TEMPLE UNIVERSITY
Department of Civil And Environmental Engineering

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Application of Natural and Synthetic Nano-/Micro-Fibers in 3D Printed Cementitious Composites

ACI 123: Research in Progress

Presented By:
Abdullah Al Fahim

Advisor:
Dr. Mehdi Khanzadeh Moradllo

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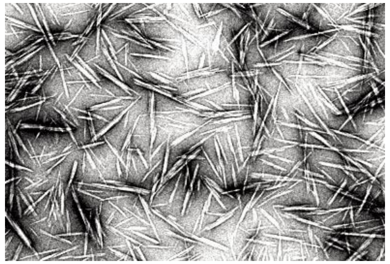
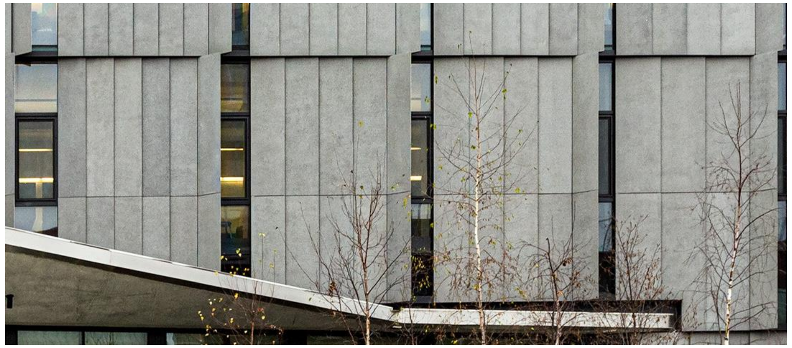
Motivation & Innovation

- 3D printed cementitious materials has been receiving increasing attention
- Challenges exist to deliver cost-effective and sustainable 3D printed cementitious mixtures
- Cellulose Nanomaterials are “green” nanoparticles that can improve the mechanical properties of cement-based materials
- Alkali-activated materials has the potential to decrease the reliance on traditional cement





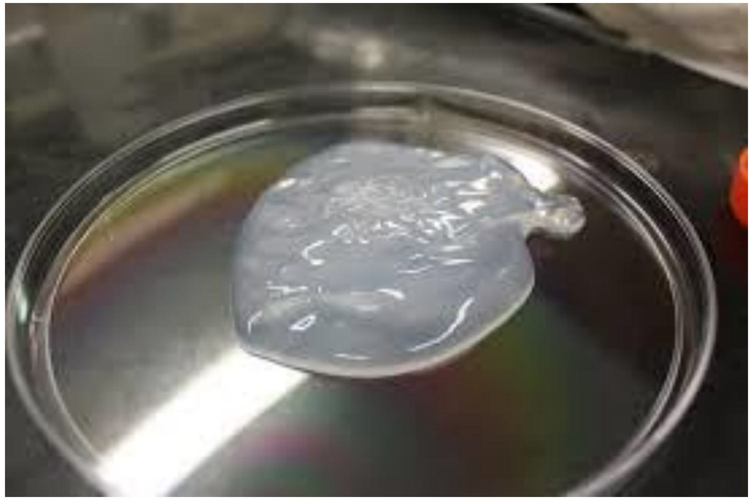
Introduction

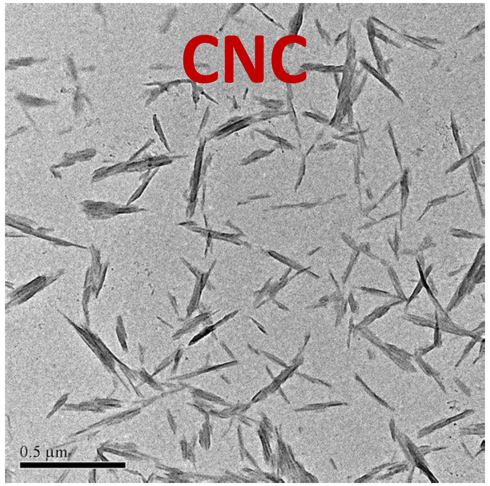
- 3D printing has emerged as a promising technology in the construction industry
- Incorporation of fibers into cementitious composites can improve
  - Tensile strength
  - Ductility
  - Toughness
  - Fracture strength
  - Impact resistance
  - Fatigue performance, and
  - Durability of the composite

