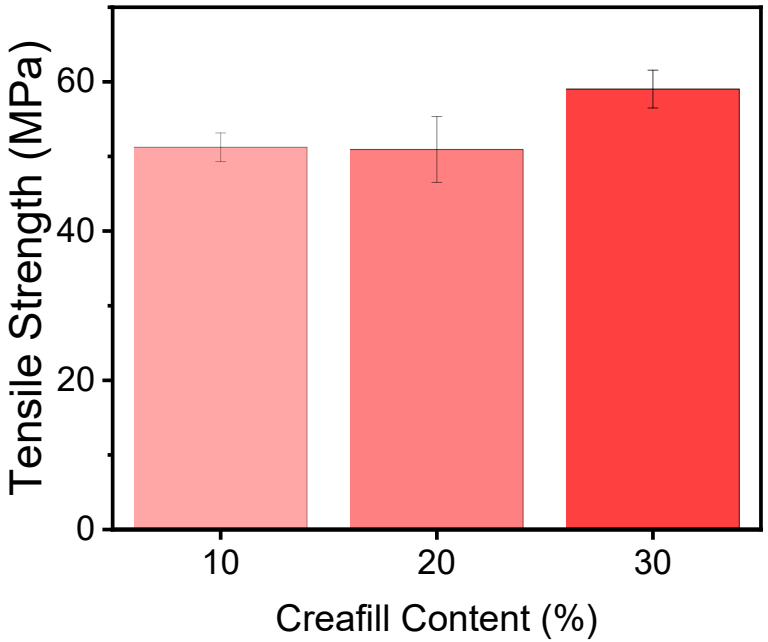
Flax

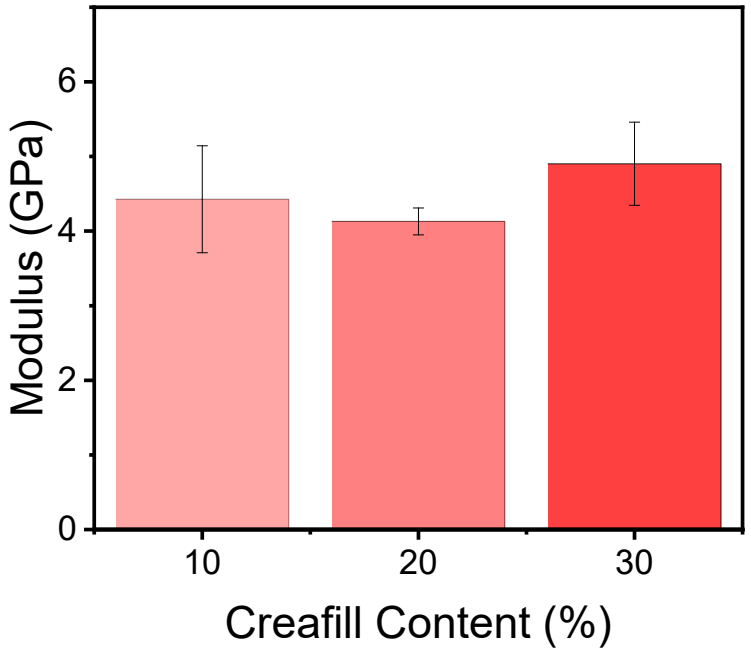
Wheat Straw

Macrofibers

Scale bars: 1 cm

Varying Filler Concentration

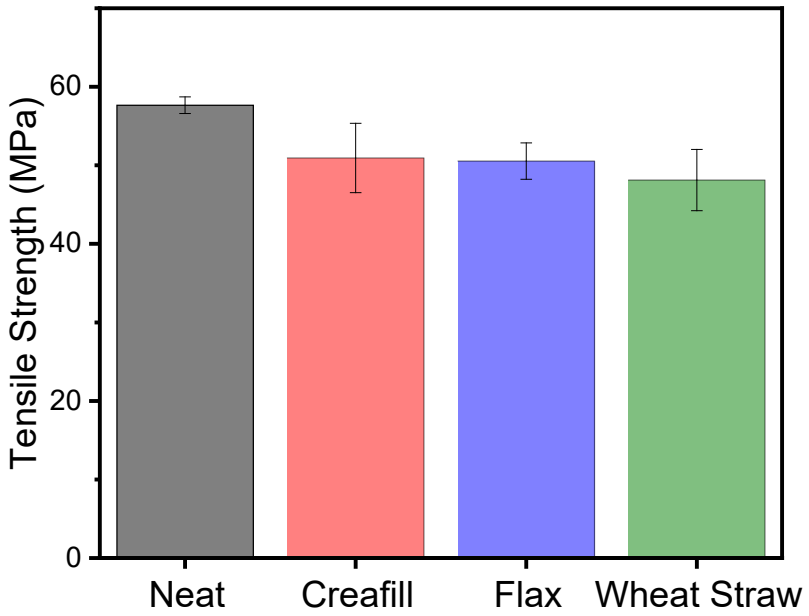


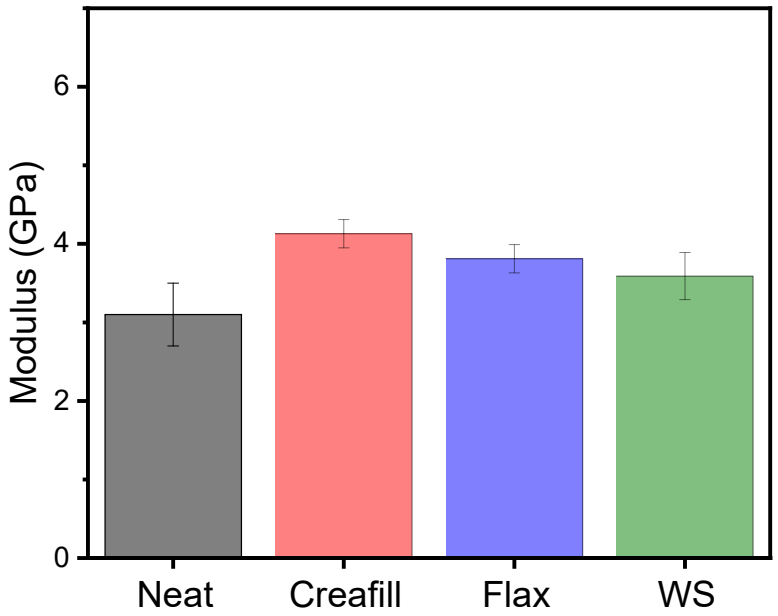


Takeaway: There is an optimum amount of filler to maximize both strength and modulus.

20 wt% filler content (historically used) chosen as optimum

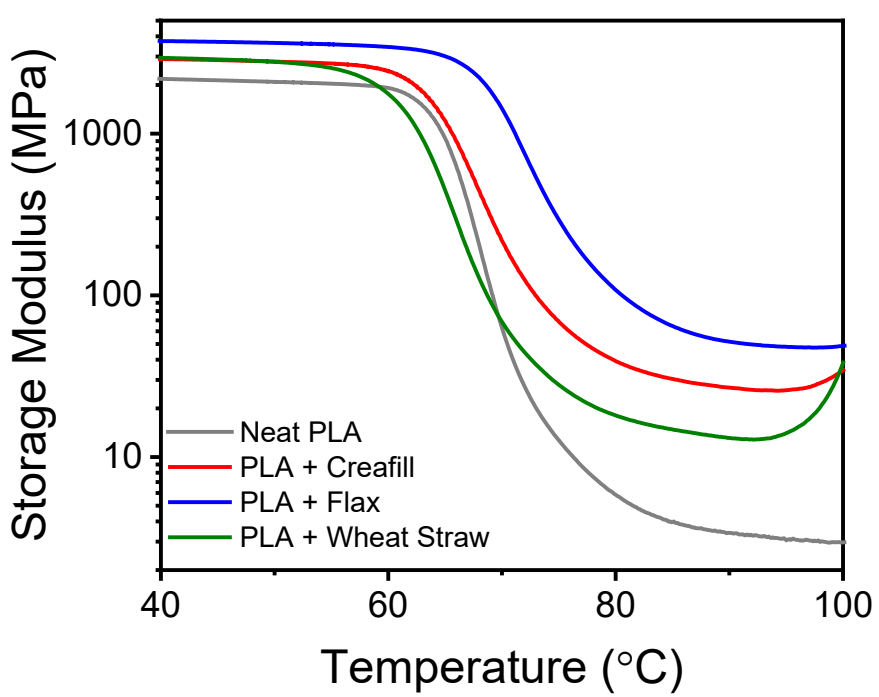
PLA (80wt%) + Filler (20wt%)

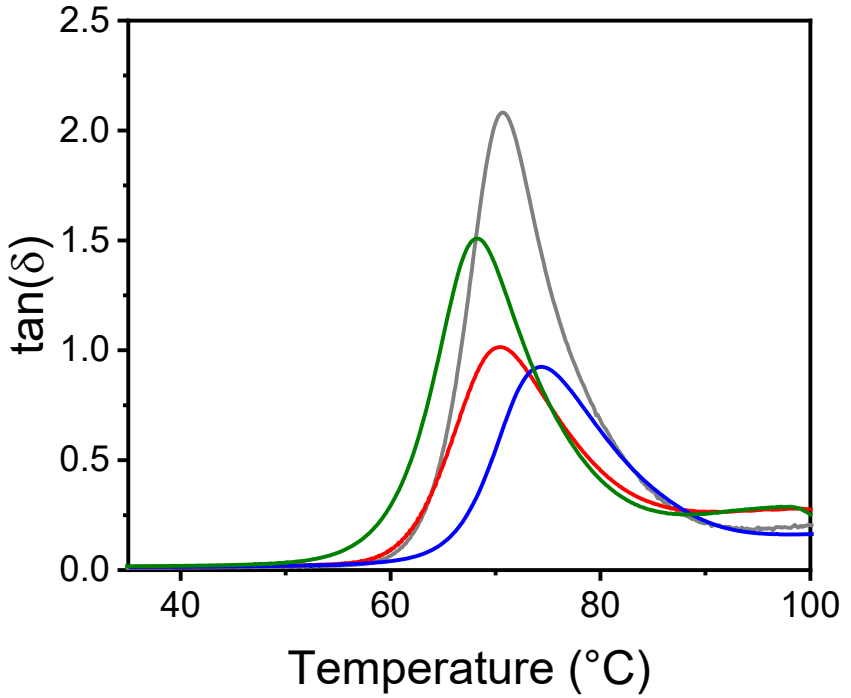




Takeaway: Natural fiber addition (20wt% fiber) into PLA results in increased modulus and slightly decreased strength.

PLA (80wt%) + Filler (20wt%)





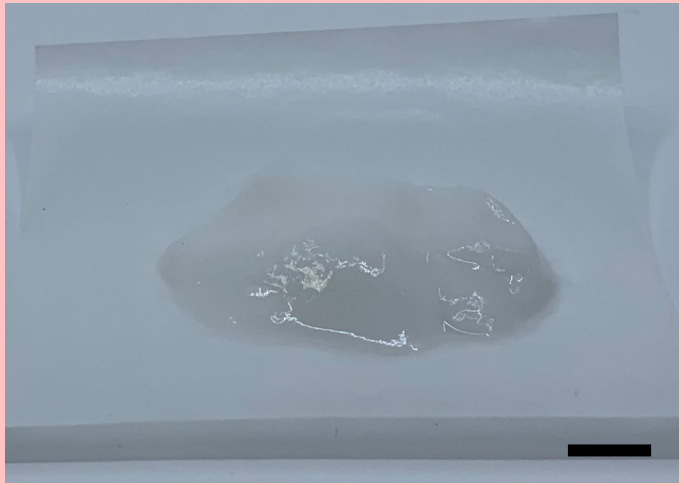
Takeaway: Dynamic mechanical analysis confirms an increase in modulus with filler, regardless of temperature.

