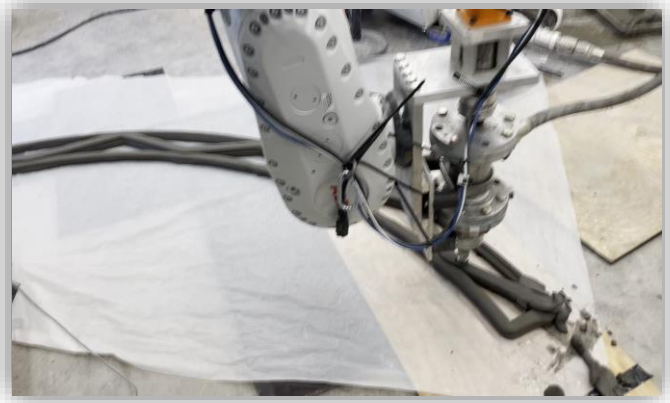

Sustainable cementitious composite containing cellulose nano fibers for concrete 3D-Printing

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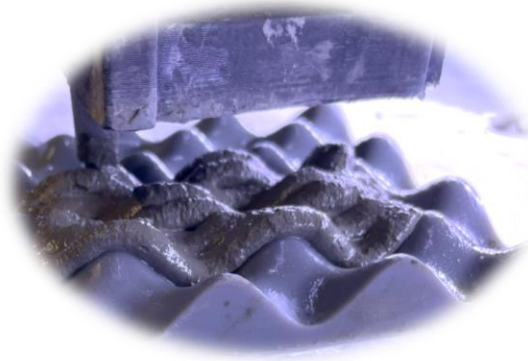
Dr. Jan Olek, Dr. Pablo D. Zavattieri, Purdue University (CE)
Dr. Jeffrey P. Youngblood, Purdue University (MSE)



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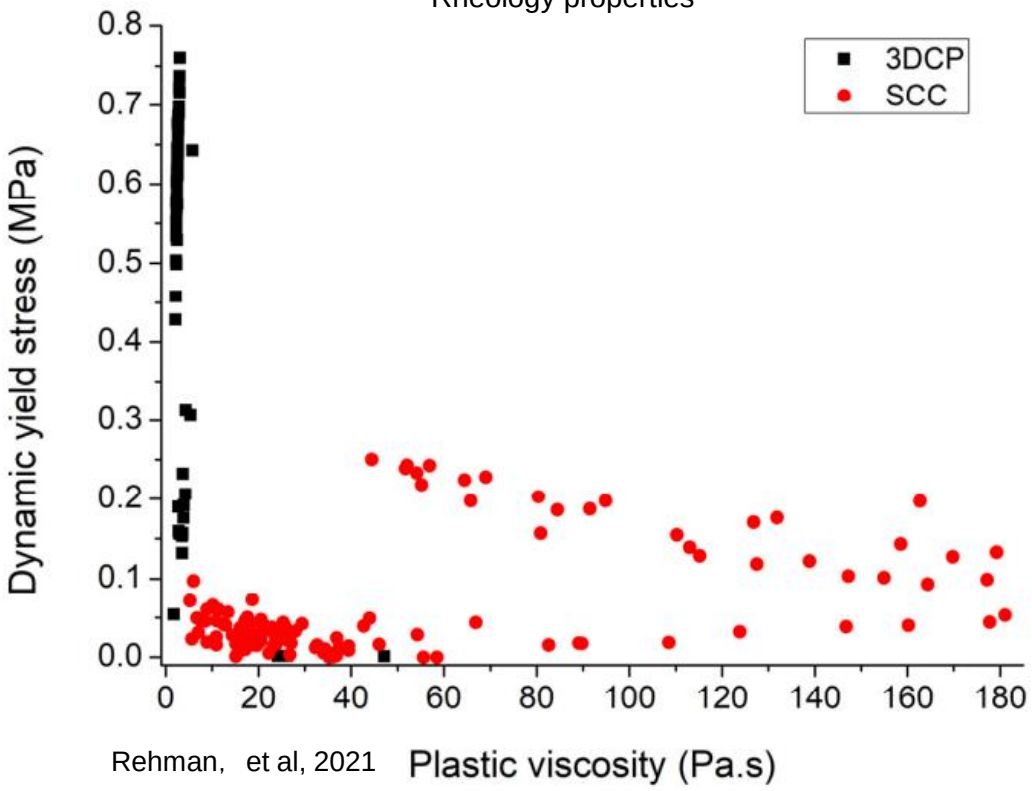
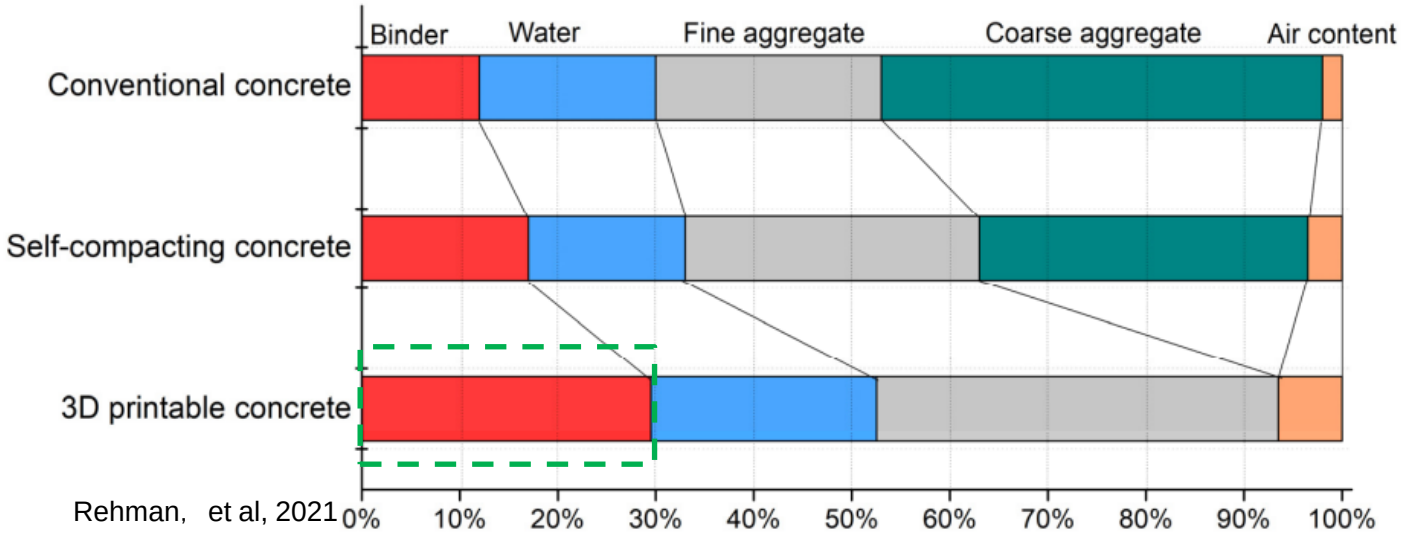
3DP Concrete

Rheology properties



Rehman, et al, 2021



Rehman, et al, 2021

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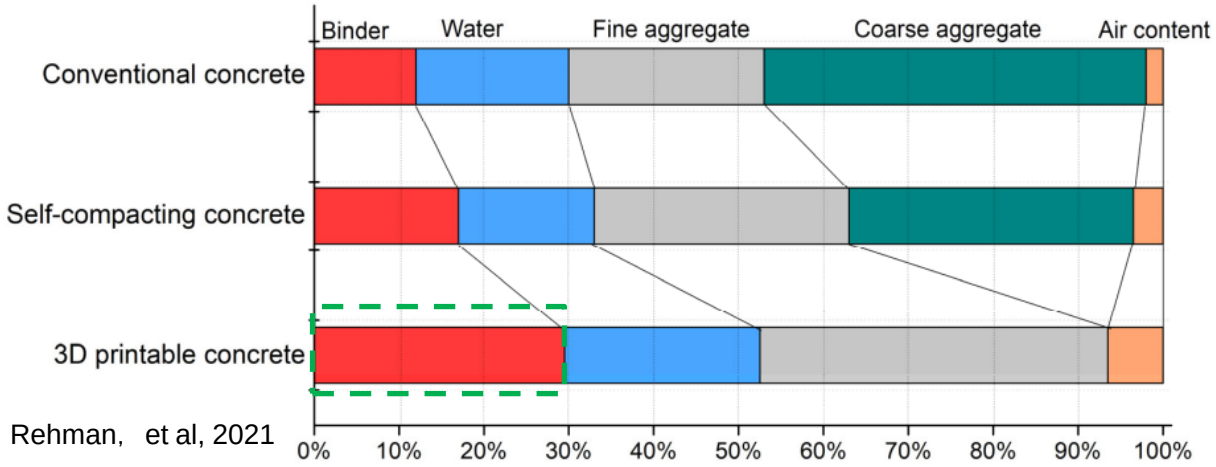
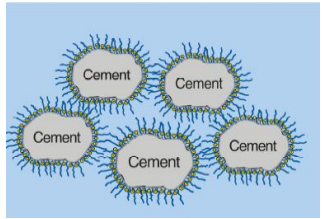
3DP Concrete



Rehman, et al, 2021

- **Water Reducing Admixtures**
  - Increase flowability and pumpability

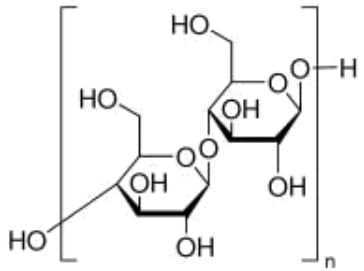


Thomas and Wilson 2002

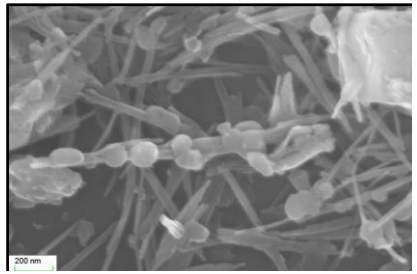
- **Accelerators**
  - Accelerate setting and early-strength development.
  - Apply at print head/extruder