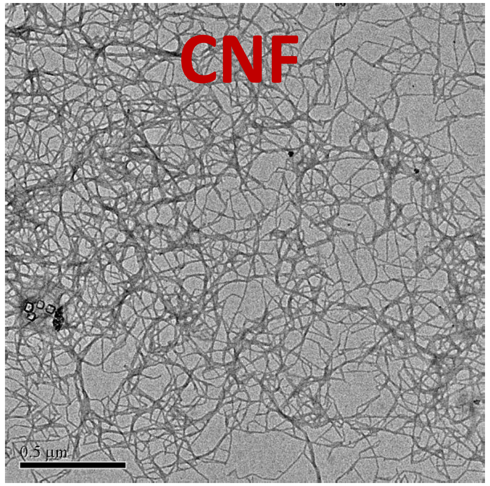
- The study explores the potential of fibers to enhance the **mechanical properties, durability, and sustainability** of 3D printed cementitious composites

Background (Natural Fibers)

- Cellulose Nanomaterials (CNs) are
  - Biodegradable
  - Renewable
  - Sustainable
  - Naturally abundant
- CNs are a promising material due to
  - High aspect ratio
  - High elastic modulus
  - High strength
- Two type of cellulose nanomaterials
  - **Cellulose Nanocrystals (CNC)**
    - 0.05-0.50 µm (L) and 3-5 nm (W)
  - **Cellulose Nanofibers (CNF)**
    - 1–5 µm (L) and 5–50 nm (W)







Background (Synthetic Fibers)

- Different types of synthetic fibers are commercially available.
- **Polyacrylonitrile (PAN) fibers** have
  - High mechanical strength
  - Strong chemical stability
  - High durability
  - Good resistance to friction and
  - High resistance to abrasion
- **Glass fibers** can
  - Improve mechanical performance
  - Good fire resistance
  - High strength

Background (Binders)

- **Ordinary Portland Cement (OPC)**
- **White cement**
- **Alkali-activated materials** has the potential to decrease the reliance on traditional cement. Alkali-activated binders are being promoted as a sustainable cementing binder systems