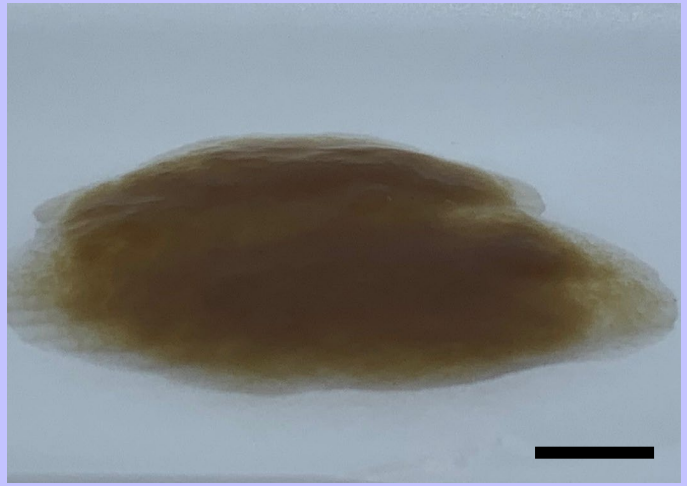
Creafill

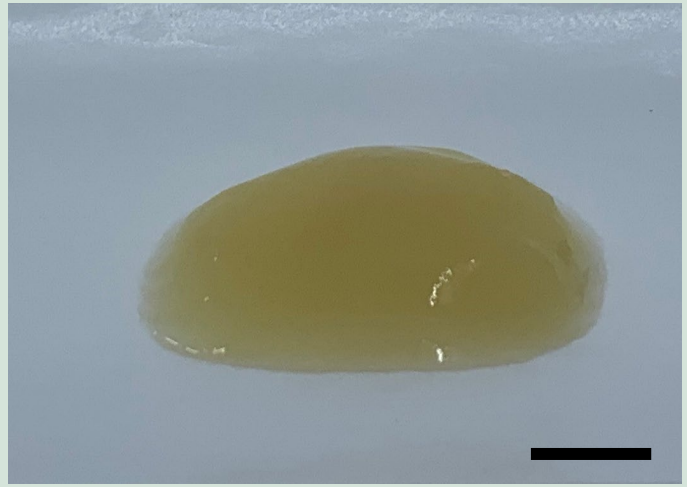
Flax

Wheat Straw

Macrofibers

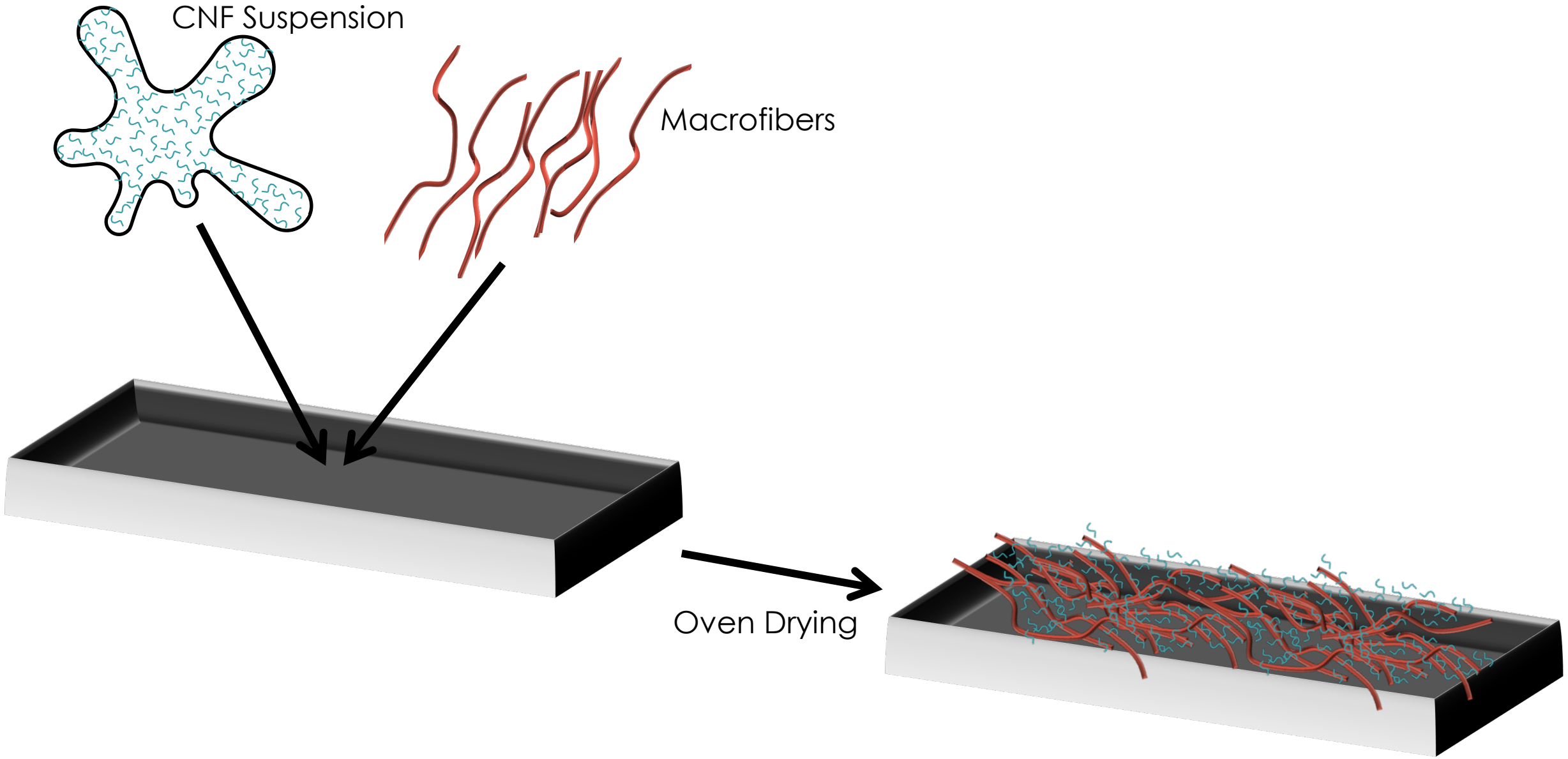






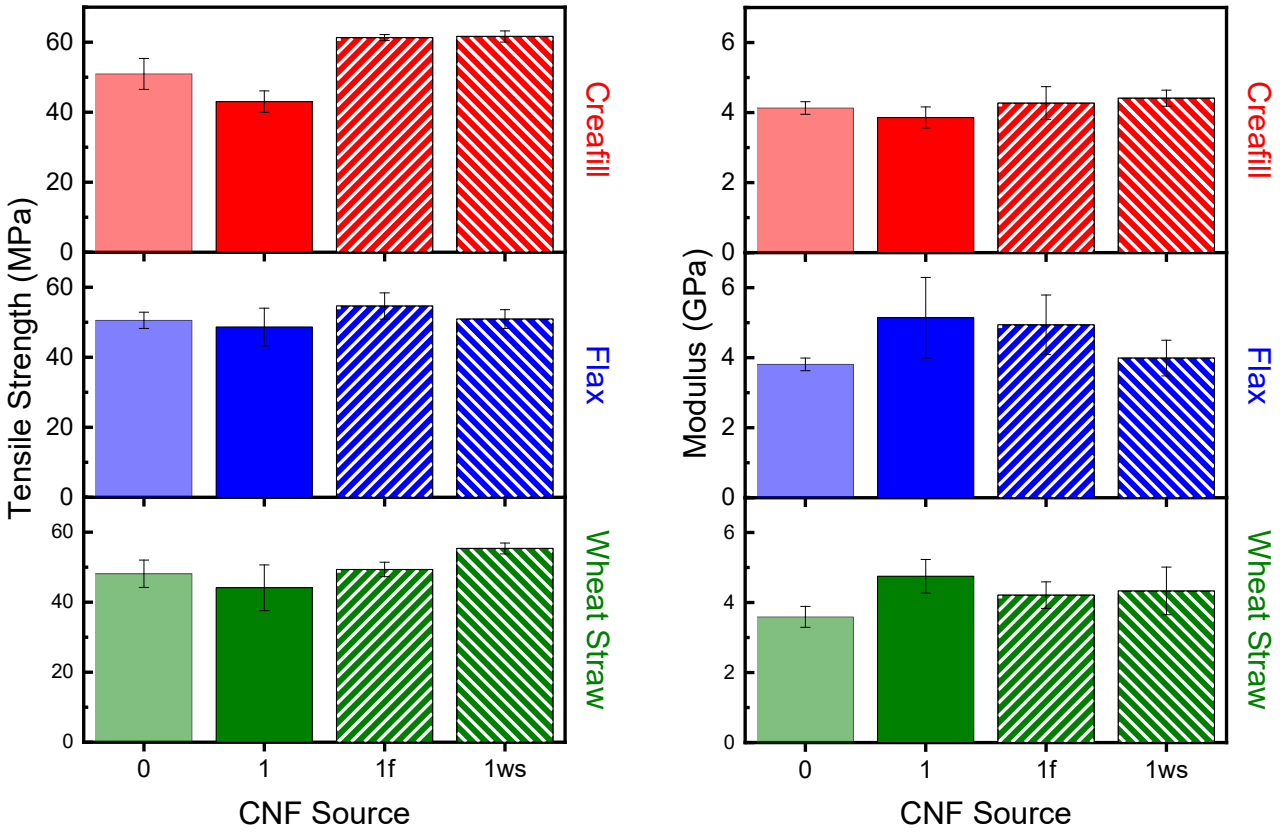
CNF Suspension

Scale bars: 1 cm



Hybrid Fibers = Macrofiber + CNF

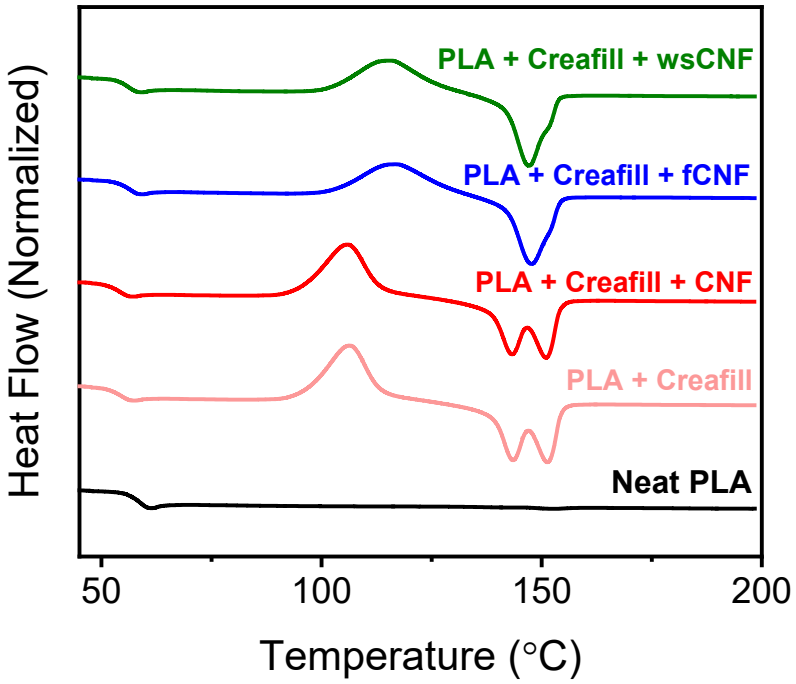
PLA (80wt%) + Filler (20wt%)
1wt% of CNF on Macrofiber

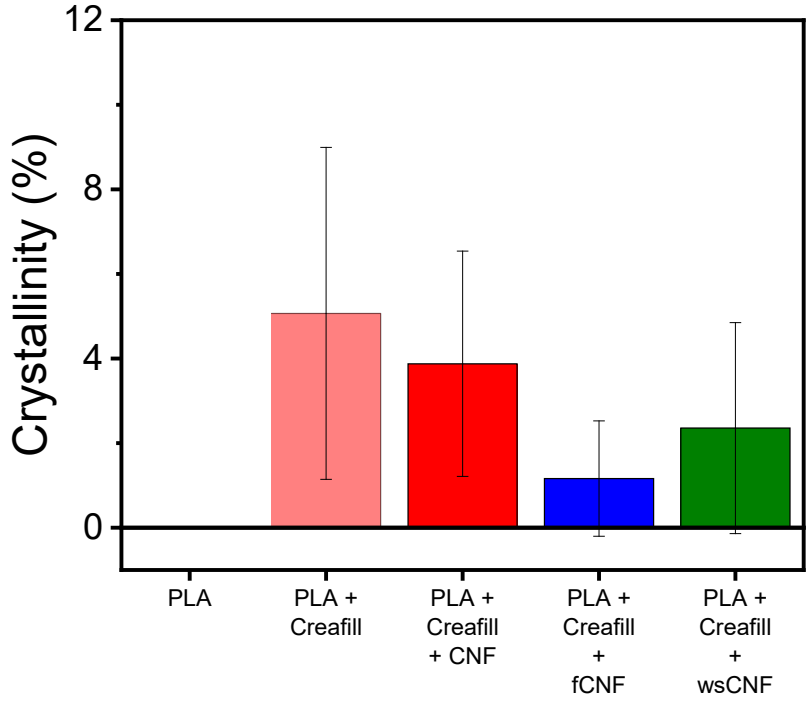


Takeaway: Hybridization of fibers increases both tensile strength and modulus.

Hypothesis: Both topology and surface chemistry impact the adhesion between the filler and matrix.