Additives

- **Viscosity modifier**
  - Enhance bleeding resistance and ink consistency (cohesion)



- **Nano materials**
  - Enhance rheology, mechanical and durability properties



- Looking for cost-effective additives
- Improving the greenness of the binder

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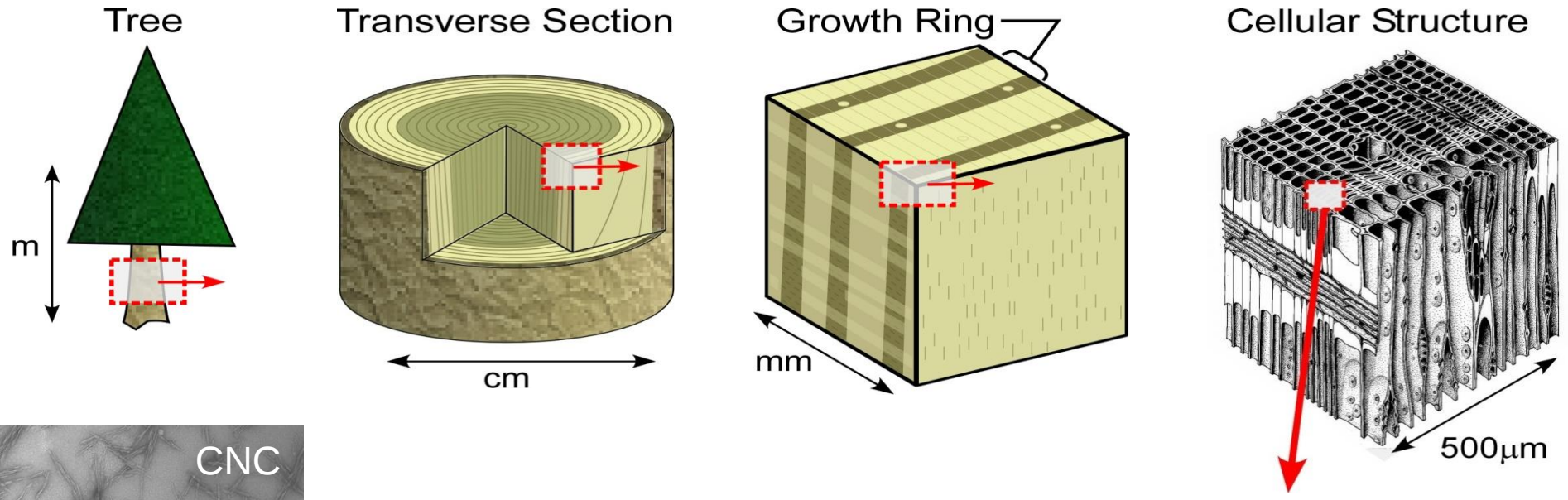
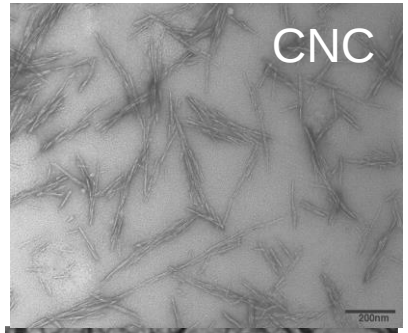
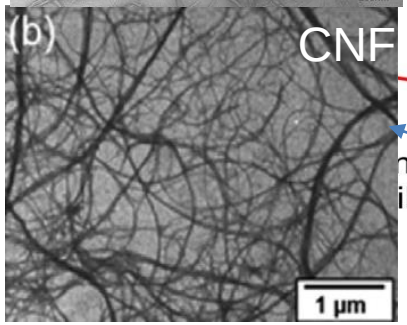
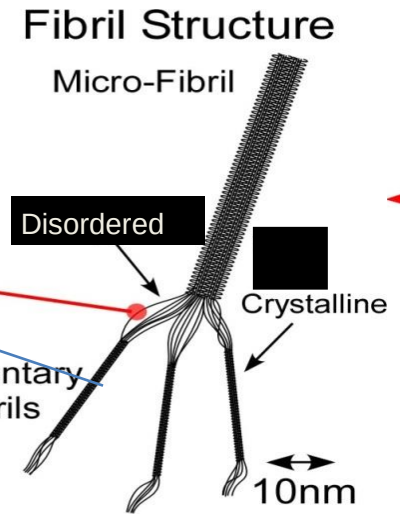
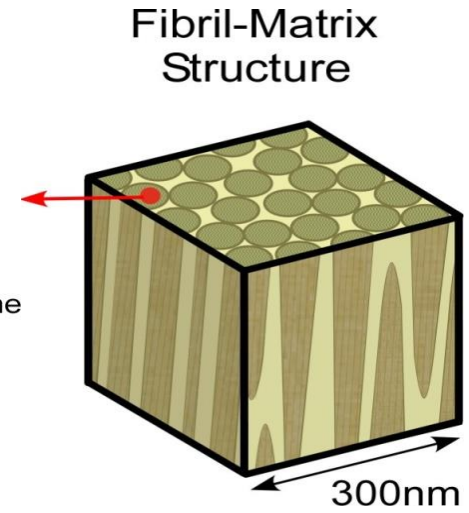
Cellulose nanomaterials

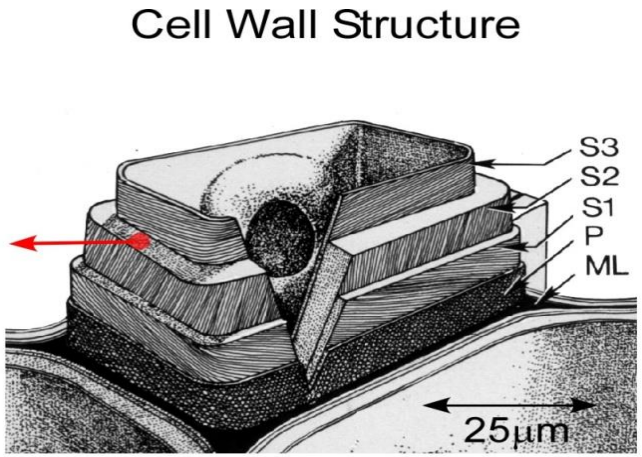












Jones et al. 2009

- Cellulose is the most common organic polymer in the World representing about 1.5 x10^{12} (trillion)tons of the total annual biomass production(Jones et al. 2009).
- **CNF are only ~$75 /lb**

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Material and Methods

Influence of CNF and limestone filler on the rheology, mechanical properties, cement hydration will be presented.

CNF: 0%, 0.15%, 0.3% wt%
The percentage was calculated by dry weight of the CNF with respect to the total dry weight of binder

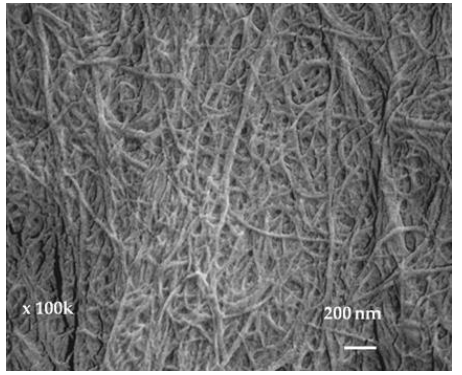
Limestone filler: 11%, 25%, 40% wt%

- 11% is the percentage of limestone filler in our **Type IL** cement
- 25% and 40% are the weight percentage of the limestone filler with respect to the total weight of the binder(consider the limestone filler in the Type IL cement)

3.0 wt% aqueous CNF gel

CNF product data sheet(UMaine)

Nominal fiber width of 50 nm and lengths of up to several hundred microns



CNF product data sheet(UMaine)