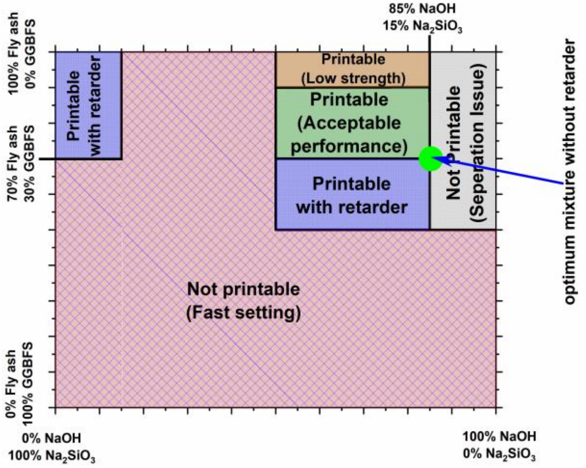
Fly ash

+

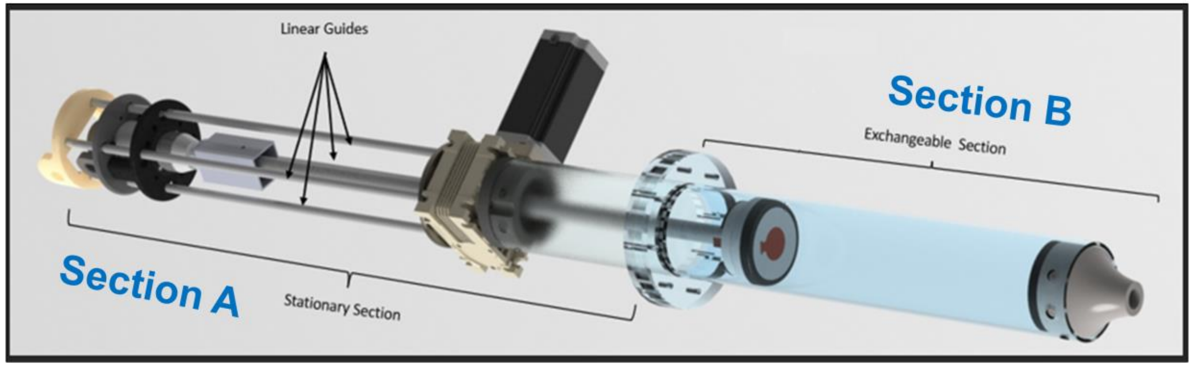
GGBFS

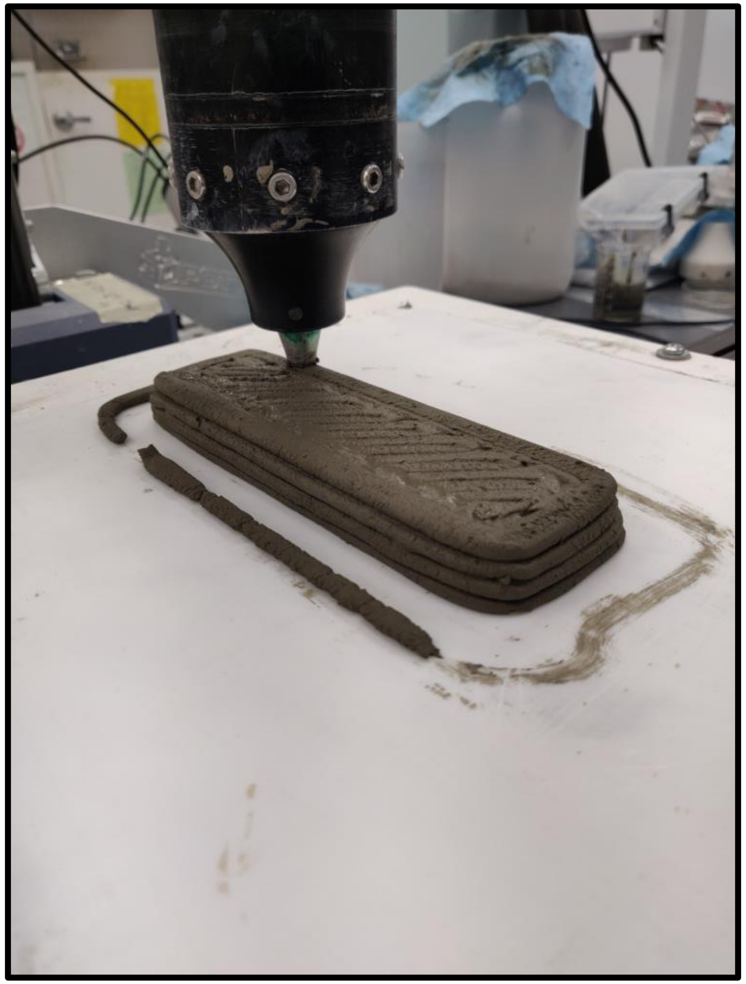
+ Activator = Alkali-Activated Cementitious composites

- ➢ A FA/GGBFS mass ratio of 70:30 was selected as aluminosilicate precursor
- ➢ A NaOH (5M)/Na_2SiO_3 mass ratio of 85:15 was selected as alkaline activator



Background (3D Printer)