PLA (80wt%) + Filler (20wt%)
1wt% of CNF on Macrofiber

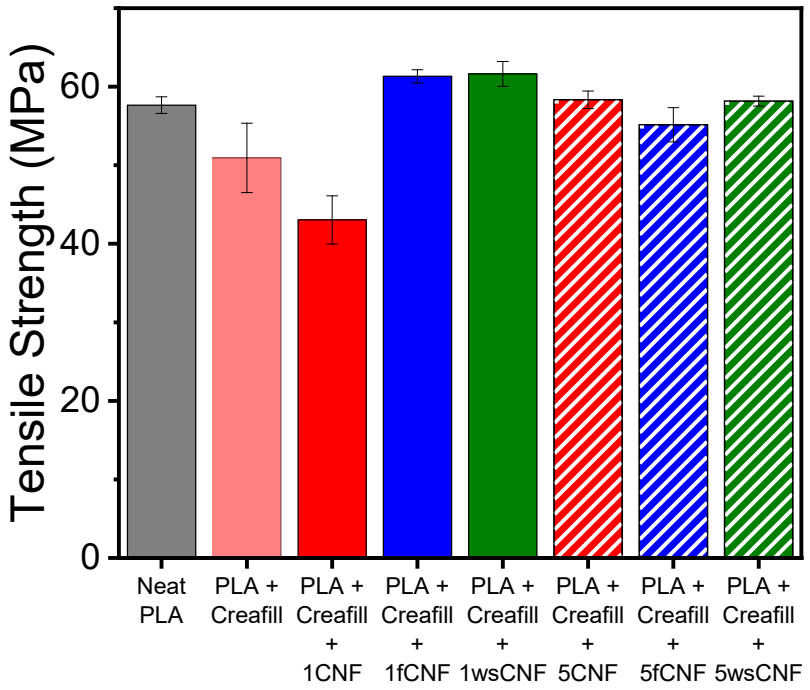


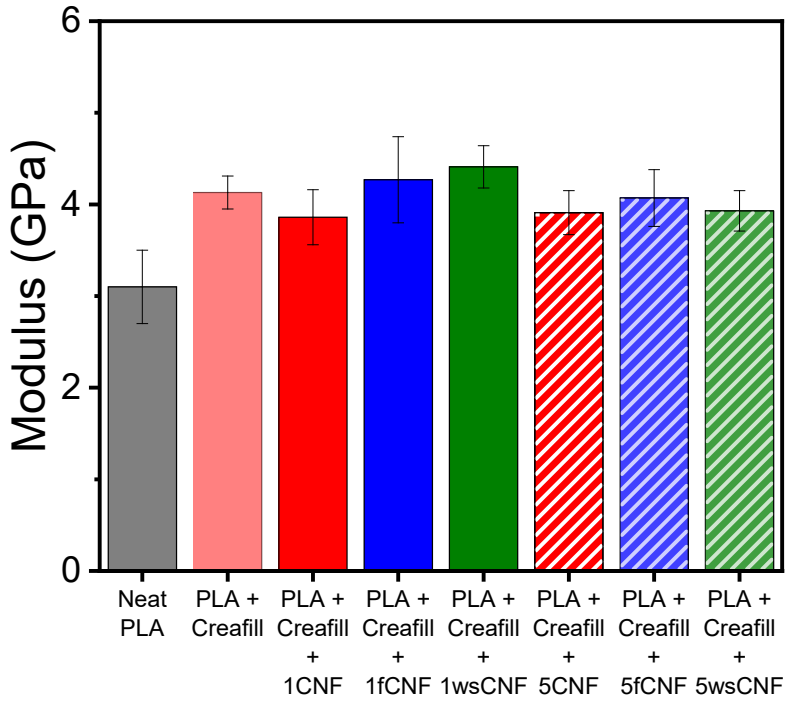


Takeaways: The ideal hybrid filler composition is Creafill + fCNF or Creafill + wsCNF based on minimized crystallization and increased strength/modulus.

There is a shift to higher T_{cc} and a suppression in the melting peak for these compositions.

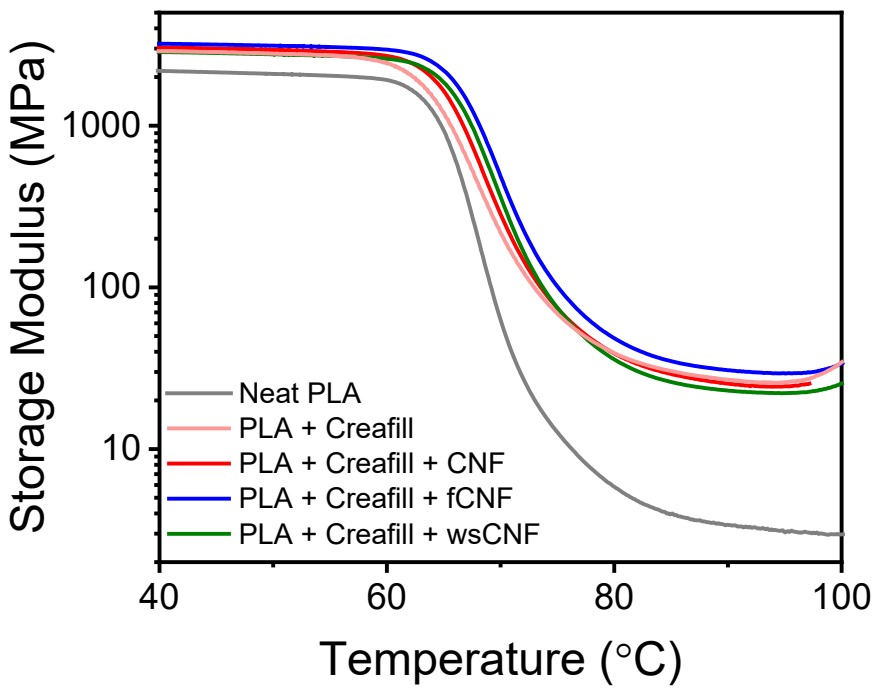
Varying CNF Source and Concentration

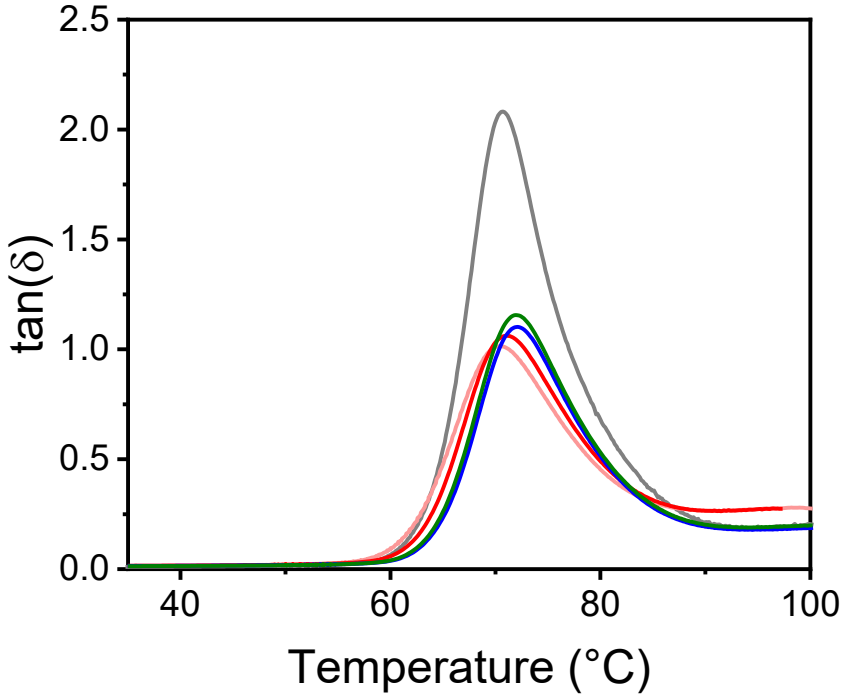




Takeaway: There is an optimum amount of CNF addition (1%) for fiber hybridization to maximize both strength and modulus.

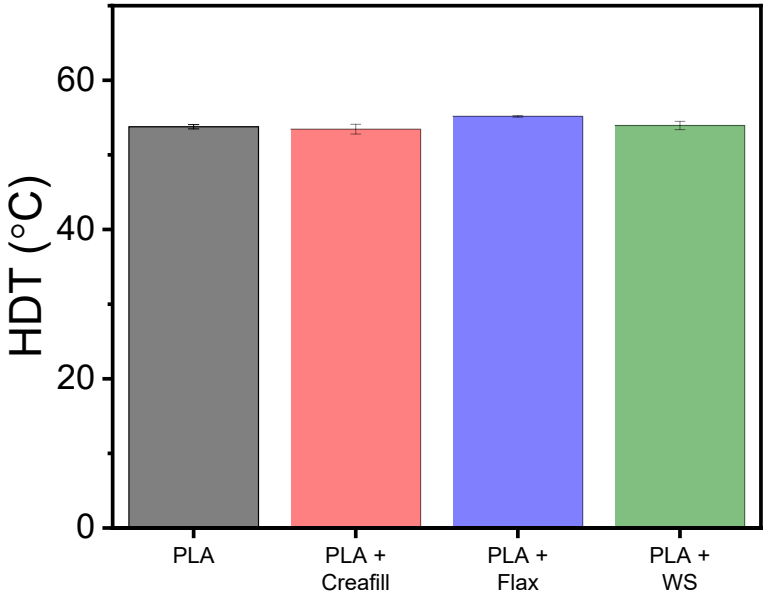
PLA (80wt%) + Filler (20wt%)

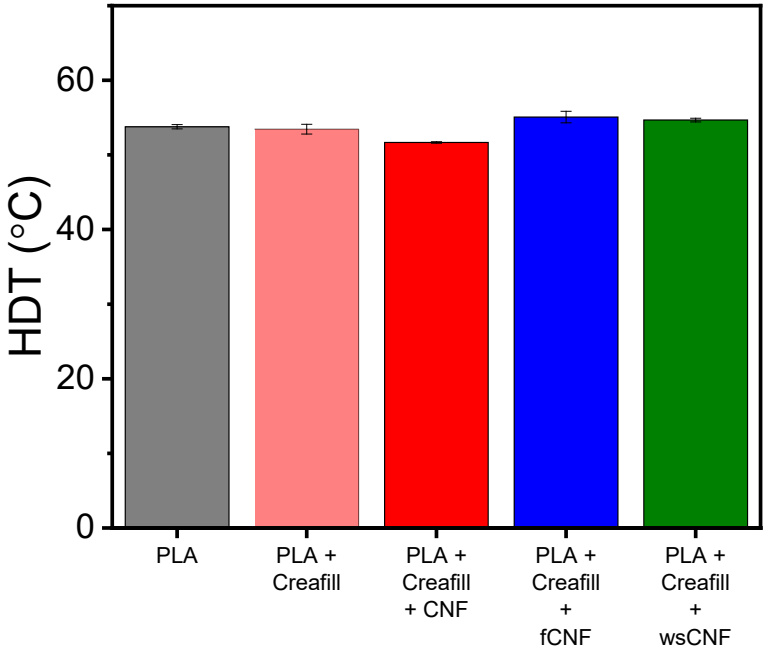




Takeaway: Dynamic mechanical analysis confirms no appreciable difference in modulus for all Creafill hybridized composites.

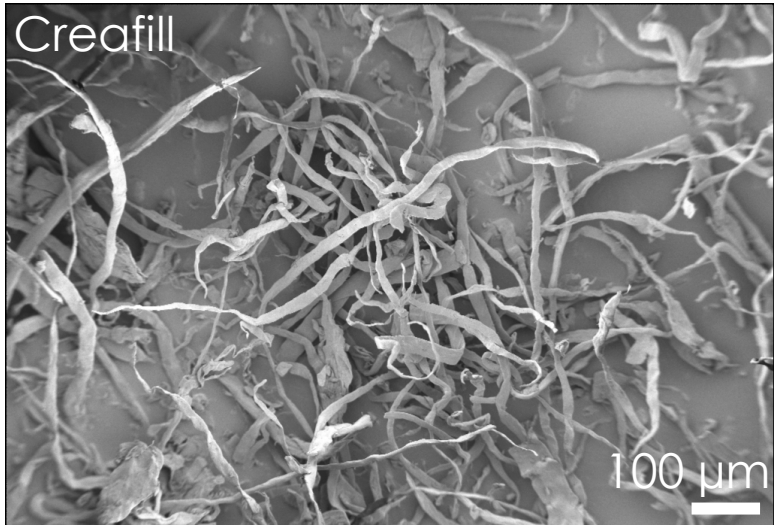
PLA (80wt%) + Filler (20wt%)