Fine limestone filler with median diameter of 1.4 micron

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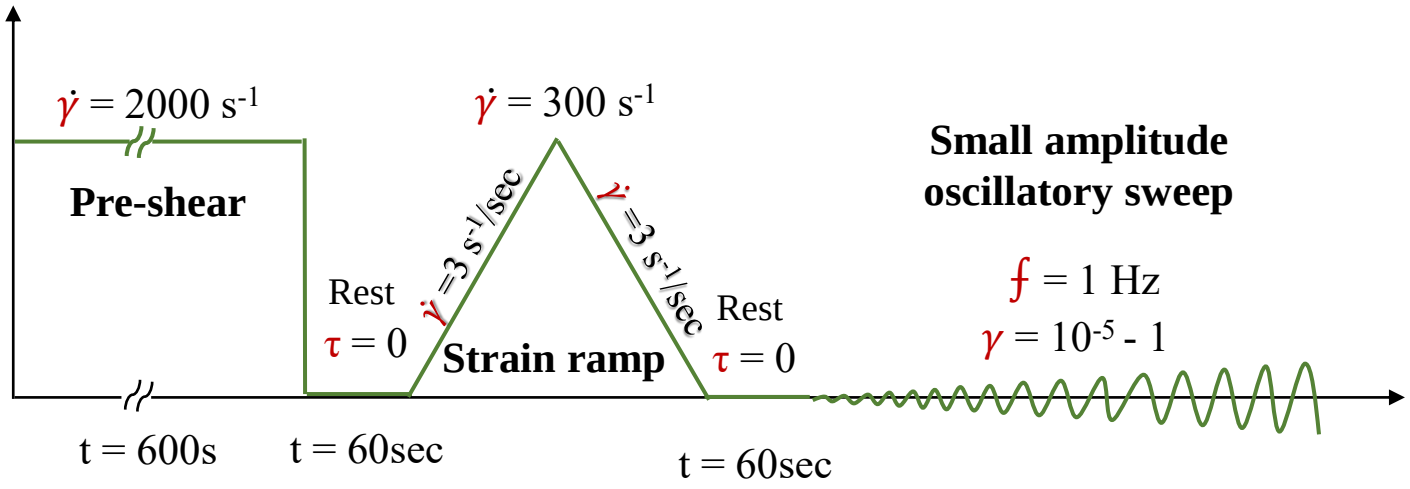
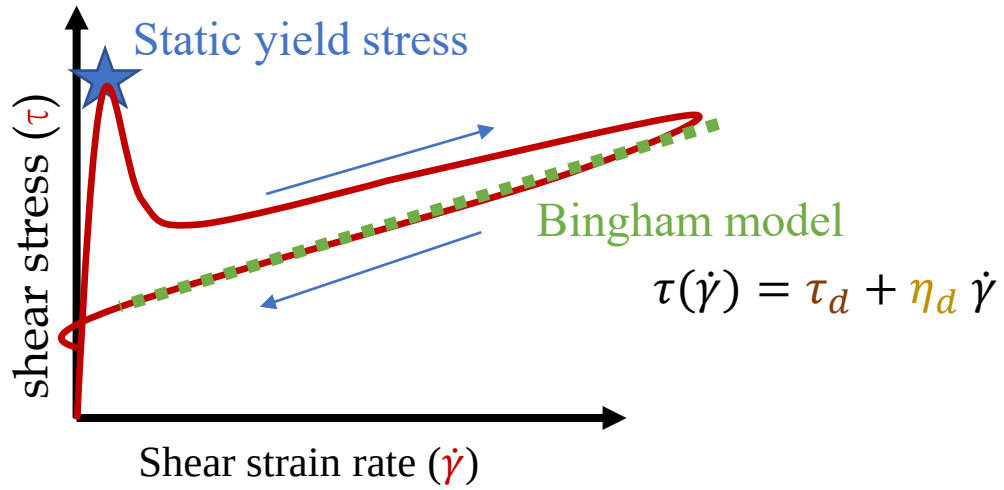
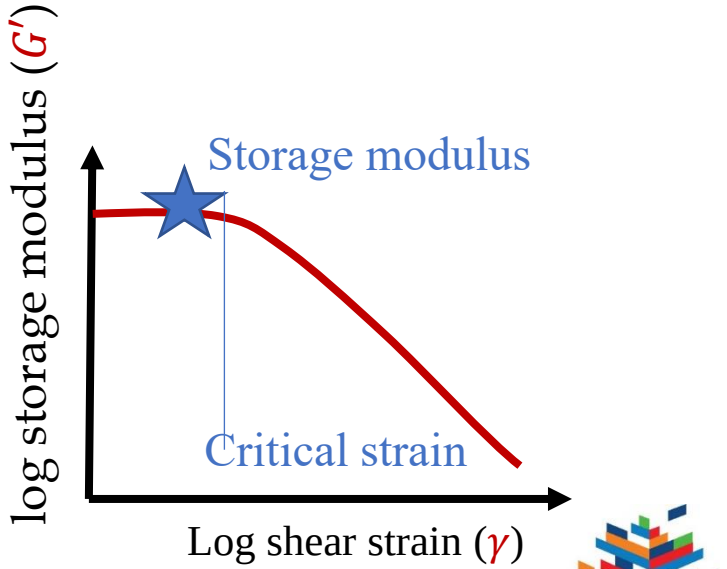
Rheological protocol

Applied:

- Shear stress (τ)
- strain rate ($\dot{\gamma}$)







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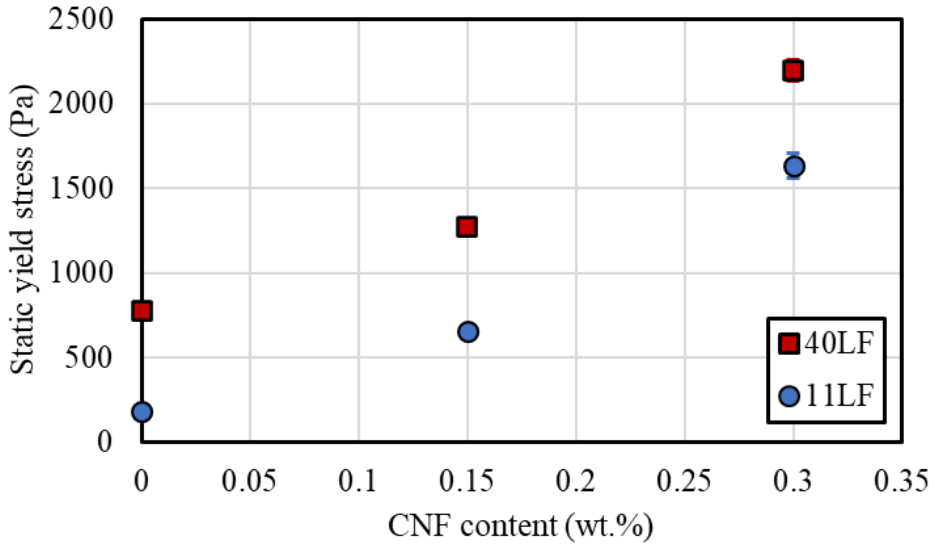
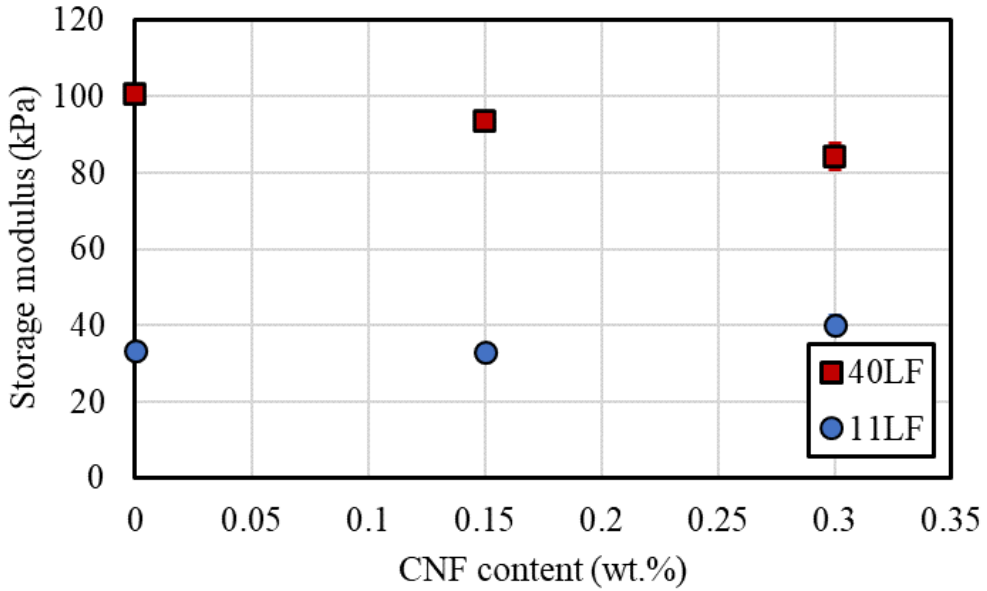
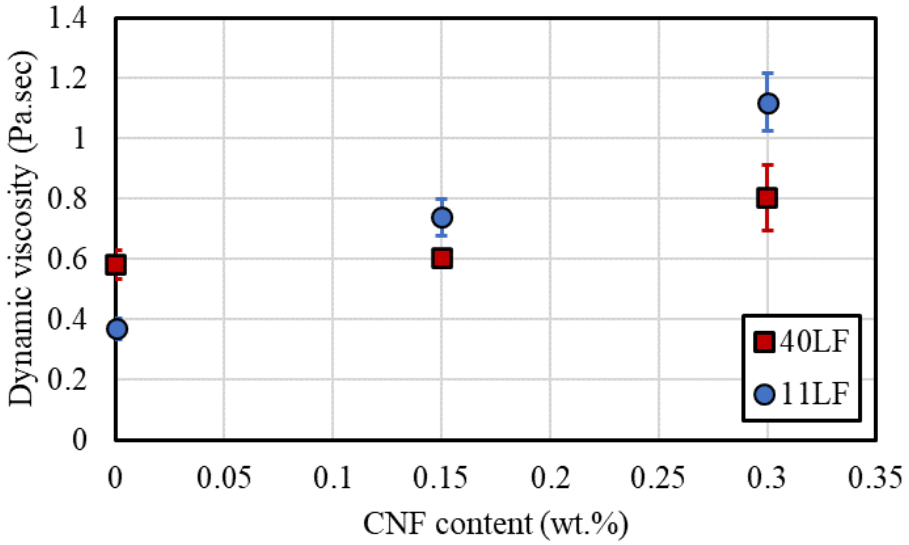
Rheology Results







- Incorporating 0.3 wt% CNF increased the static yield stress of cement paste by ~800%.
- Addition of CNF enhances static yield stress by 4500 Pa/ 1 wt. %. In comparison, nanoclays offer 400 Pa / 1 wt.%(Douba, et al. 2022).
- Addition of CNF alone increases dynamic viscosity. However, addition of CNF with LF have minimal effects on dynamic viscosity and pumping pressure.
- Addition of CNF do not significantly influence storage modulus while addition of limestone fille increase the storage modulus