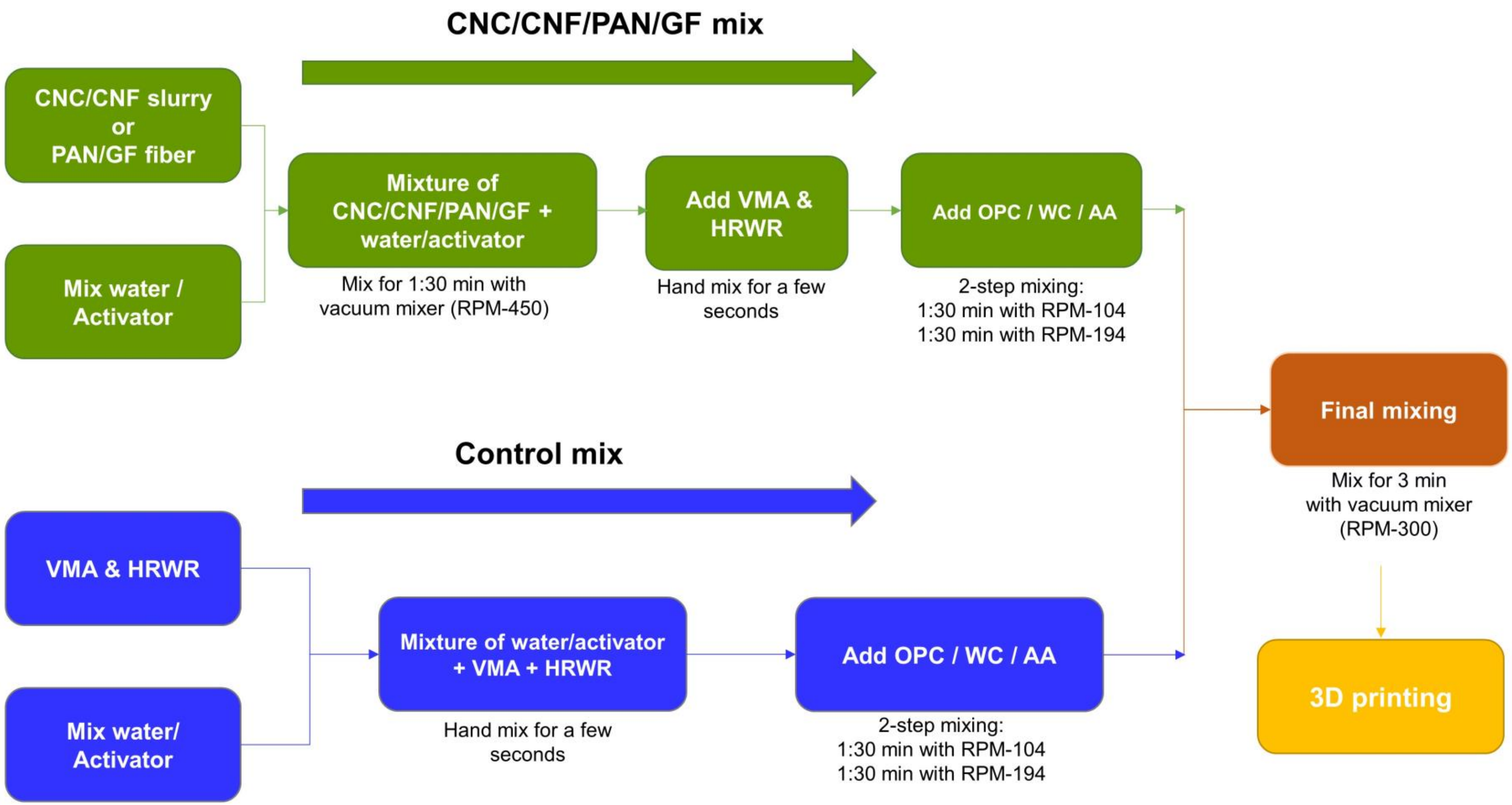
Research Approach

- Developing Printable Mixtures with Different Dosages of fibers
- Impact of Fibers on Fresh Properties
- Impact of Fibers on Mechanical Performance
- Impact of Fibers on Mass Transport Properties
- Impact of Fibers on Microstructure

Experimental Program (Mix Design)

Mixture Type	Dosage								
	0.00%	0.10%	0.15%	0.25%	0.30%	0.50%	1.00%	1.50%	1.75%
OPC-CNC									
OPC-CNF									
OPC-PAF									
OPC-GF									
AA-CNC									
WC-CNC									

Experimental Program (Mixing Procedure)



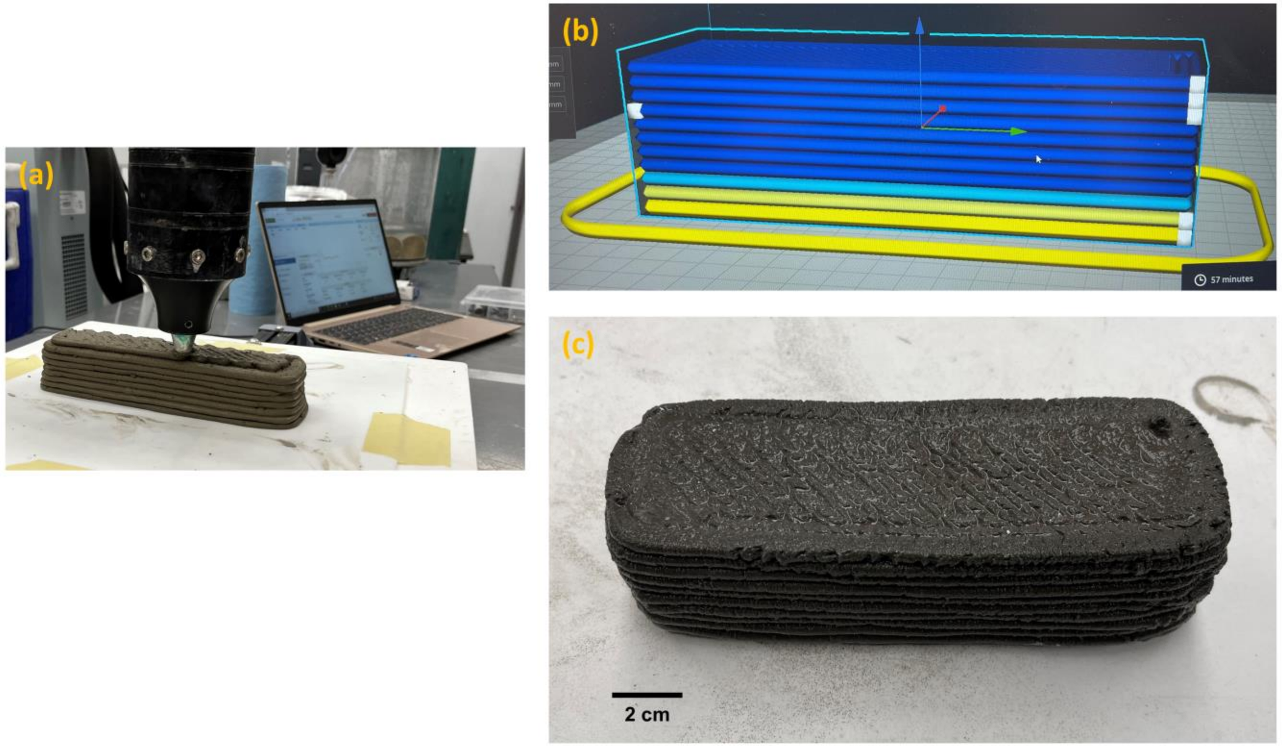
Experimental Program (Mixing Procedure)