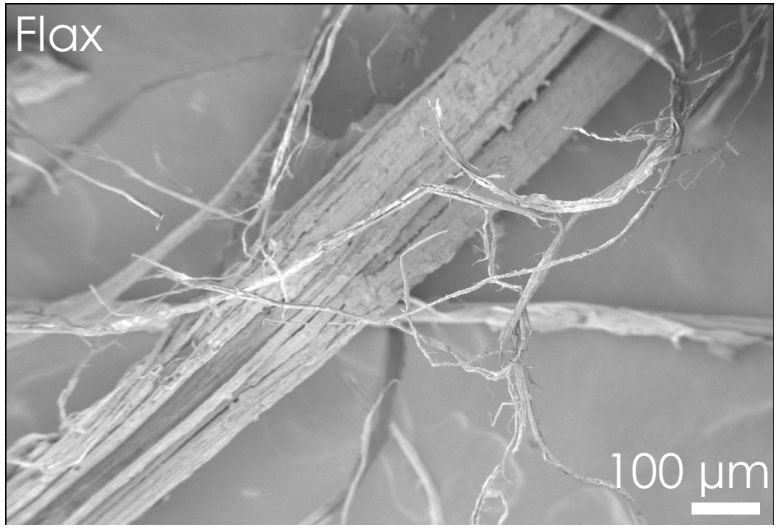


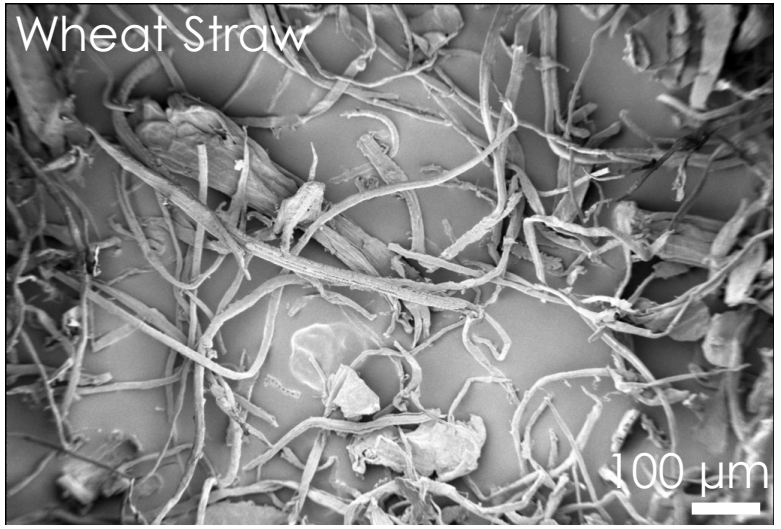


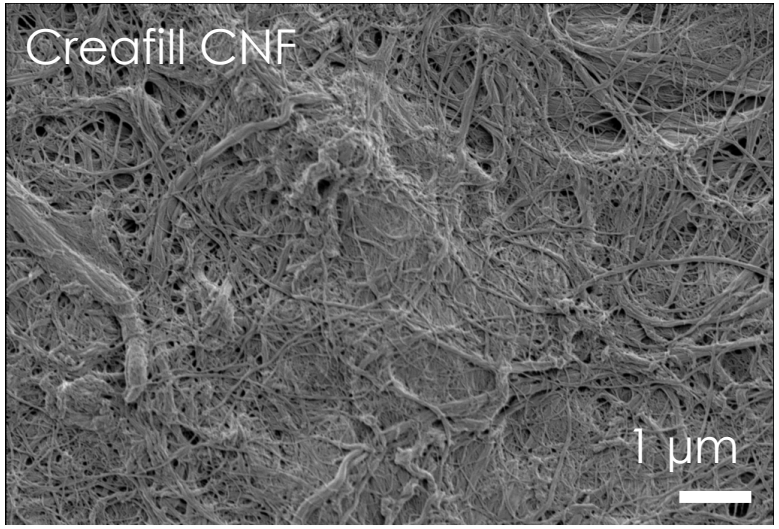
Takeaway: There is minimal variability in heat deflection temperature (HDT) regardless of filler type.

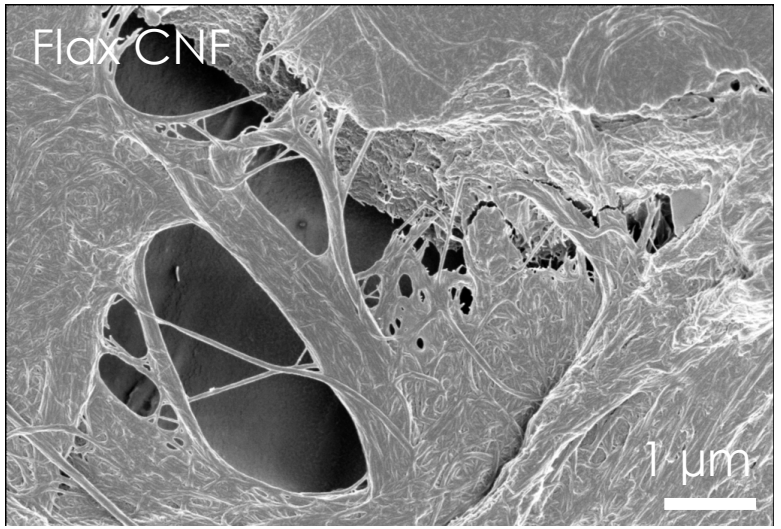
Hypothesis: Both topology and surface chemistry impact the adhesion between the filler and matrix.

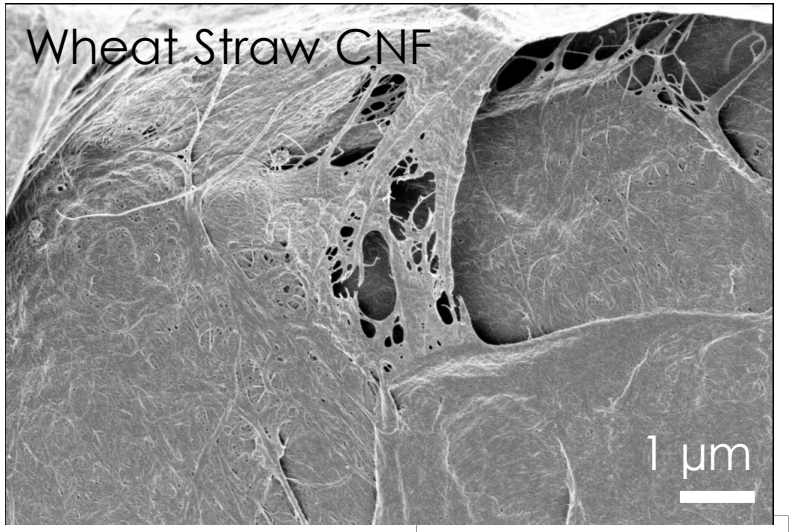




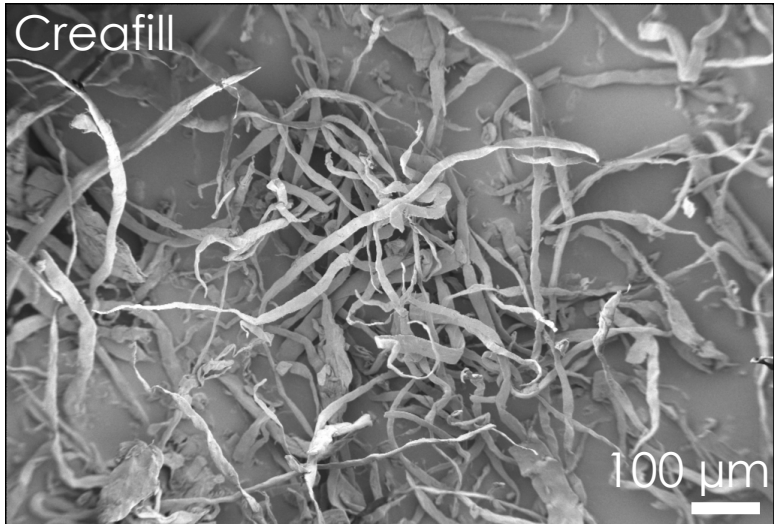


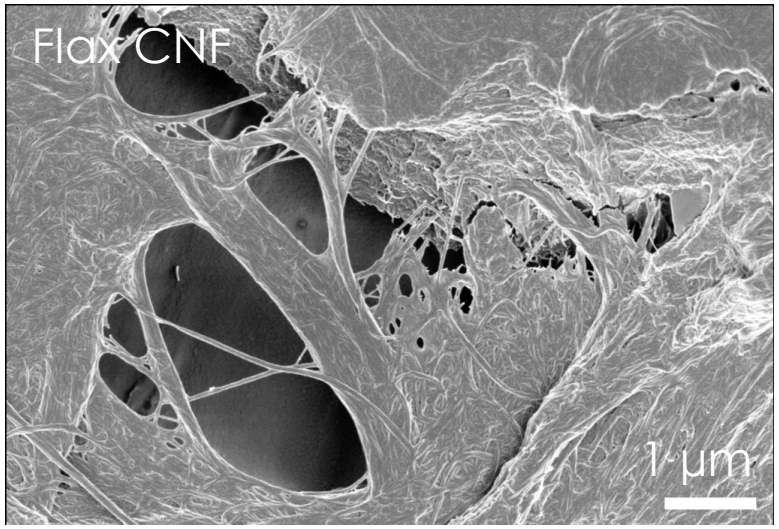






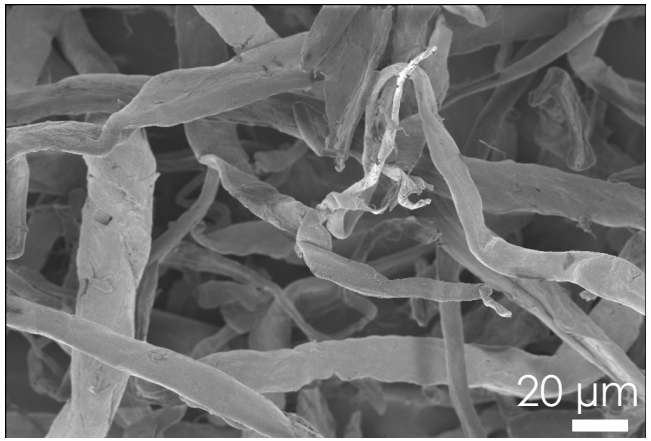
Hypothesis: Both topology and surface chemistry impact the adhesion between the filler and matrix.