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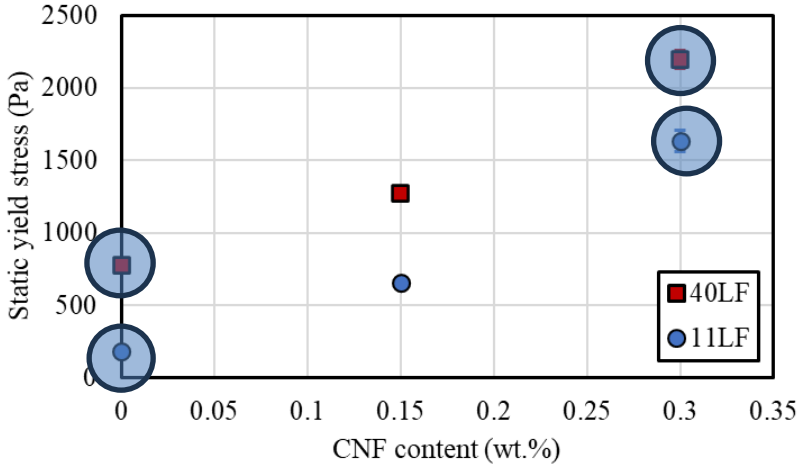
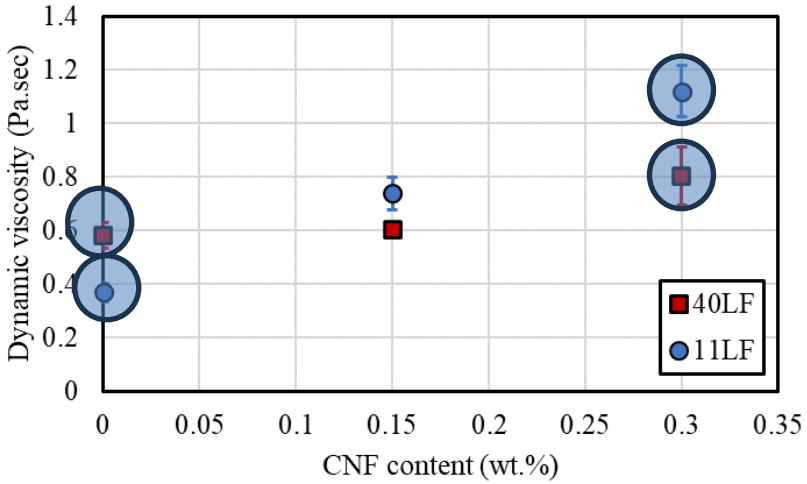
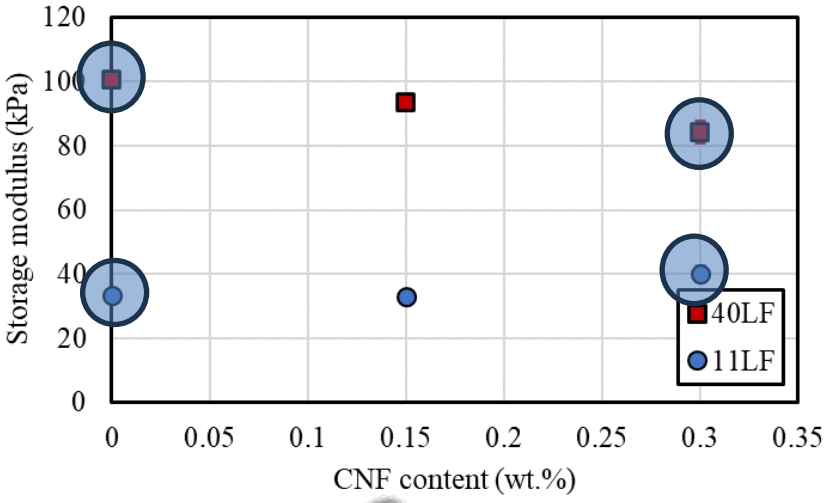
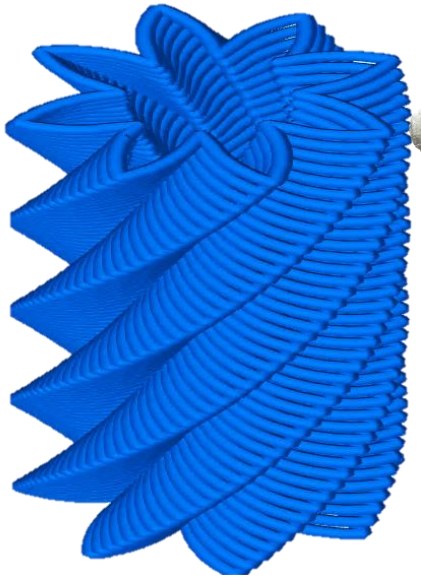
Rheology Results