Sample Preparation

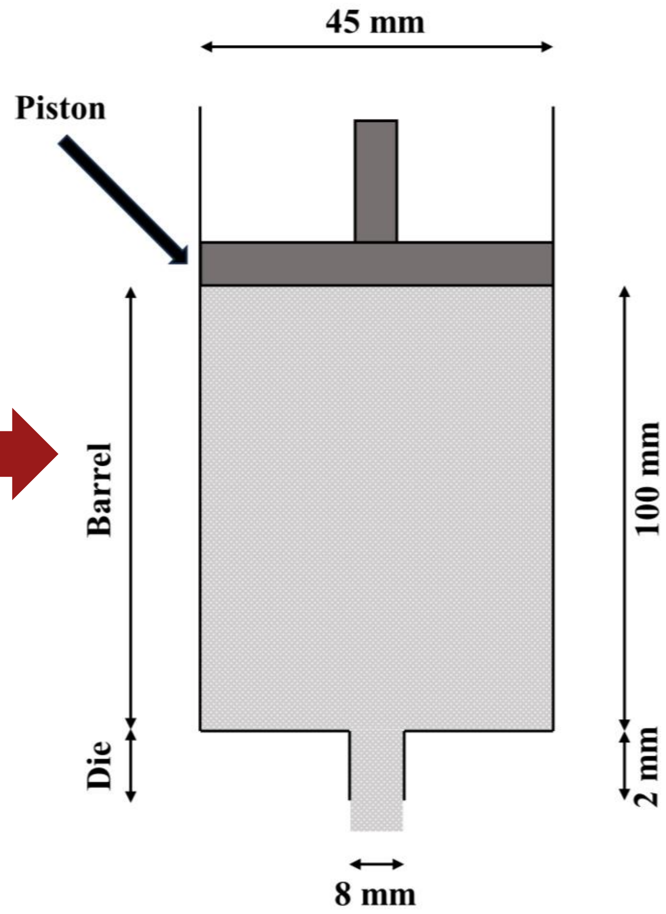
- Ultimaker Cura is utilized for 3D modeling
- Geometry: 25(H) × 25(W) × 178(L) mm^3
- 5 layers
- Perimeter filament: straight-line pattern
- Infill filament: zigzag pattern

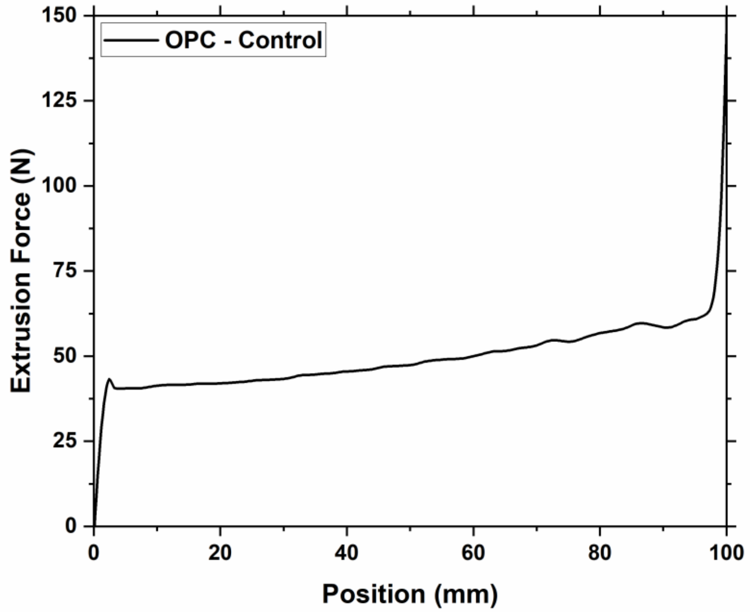
Curing

- OPC/WC - wet-cured at 23°C for 28 days
- AA – sealed-cured at 23°C for 28 days or heat-cured at 60°C for 7 days