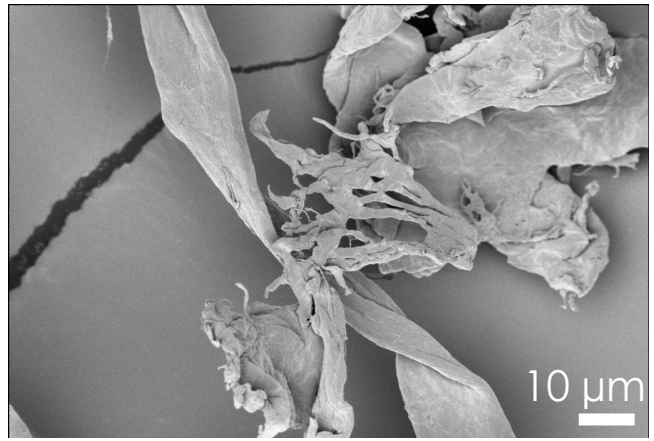


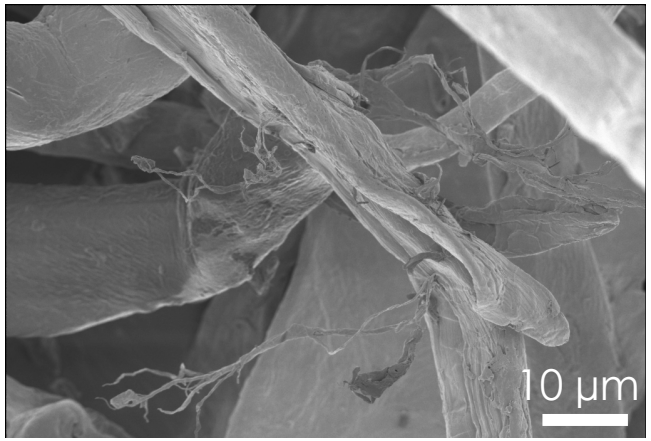


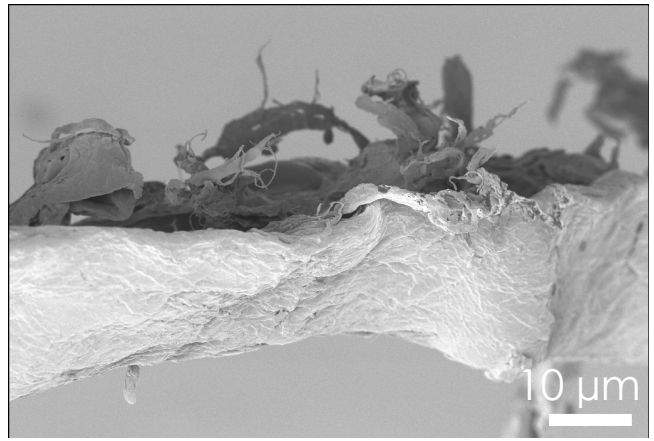
Hybridization

Creafill + Flax CNF



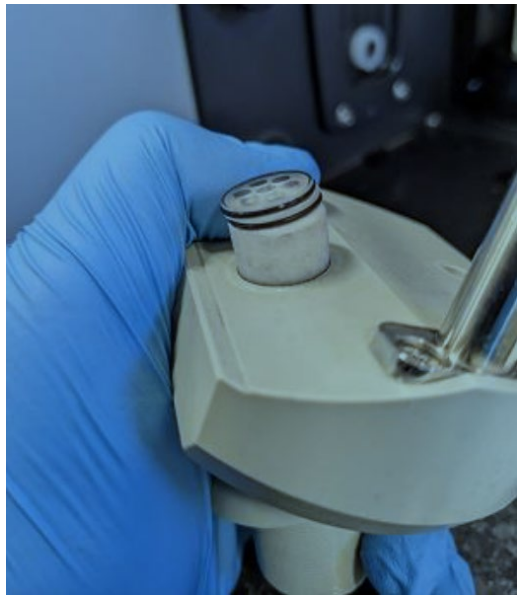


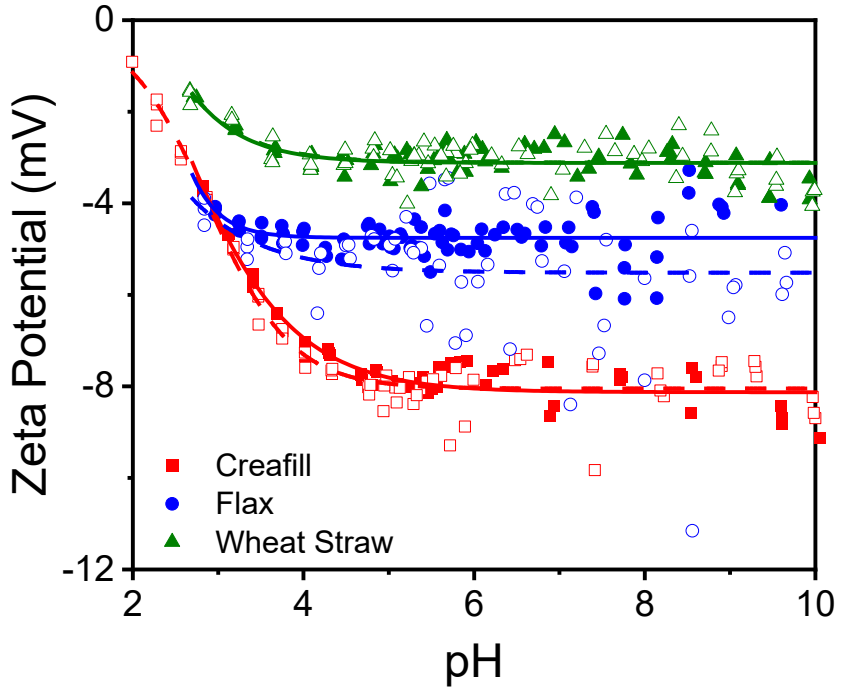




Anton Paar

Credit: Brian Rodenhausen





Takeaway: Most Hydrophilic → Least Hydrophilic
Wheat Straw → Flax → Creafill

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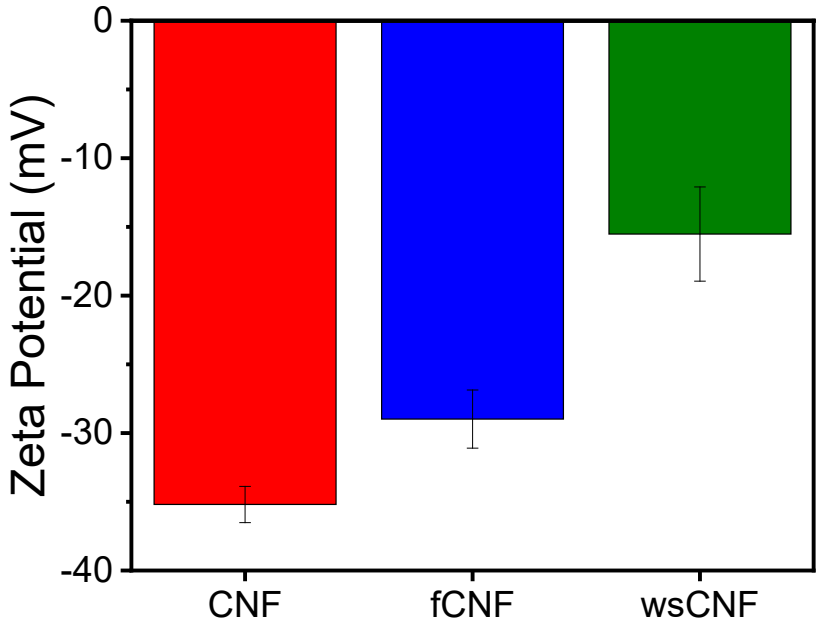
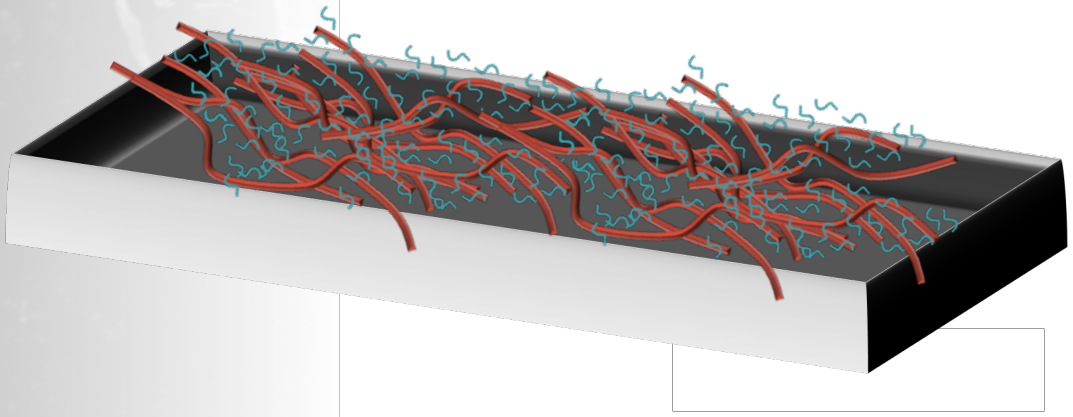


Takeaway: Most Hydrophilic → Least Hydrophilic
Creafill → Flax → Wheat Straw

Conclusions

- Hybrid fillers increase the strength and modulus of PLA composites.
- CNF sourced from flax (fCNF) and wheat straw (wsCNF) outperforms CNF sourced from bleached pulp (CNF) as a composite reinforcement.



Questions?

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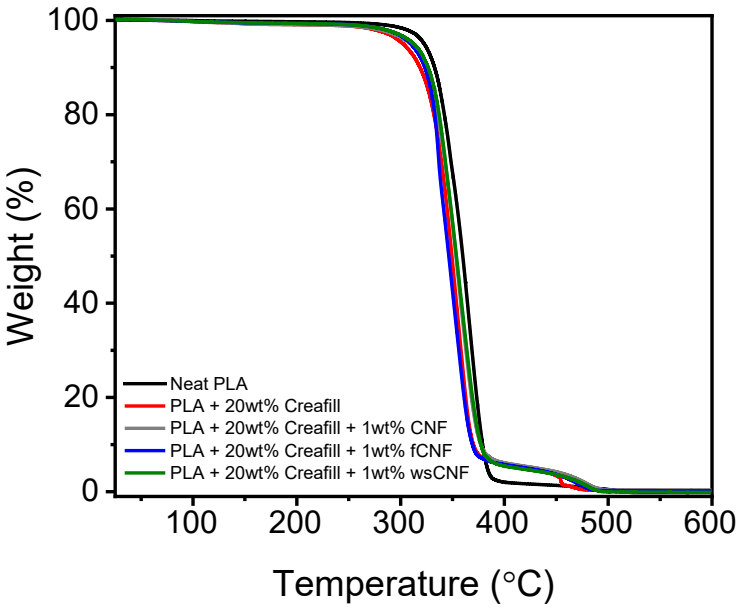
Abstract

Thermoplastic composites are of significant interest in a variety of industries ranging from automotive to construction as they present a recyclable, low cost, and lightweight alternative material without sacrificing performance. Additionally, hybrid composites which contain more than one type of reinforcement (*e.g.,* natural fibers and cellulose materials (CM)) have gained increasing attention where target properties are enhanced via composite formulations. Herein, three different fibers (*i.e.,* creafill, flax, and wheat straw) are mixed with three different CM and incorporated into polylactic acid (PLA) via melt compounding. PLA was chosen as the matrix material for all hybrid composites due to its industrial compostability and its demonstrated applicability in 3D printing. The mechanical and thermomechanical properties of the resulting thermoplastic, hybrid composites are reported where the composite strength and modulus exhibit marked increases compared to the non-hybrid composites. In addition, by matching the fiber and CM, the material demonstrates further improvements; the mechanism for property enhancement is explored as a function of CM. Finally, these hybrid composites are formulated and targeted for automotive and tooling applications.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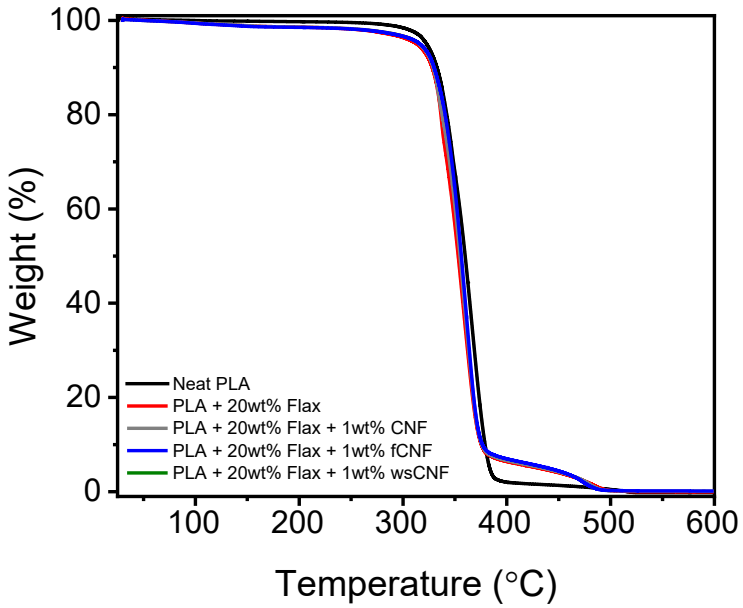
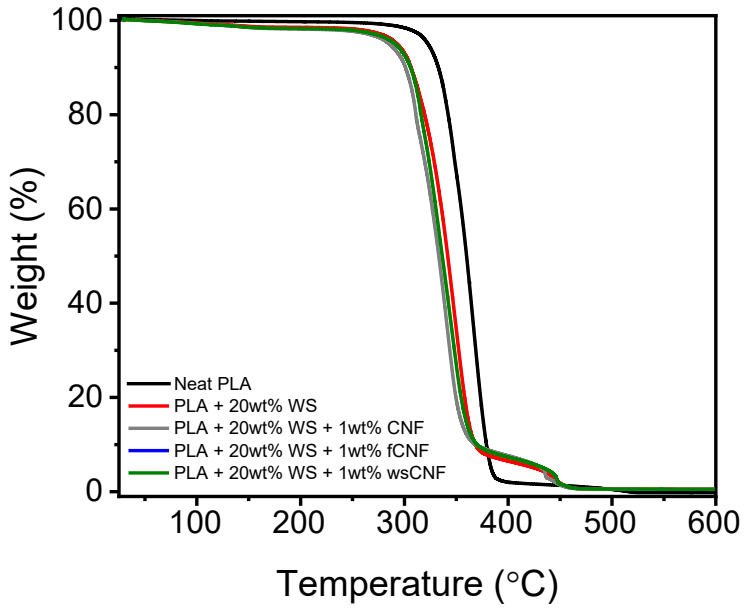
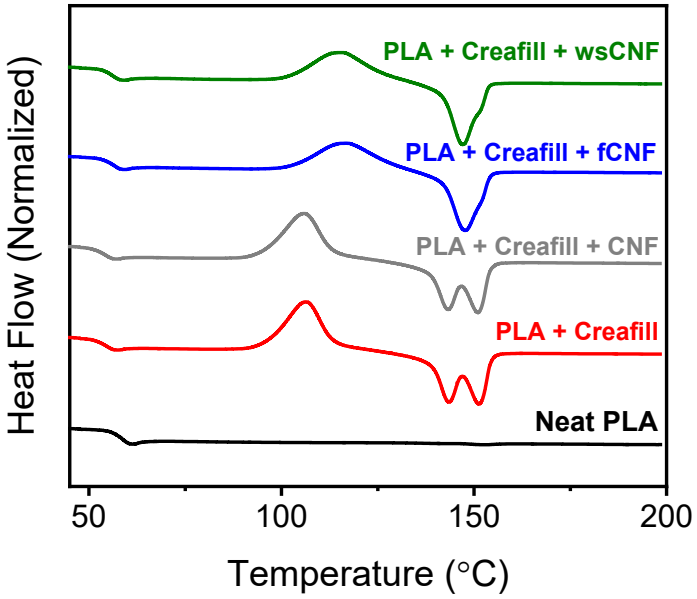
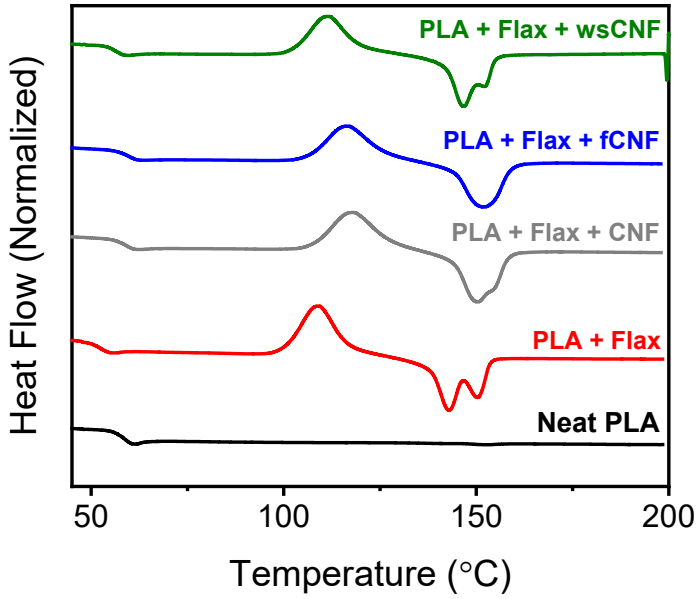
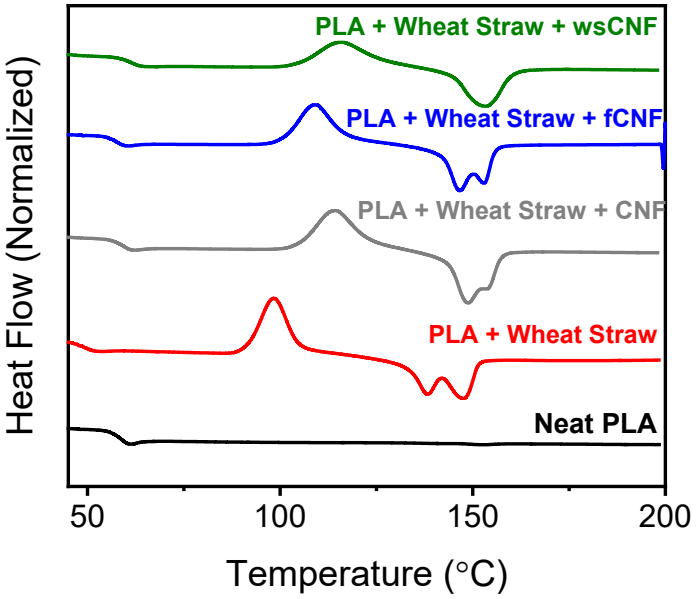
Temperature (°C)
Neat PLA
PLA + 20wt% Creafill
PLA + 20wt% Creafill + 1wt% CNF
PLA + 20wt% Creafill + 1wt% fCNF
PLA + 20wt% Creafill + 1wt% wsCNF