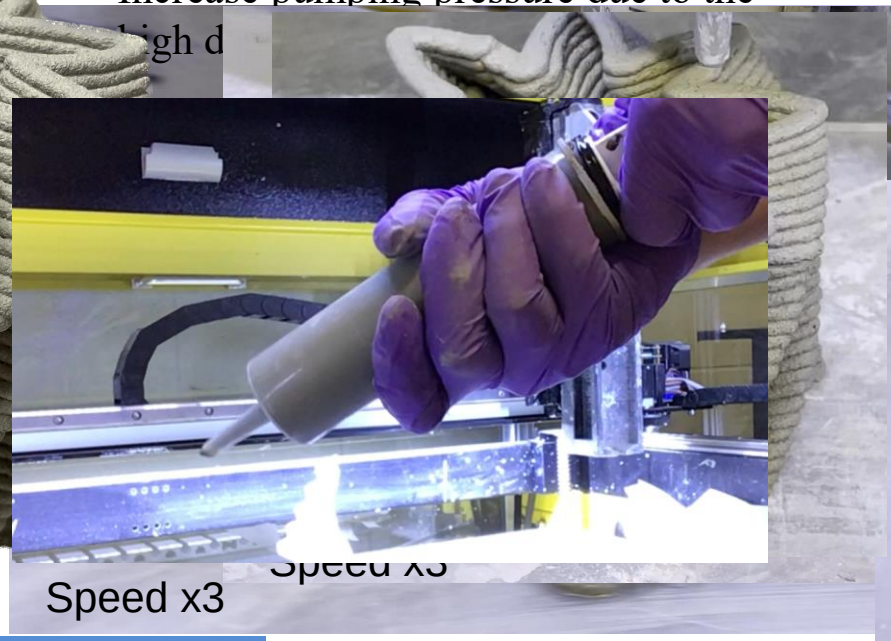






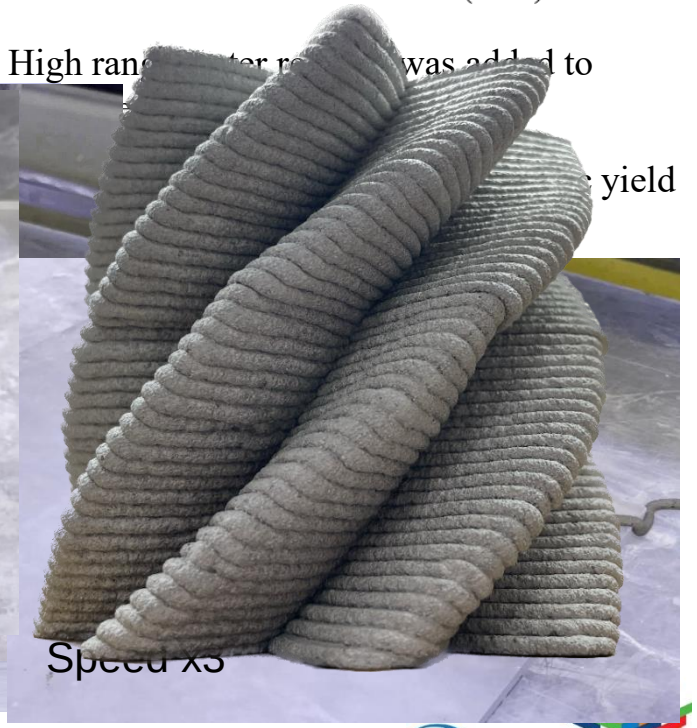
Sand/Binder=1

- Increase pumping pressure due to the high d



Speed x3

- High ran ter r was add d to yield



Speed x3

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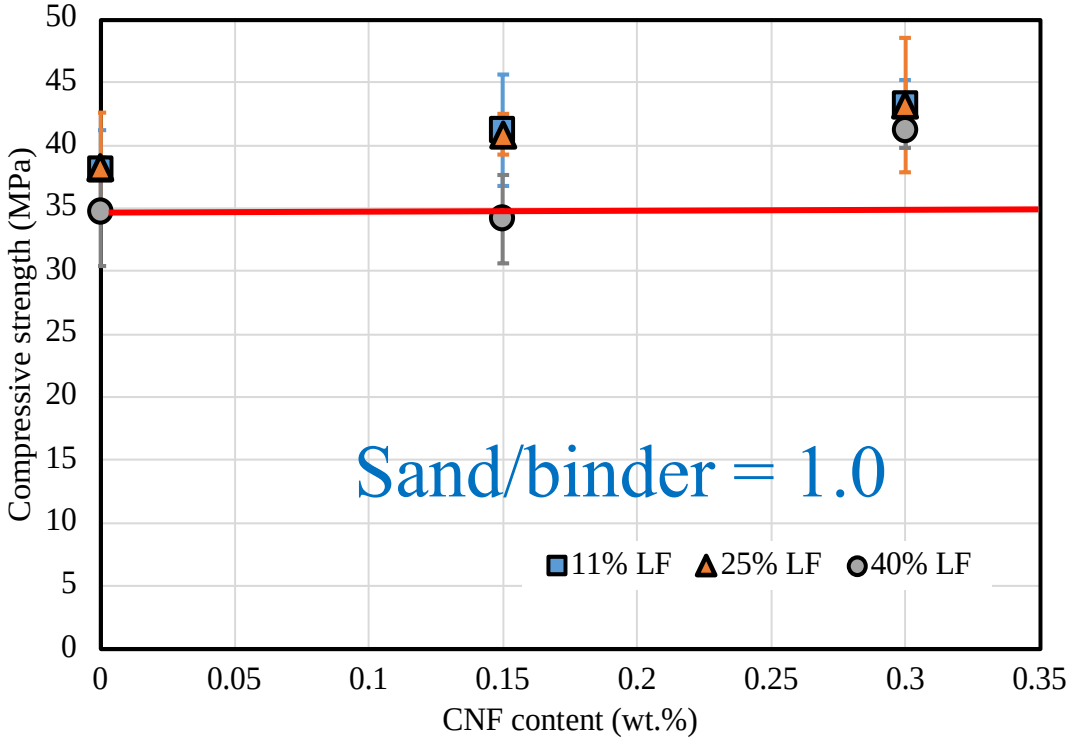
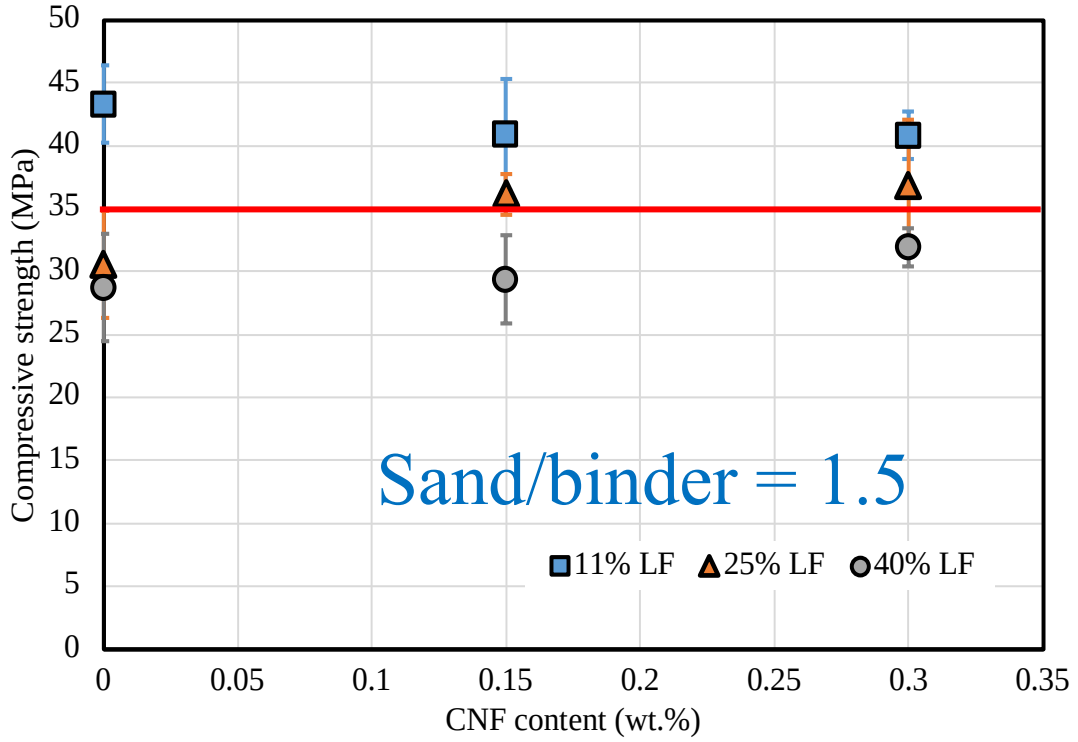
Compressive strength

- CNF can improve compressive strength, but a 40 wt.% replacement of limestone sacrifices compressive strength.
- Despite replacing up to 40 wt.% of cement type I with limestone filler, the compressive strength(with 0.3%CNF) is still within 15% of the reference which is above the 35 MPa(28 days) typically required for general construction and residential concrete up to 2 stories.





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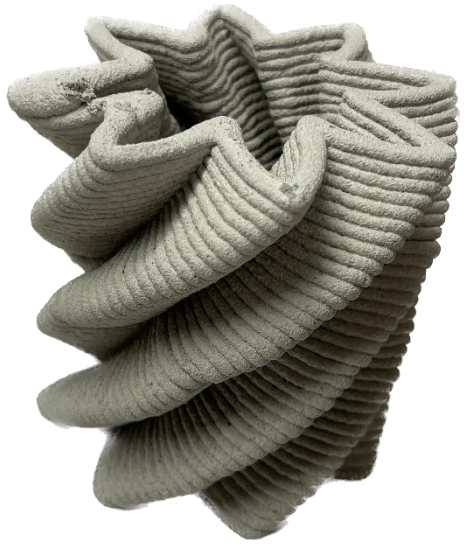
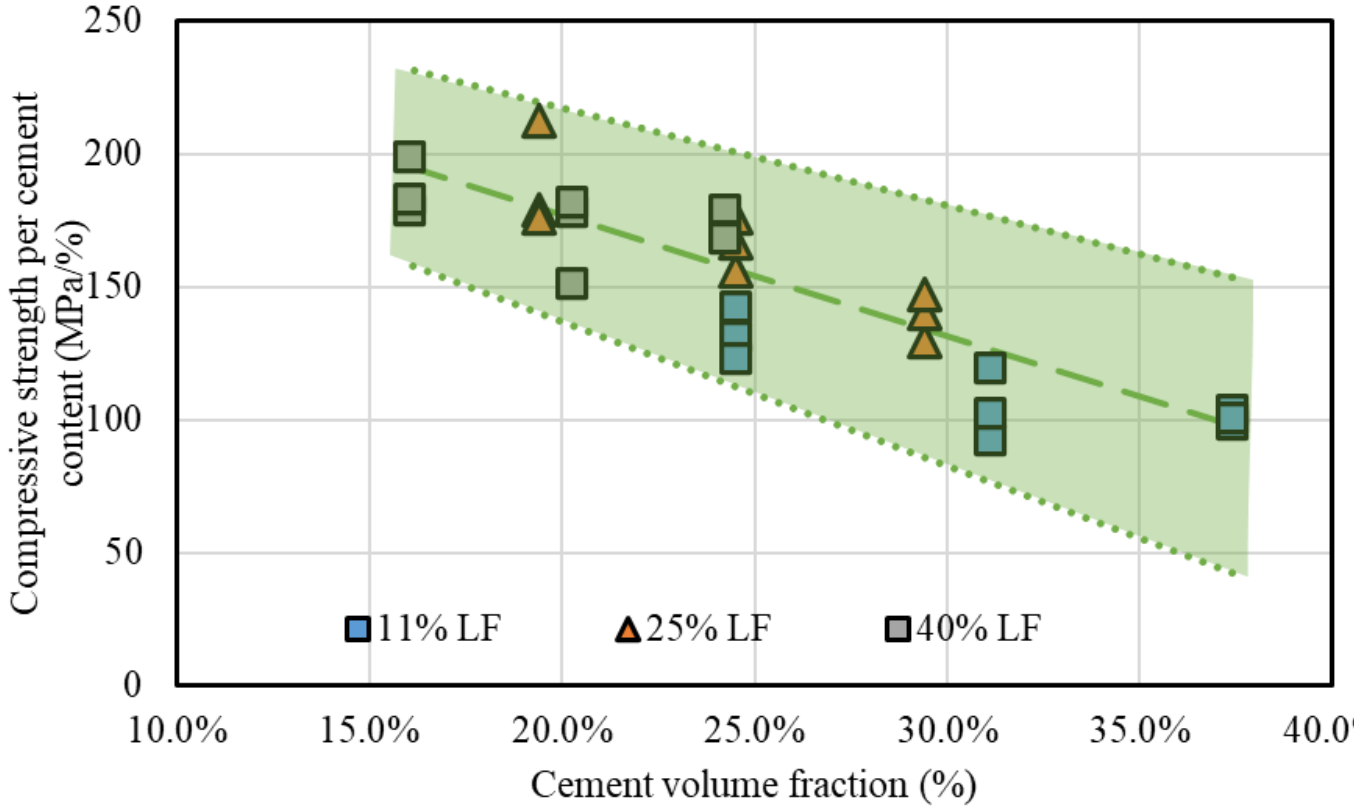
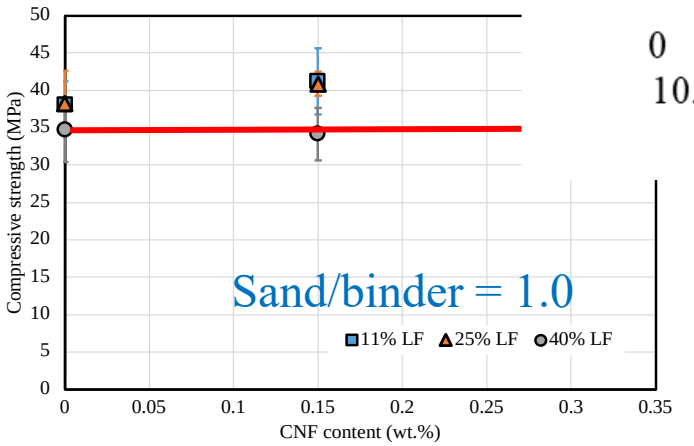
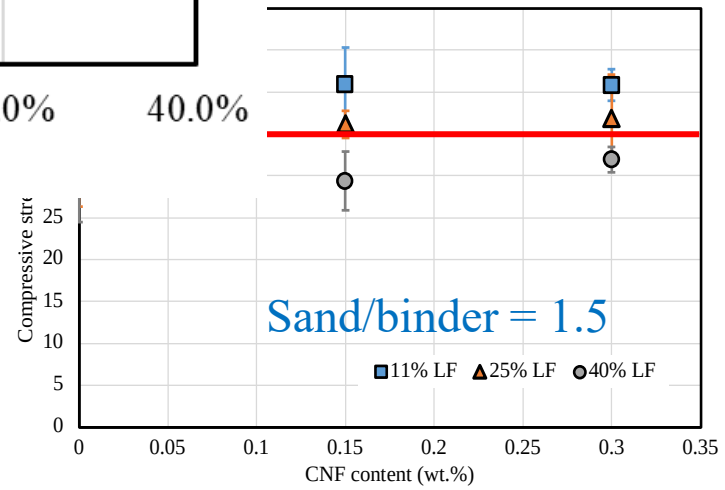
Compressive strength