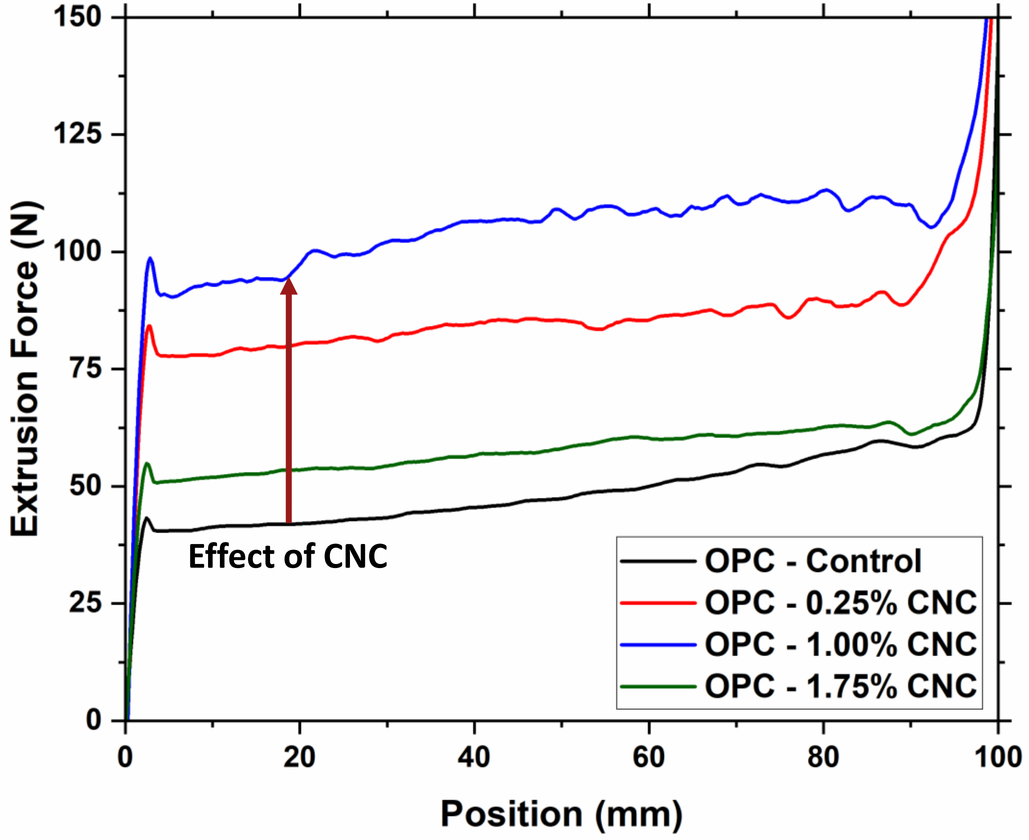
Experimental Program (Fresh Properties-Syringe Method)



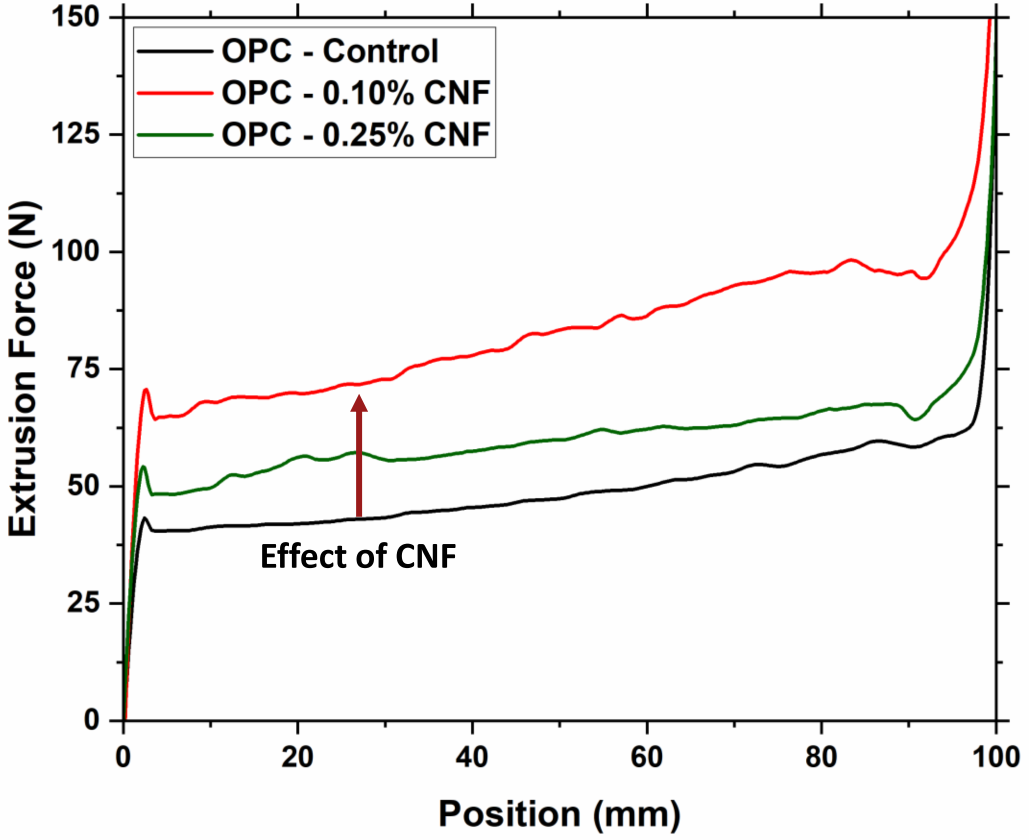


Experimental Program (Fresh Properties-Syringe Method)