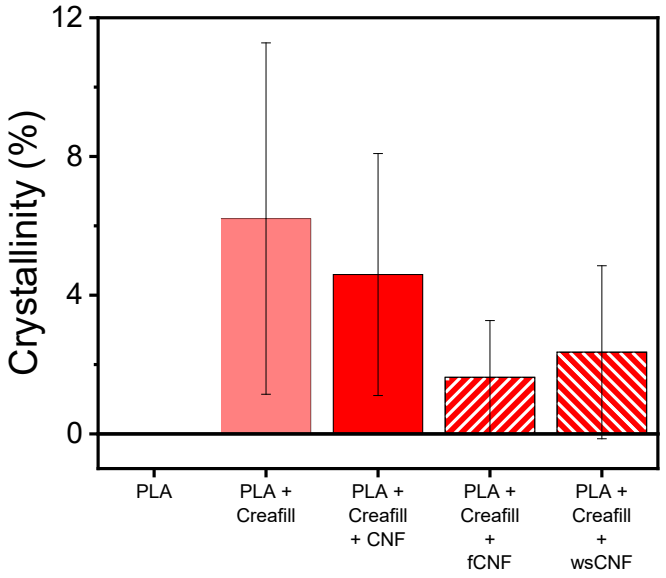

Weight (%)
Temperature (°C)
Neat PLA
PLA + 20wt% Flax
PLA + 20wt% Flax + 1wt% CNF
PLA + 20wt% Flax + 1wt% fCNF
PLA + 20wt% Flax + 1wt% wsCNF

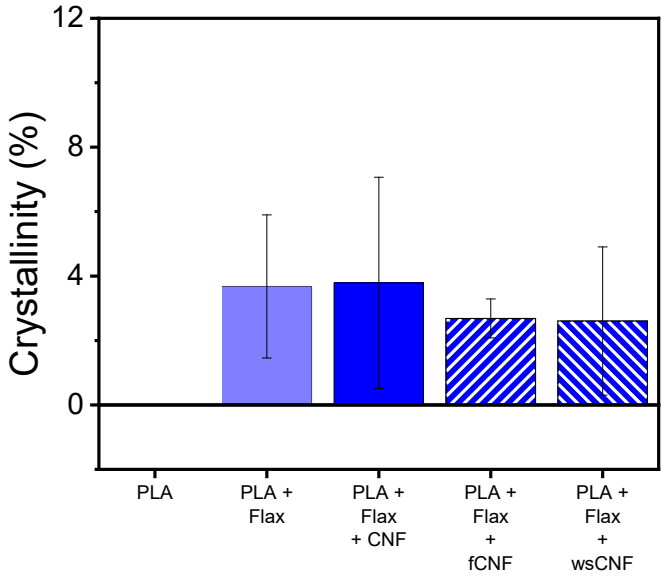

Weight (%)
Temperature (°C)
Neat PLA
PLA + 20wt% WS
PLA + 20wt% WS + 1wt% CNF
PLA + 20wt% WS + 1wt% fCNF
PLA + 20wt% WS + 1wt% wsCNF

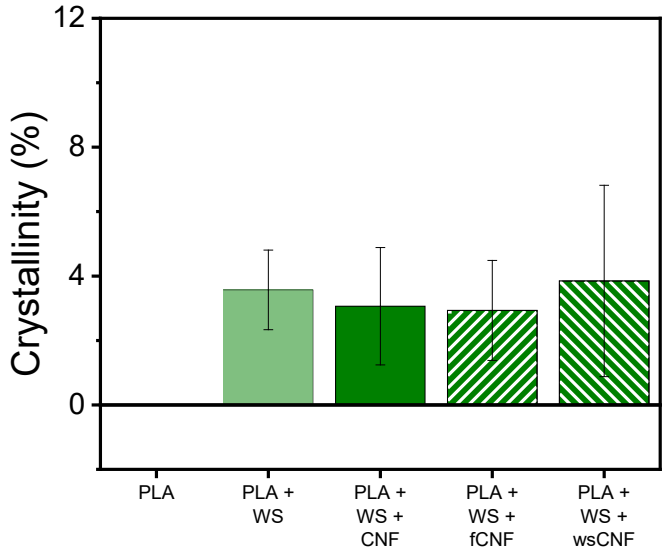












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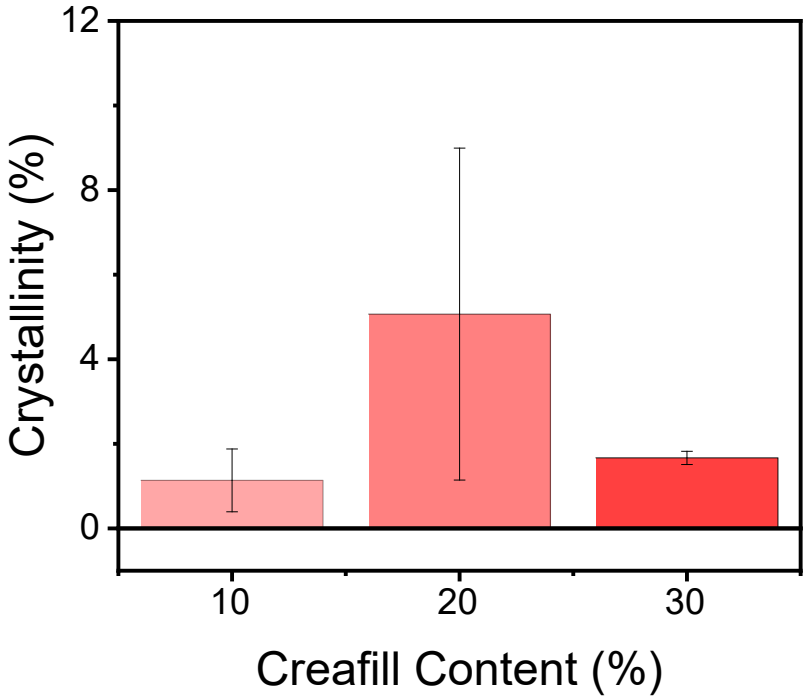
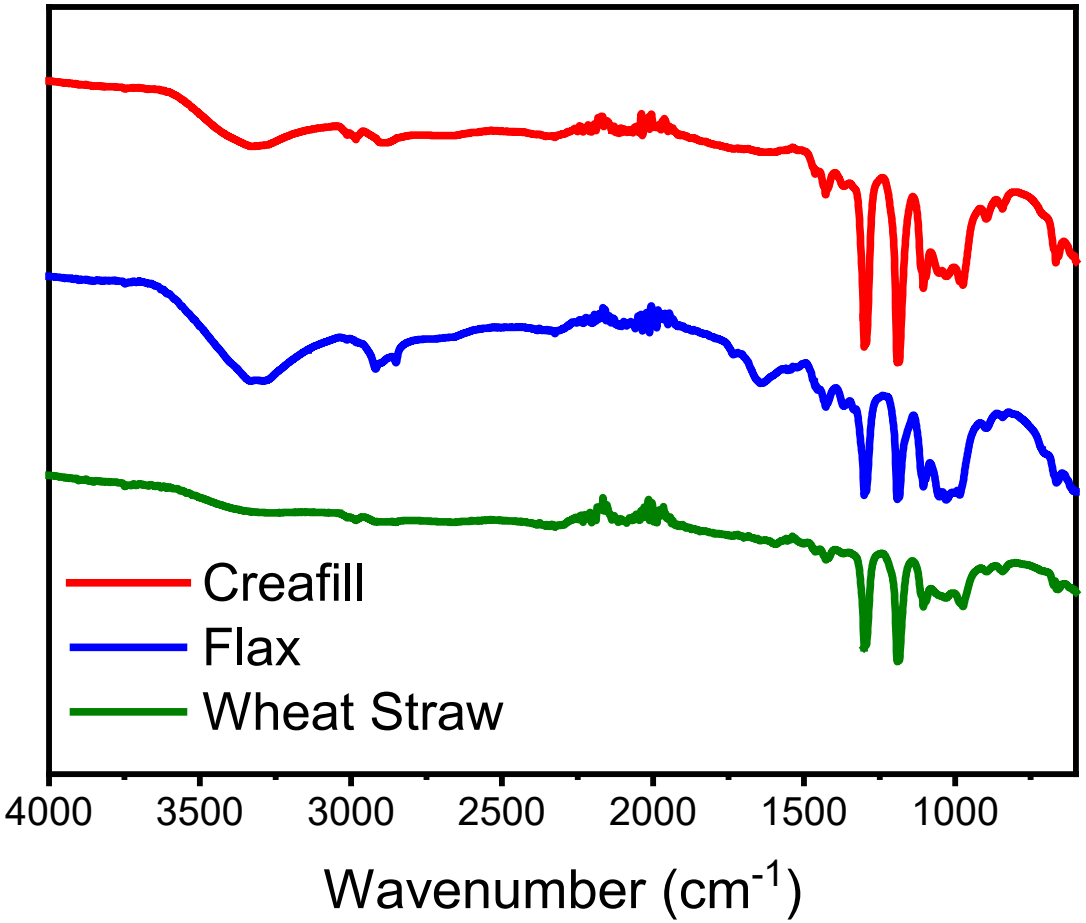
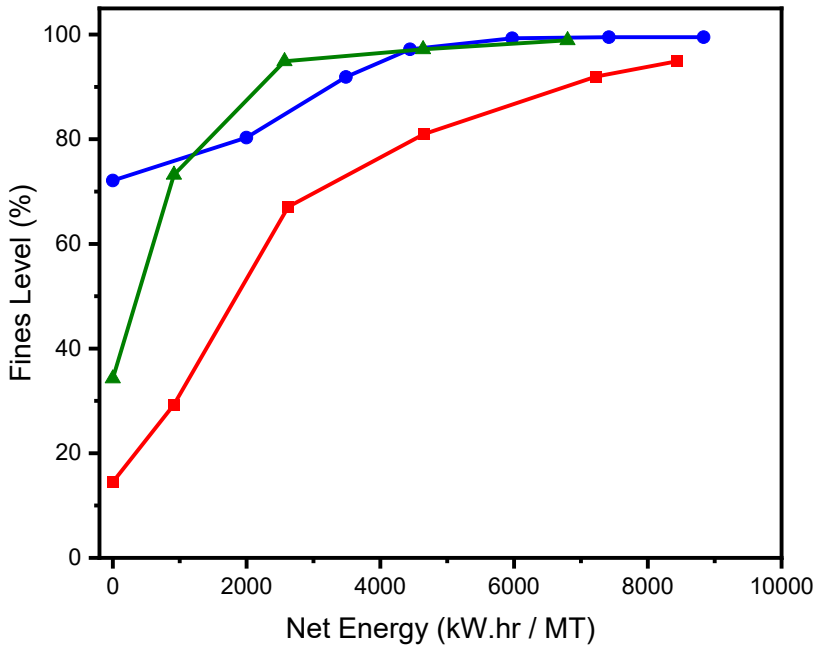

12
8
4
0
Crystallinity (%)
10
20
30
Creafill Content (%)