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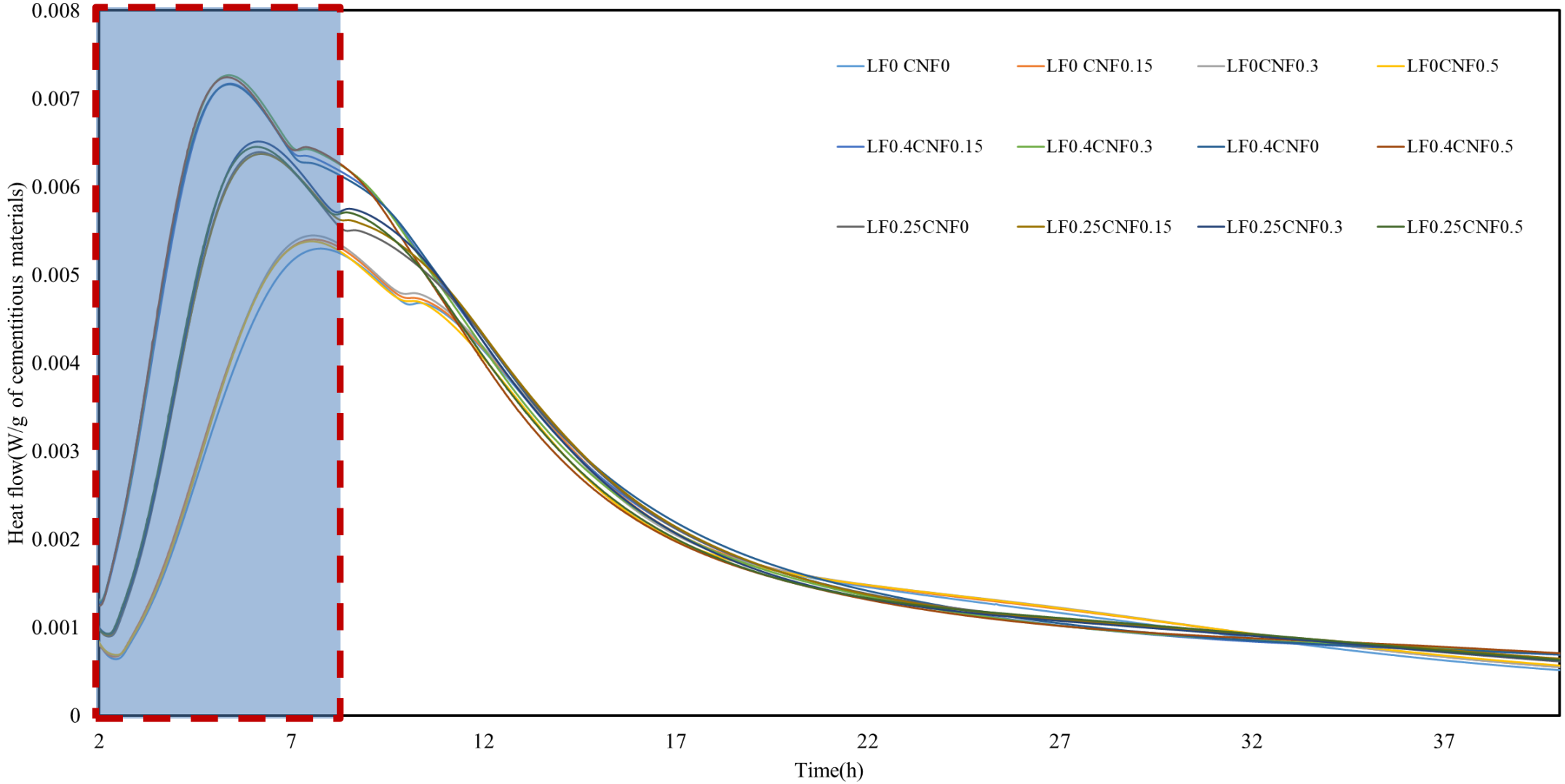
Isothermal calorimetry



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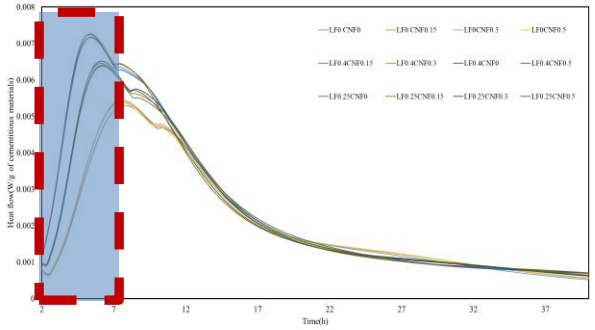
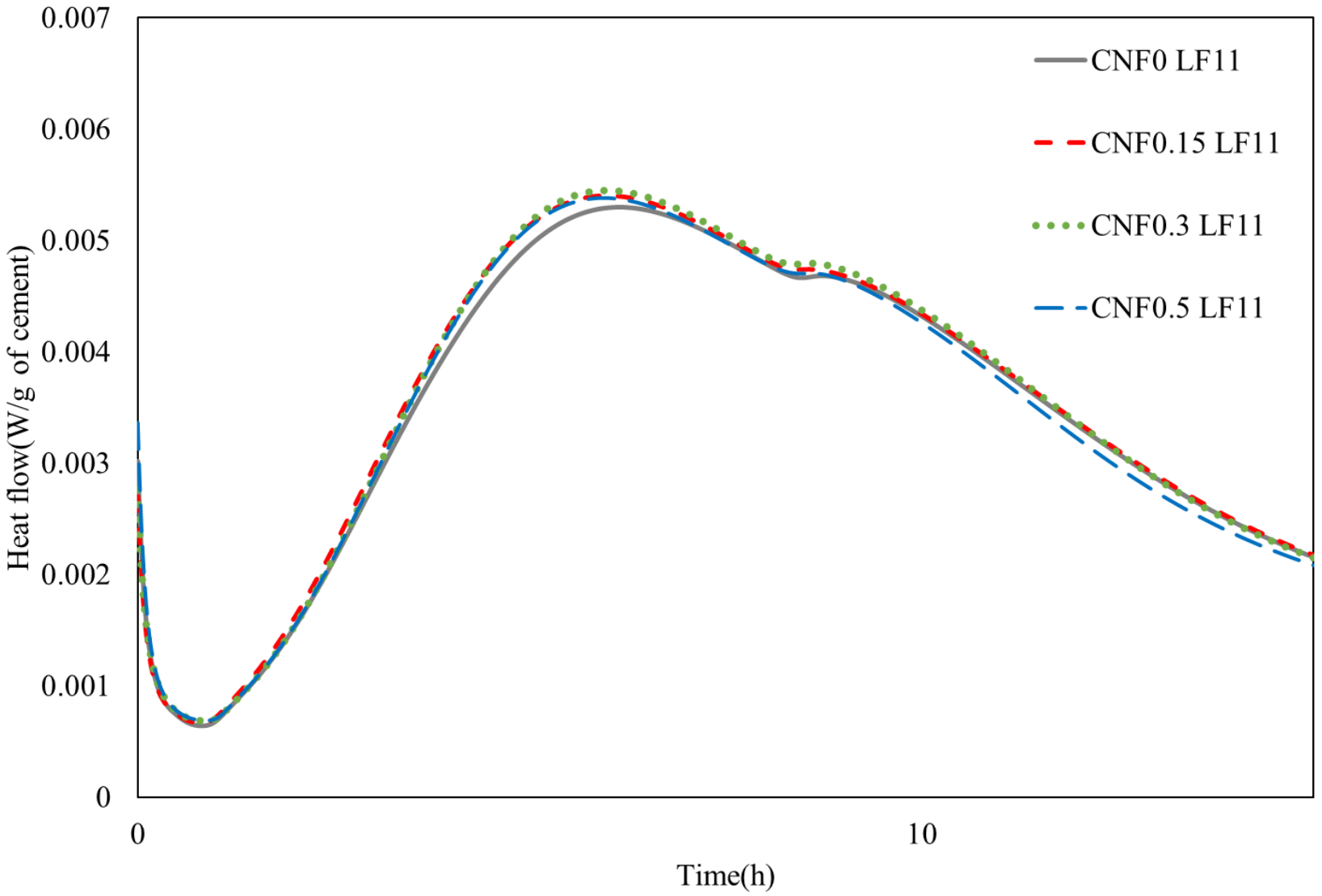
Isothermal calorimetry