OPC-CNC

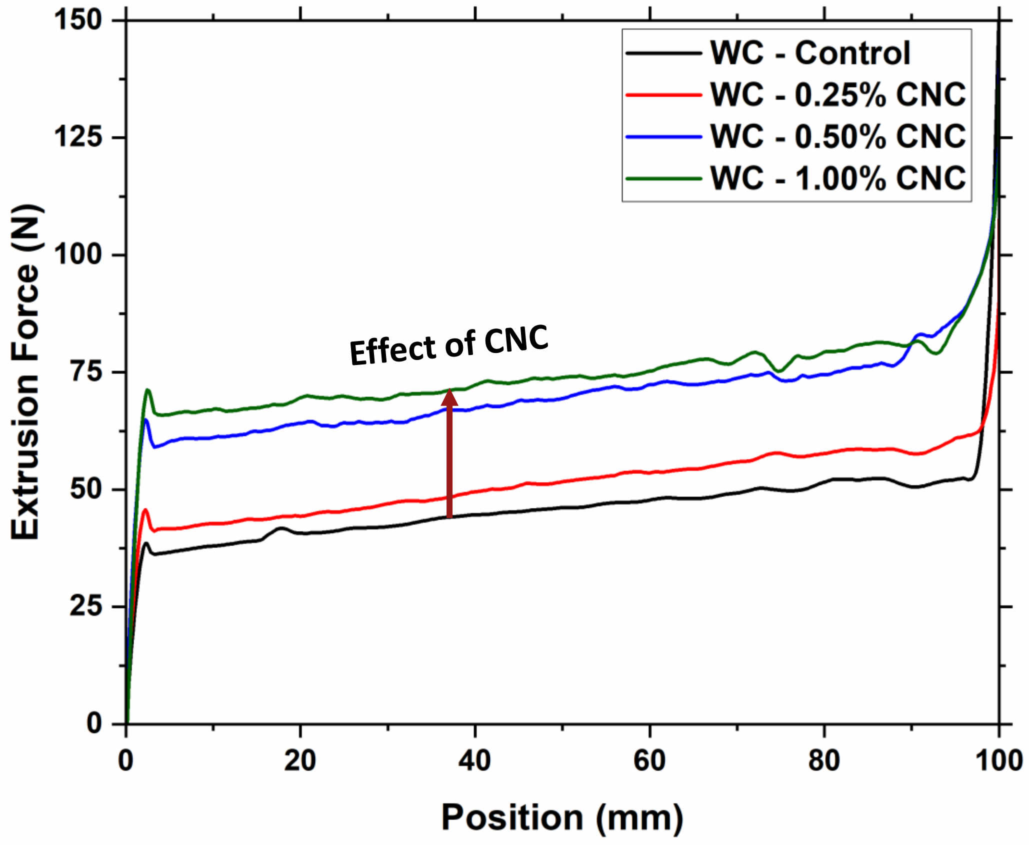


OPC-CNF

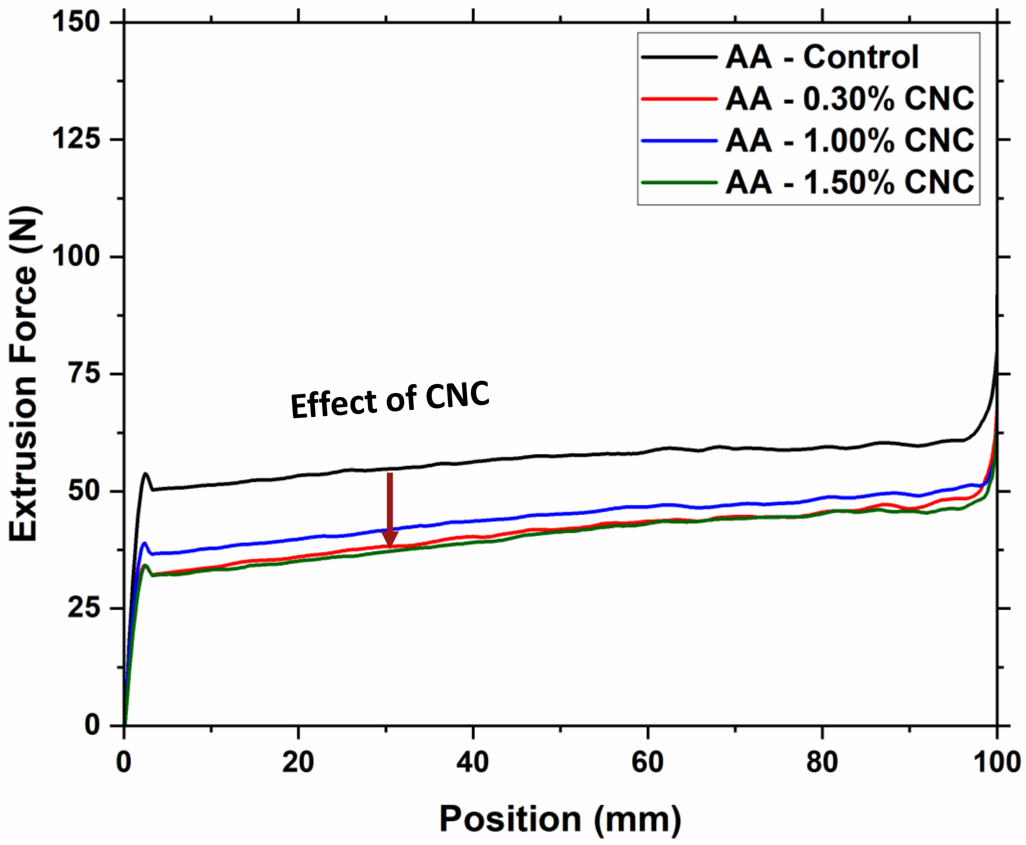


Experimental Program (Fresh Properties-Syringe Method)

WC-CNC



AA-CNC



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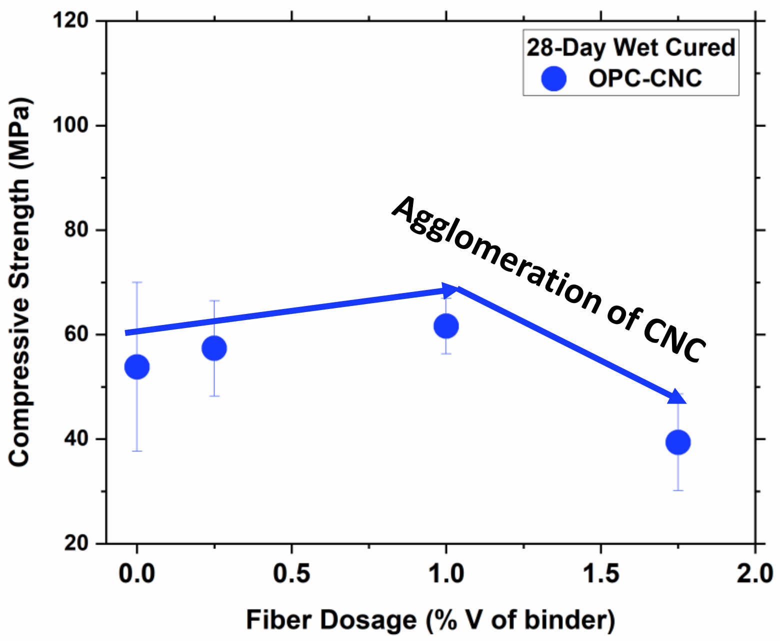