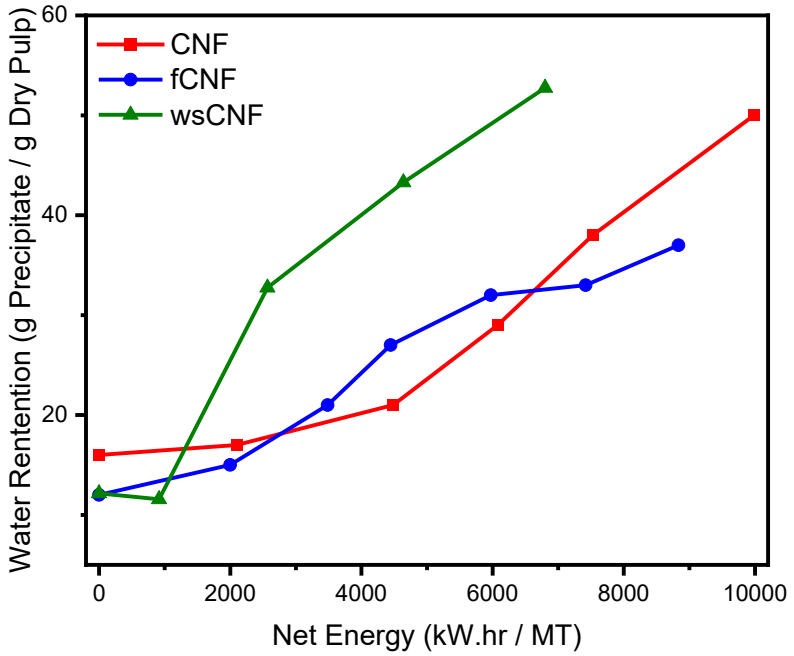
FTIR of Neat Macrofibers



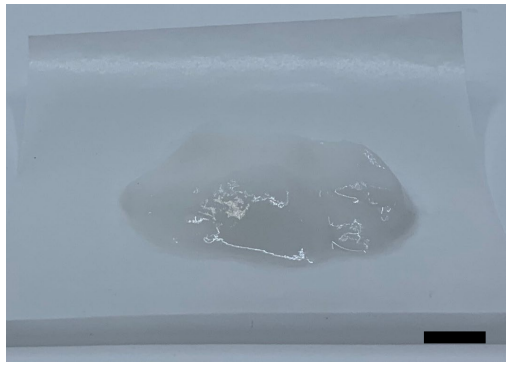
Credit: Dr. Colleen Walker

CNF Characterization

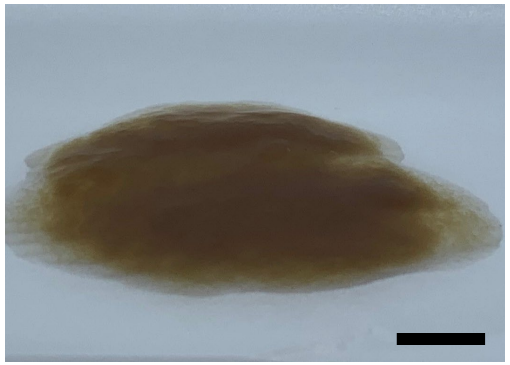




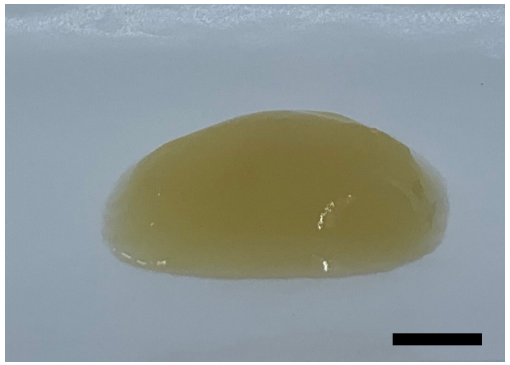
Creafill CNF



Flax CNF



Wheat Straw CNF



Scale Bar: 1 cm

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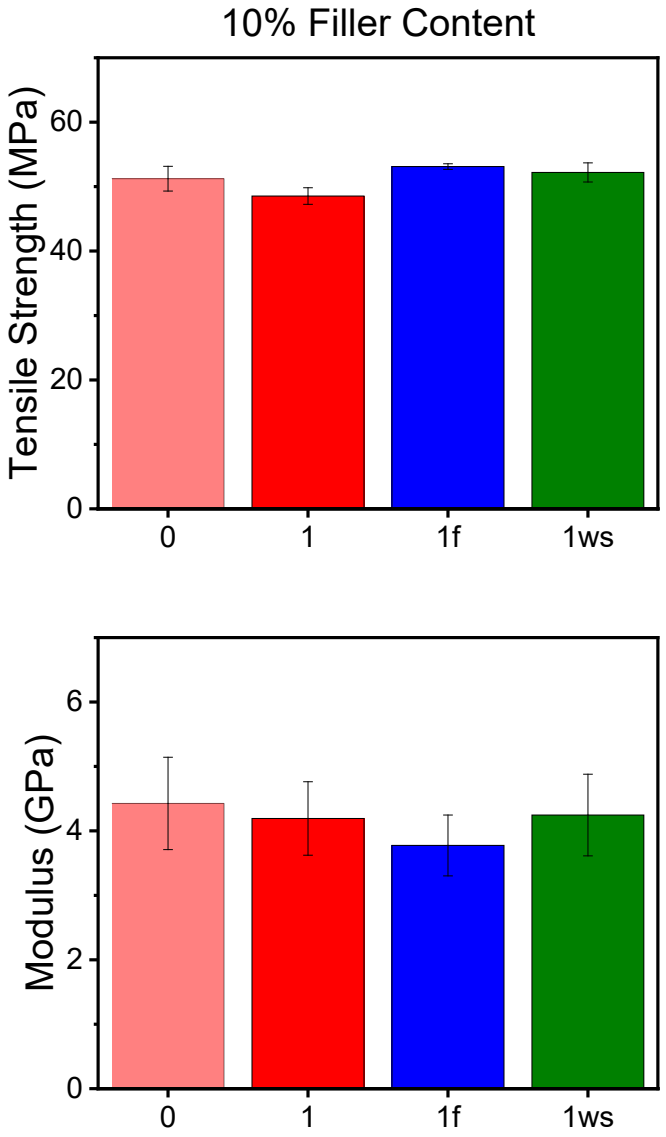
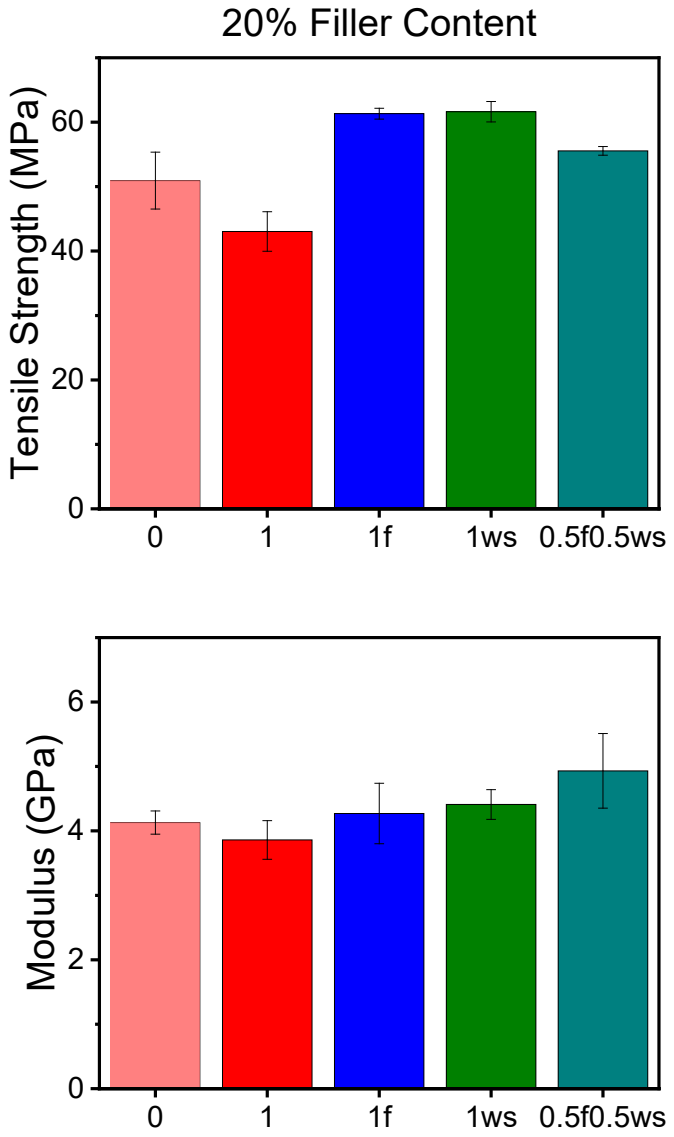
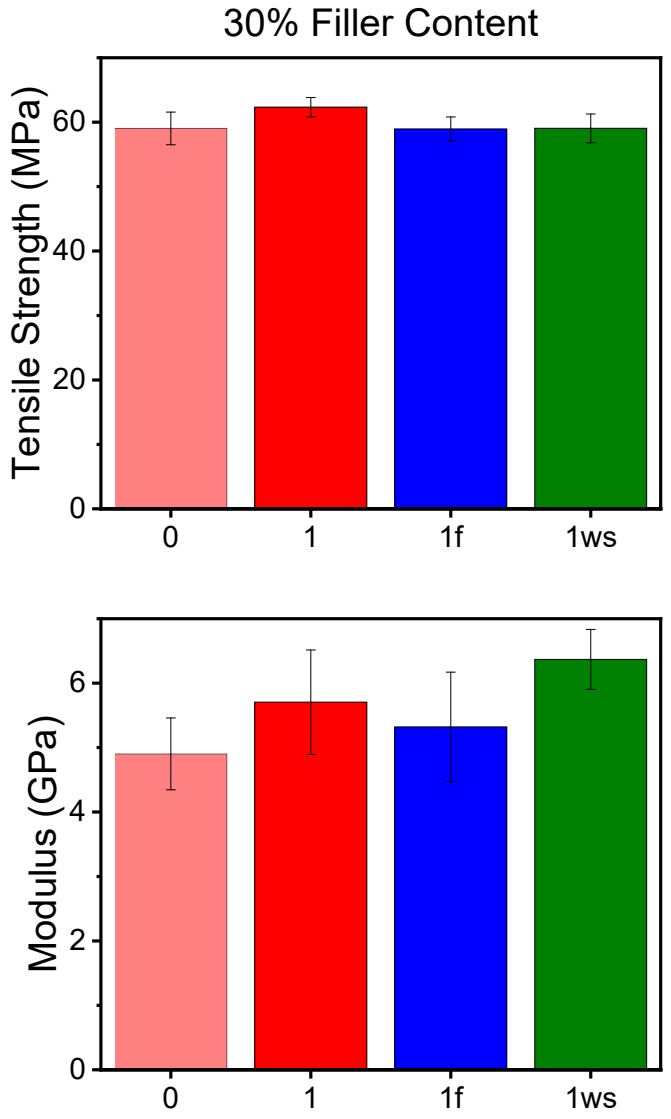
Varying Hybrid Filler Concentration







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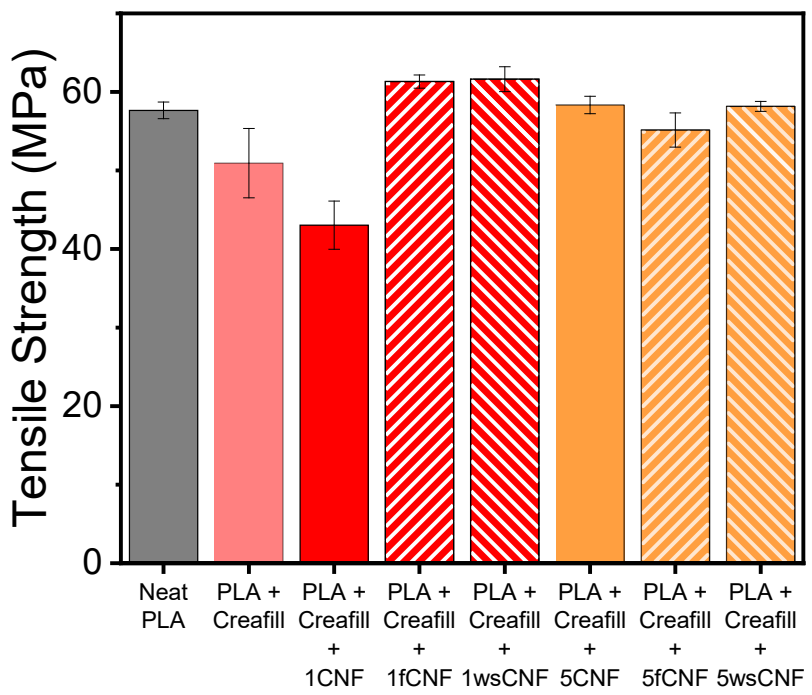
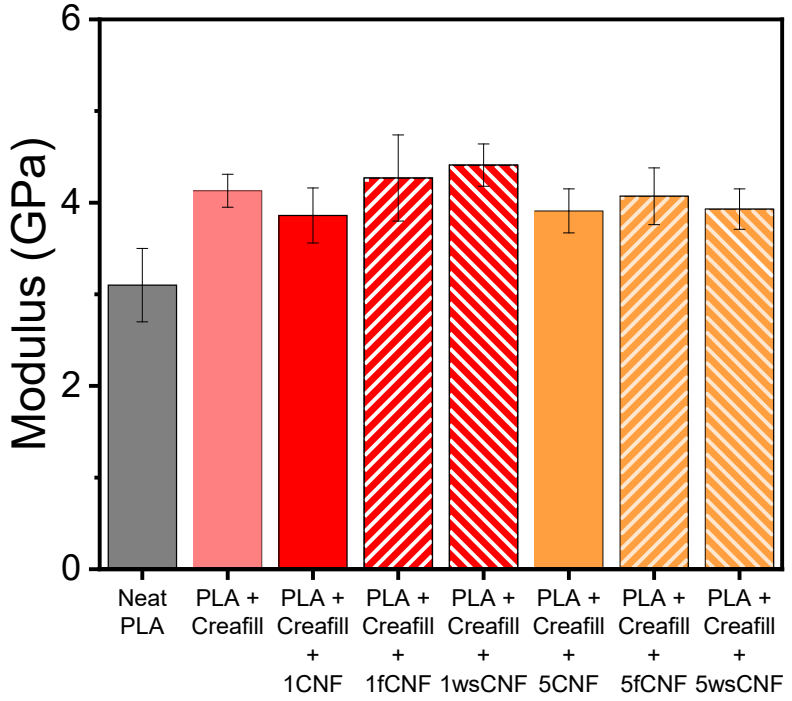
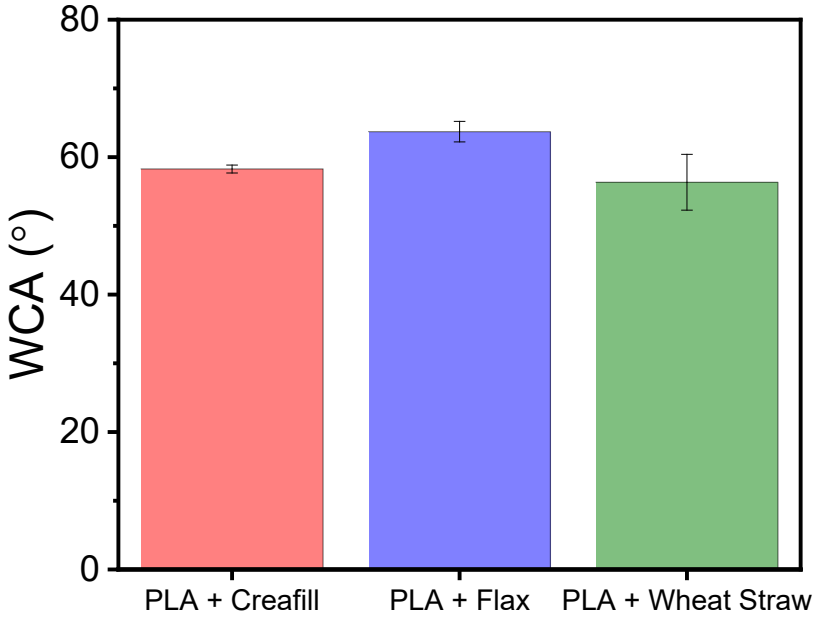