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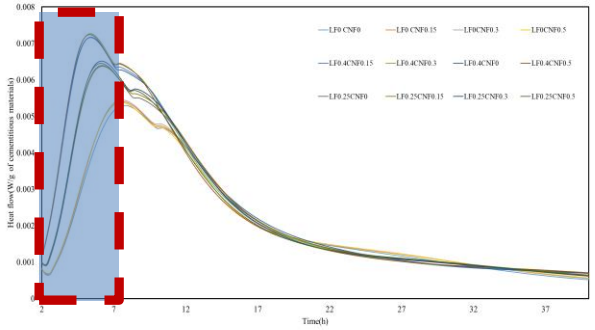
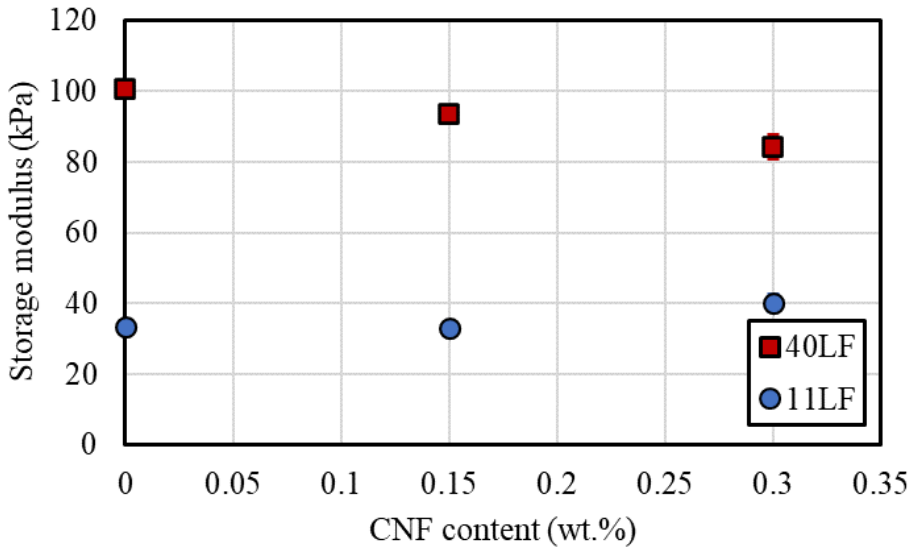
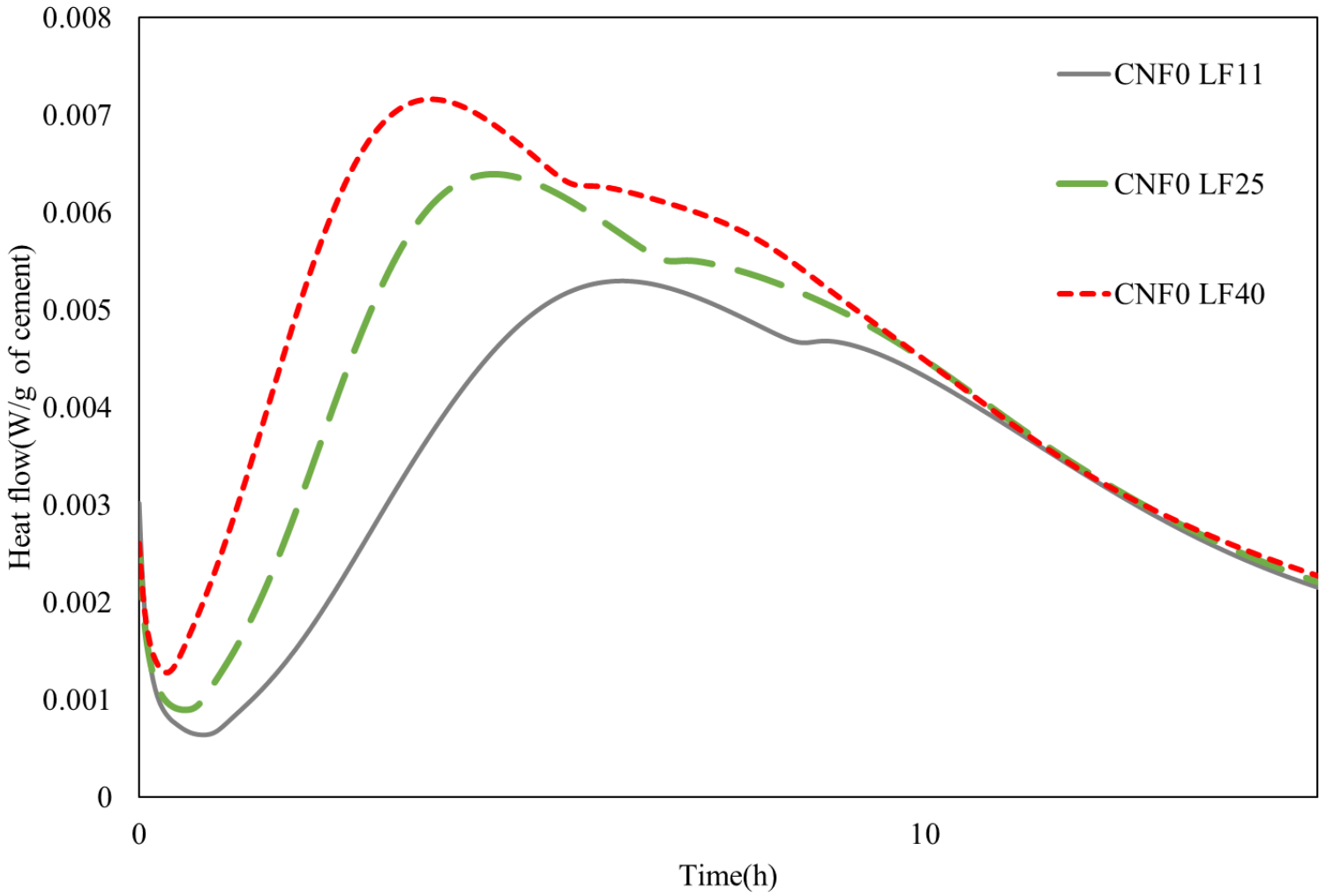
Isothermal calorimetry







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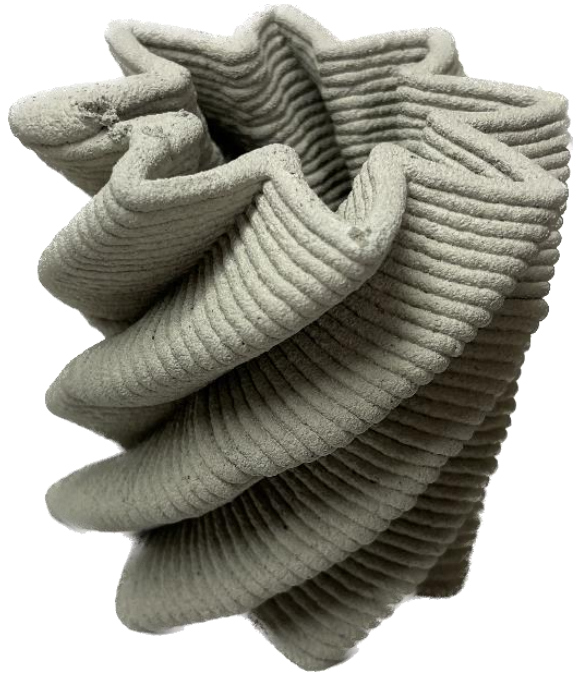
Conclusions

- Addition of CNF significantly enhances buildability(static yield stress), ink consistency and cohesiveness.

- Addition of LF accelerate the hydration, increases static yield stress and stiffness of the wet mixture(resistance to buckling).

- Addition of CNF + limestone produces highly printable cementitious mixtures with enhanced buildability and resistance to buckling.

- Despite replacing up to 40 wt.% of cement type I with limestone filler, the compressive strength didn’t get scarified with the addition of CNF. The compressive strength is above the 35 MPa typically required for general construction and residential concrete up to 2-stories.



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Reference

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Dr. Ala Eddin Douba

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Thank you

Follow up questions:

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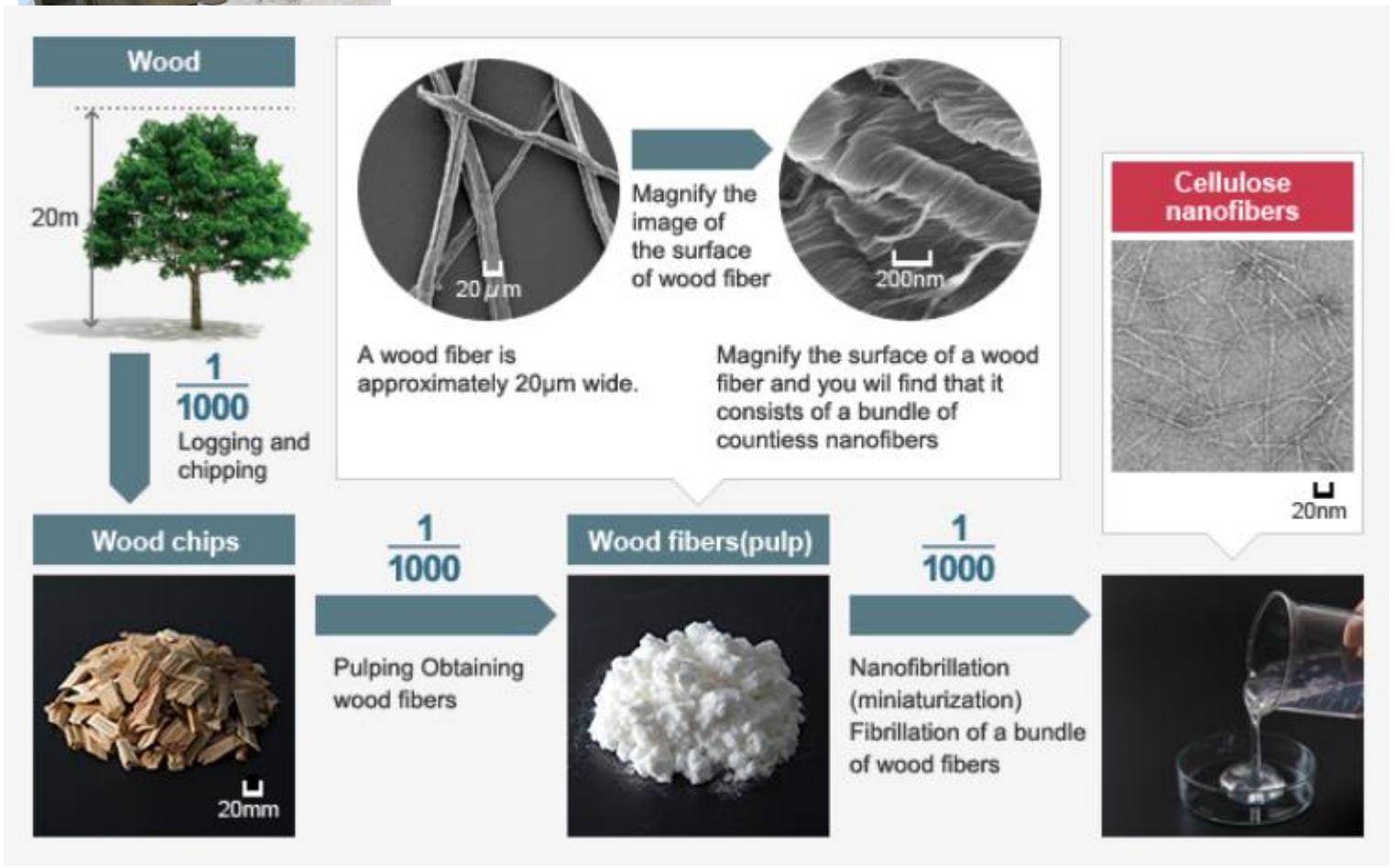

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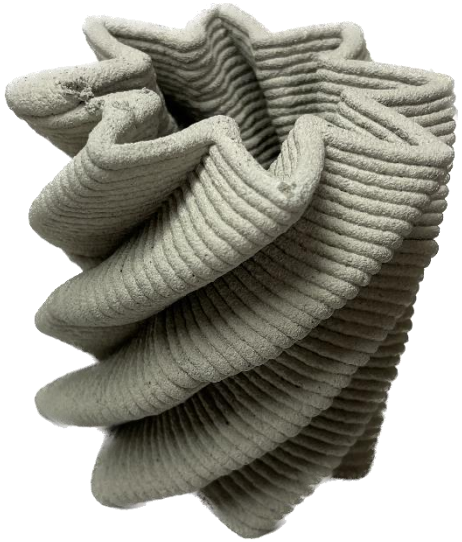
What is the challenge of 3DP concrete mixture?

- Rheology properties



Cellulose ethers

- Summary admixtures
- Hight cement usage
- Costly admixtures

Cost effective SCMs

Nature and cost-effective admixtures

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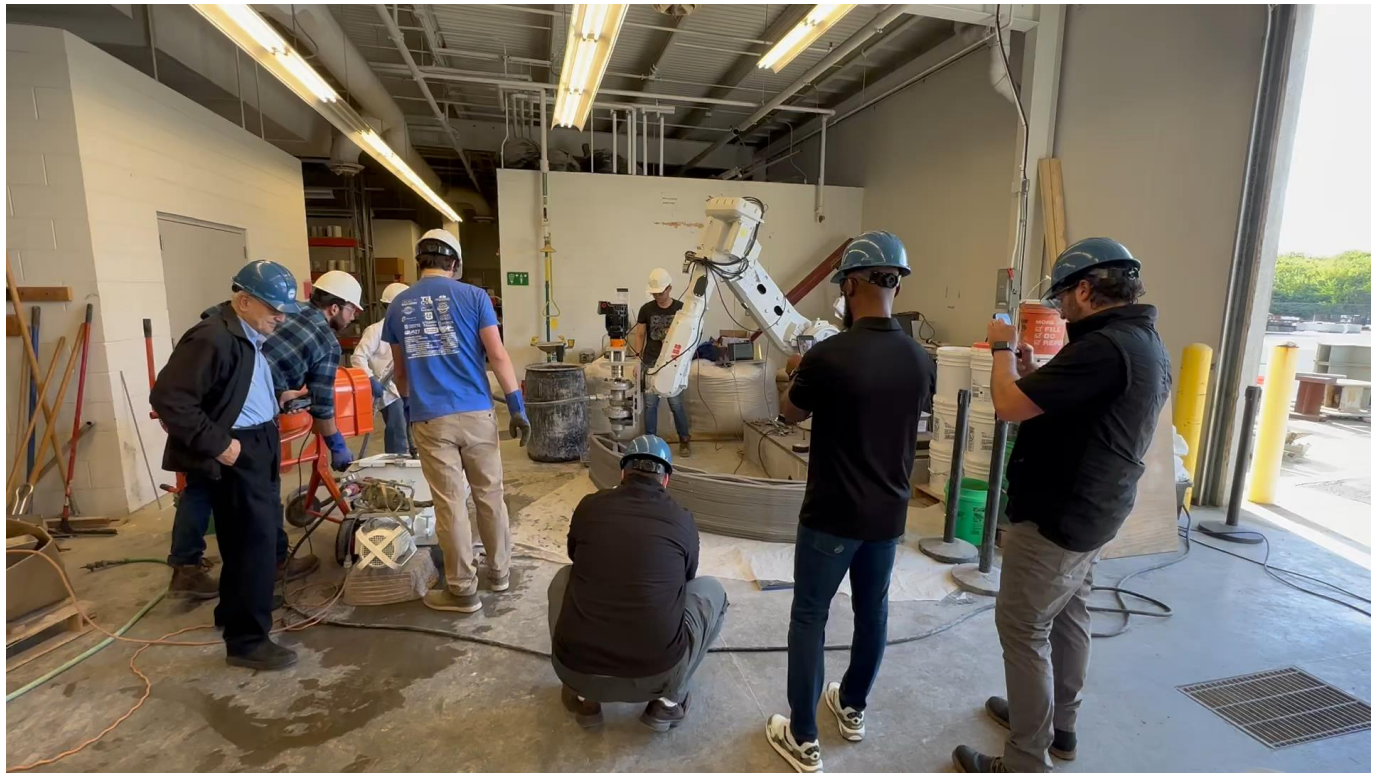
Introduction



What are the requirements of 3DP concrete mixture? What are the current challenge?

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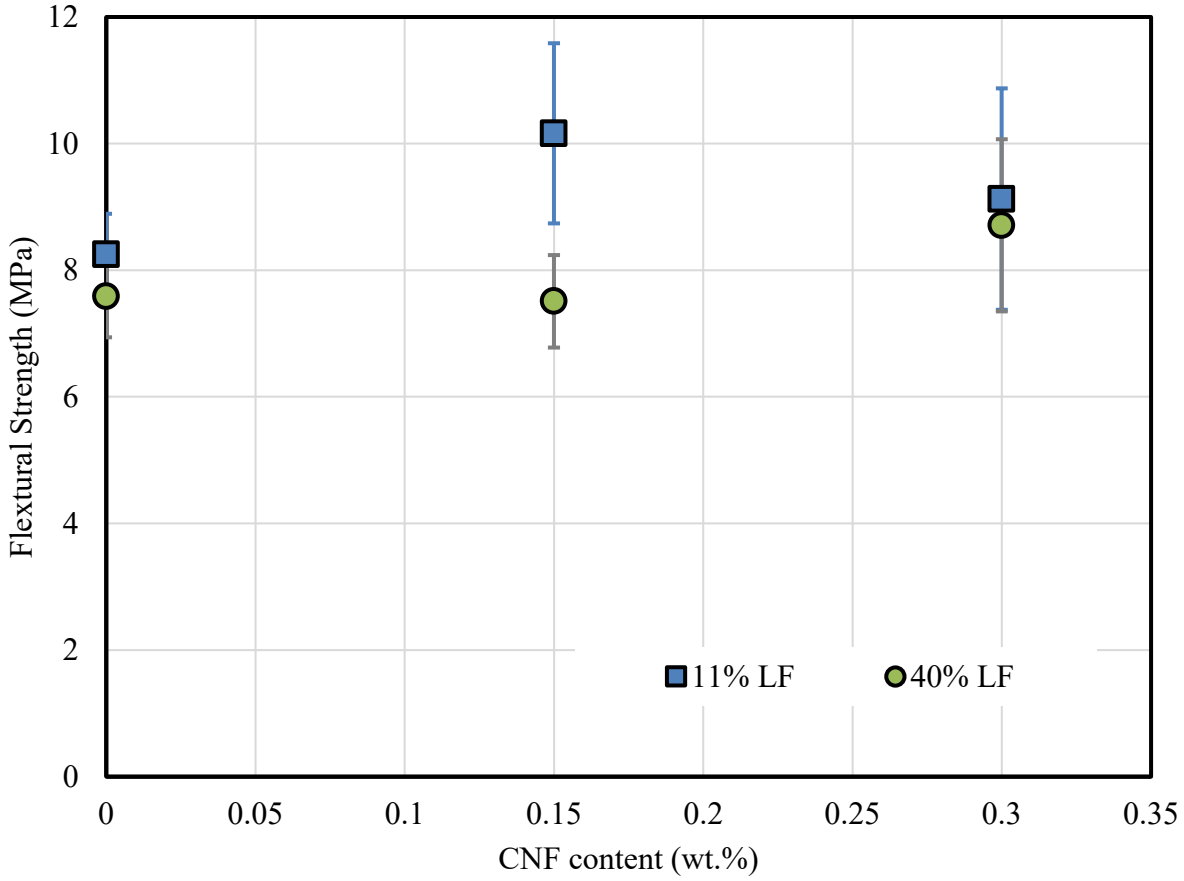
Flexural Strength



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