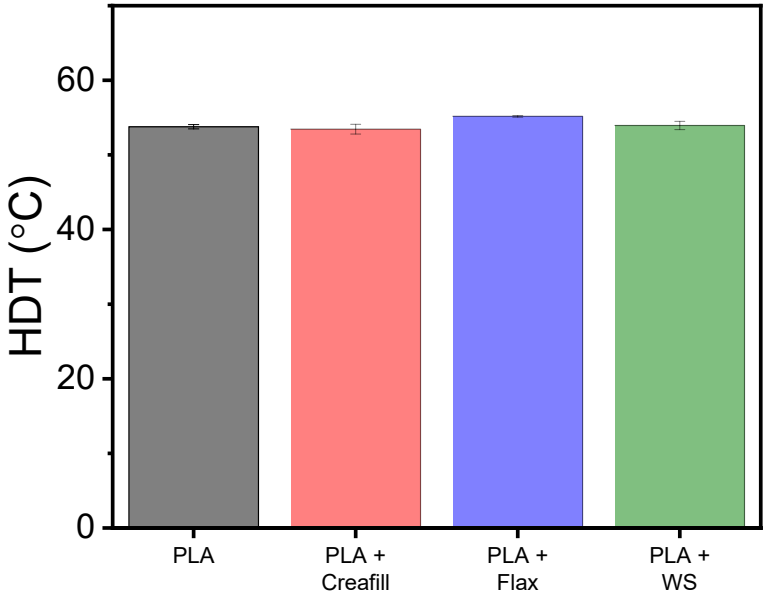
Takeaway: There is an optimum amount of CNF addition for fiber hybridization to maximize both strength and modulus.

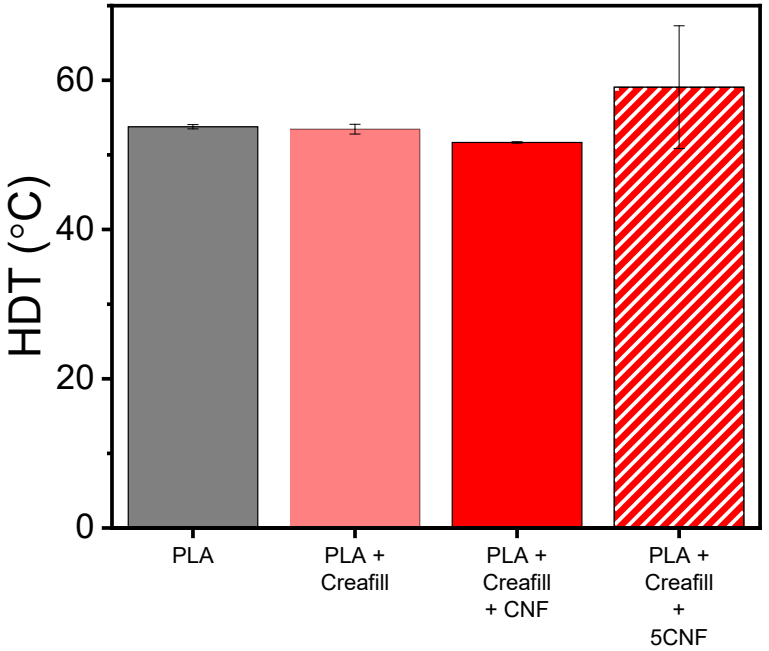
PLA (80wt%) + Filler (20wt%)

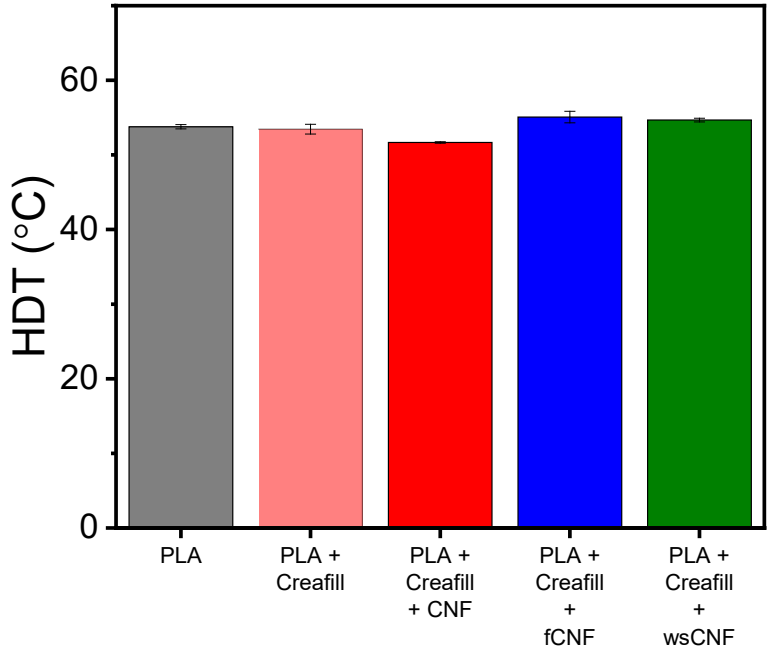


Takeaway: No appreciable difference in hydrophilicity of the composites.

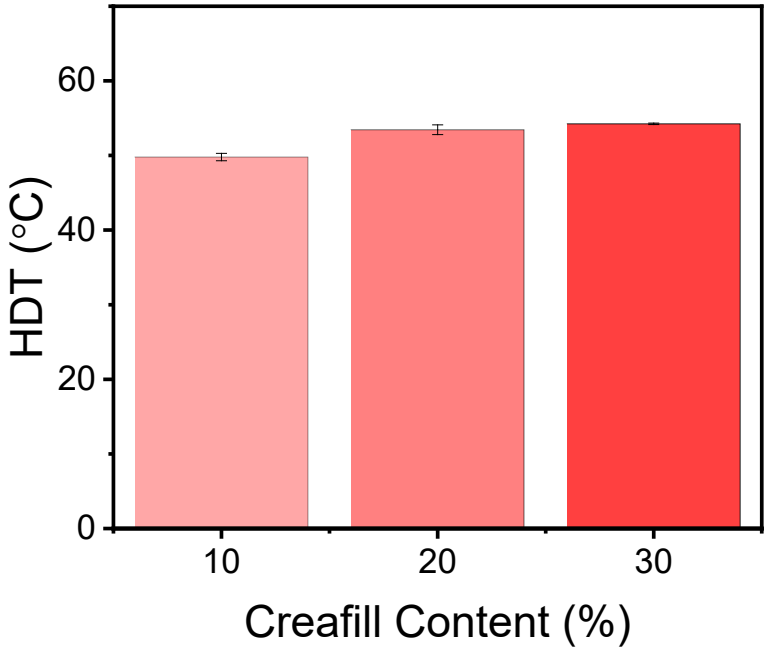
PLA (80wt%) + Filler (20wt%)



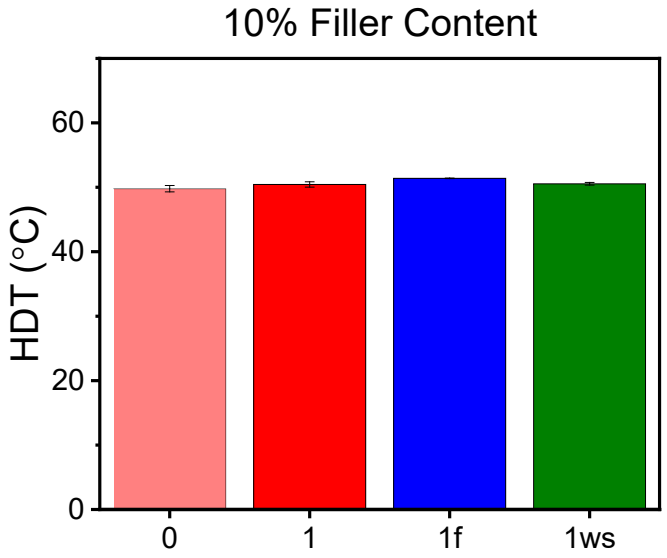


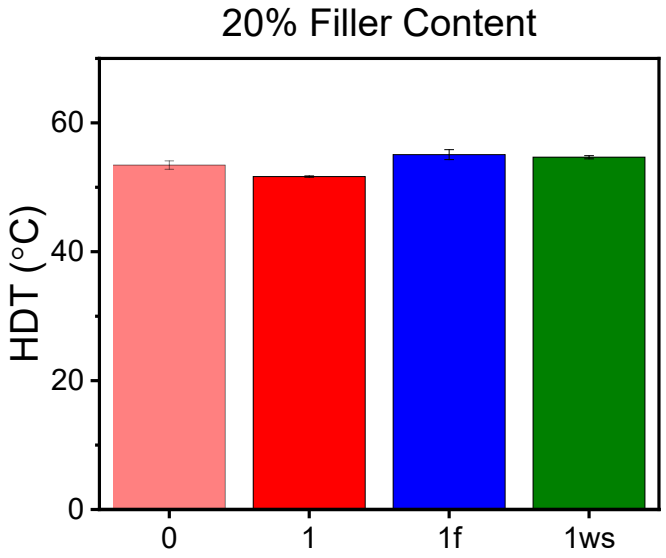


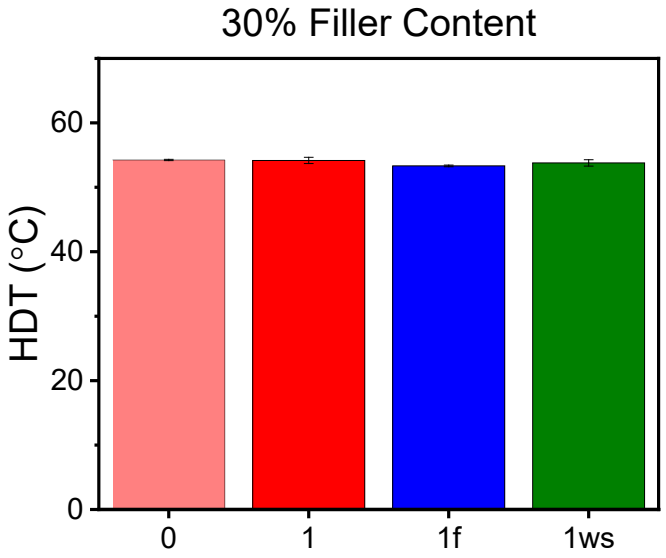
Takeaway: There is minimal variability in heat deflection temperature (HDT) regardless of filler type.



Takeaway: The heat deflection temperature (HDT) is optimized at 20wt% filler concentration.







Takeaway: The heat deflection temperature (HDT) is optimized at 20wt% filler concentration; minimal changes seen throughout.

Biomass Composition

Filler Type	Glucan (%)	Xylan (%)	Lignin (%)
Creafill	79.33 ± 1.65	18.4 ± 0.67	-
Flax	73.46 ± 0.71	6.97 ± 1.73	15.34 ± 0.26
Wheat Straw	49.92 ± 0.92	21.8 ± 0.47	24.82 ± 2.17

Hypothesis: Both topology and surface chemistry impact the adhesion between the filler and matrix.