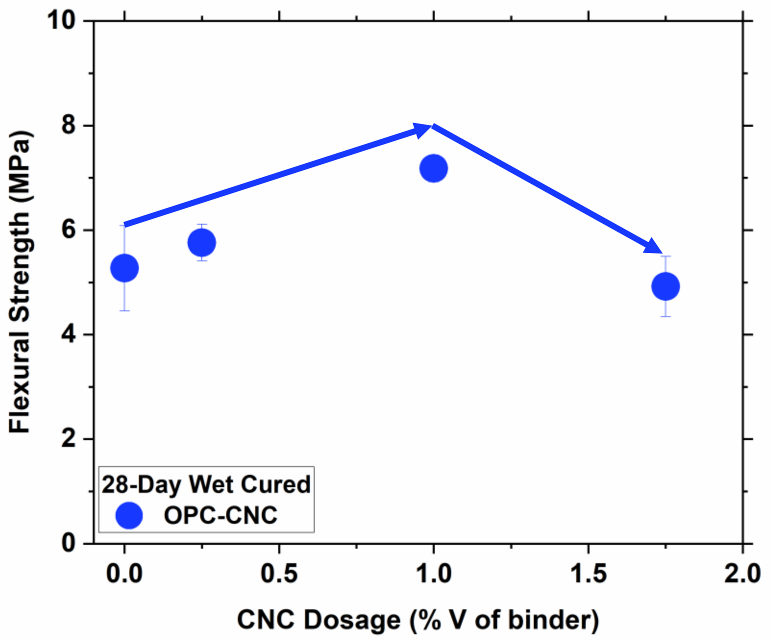
Experimental Program (Compressive & Flexural Strength)

OPC-CNC

- Compressive and flexural strength increases ≤ 1.00%.
- Concentration > 1.00%, agglomeration starts and work as a weak point.

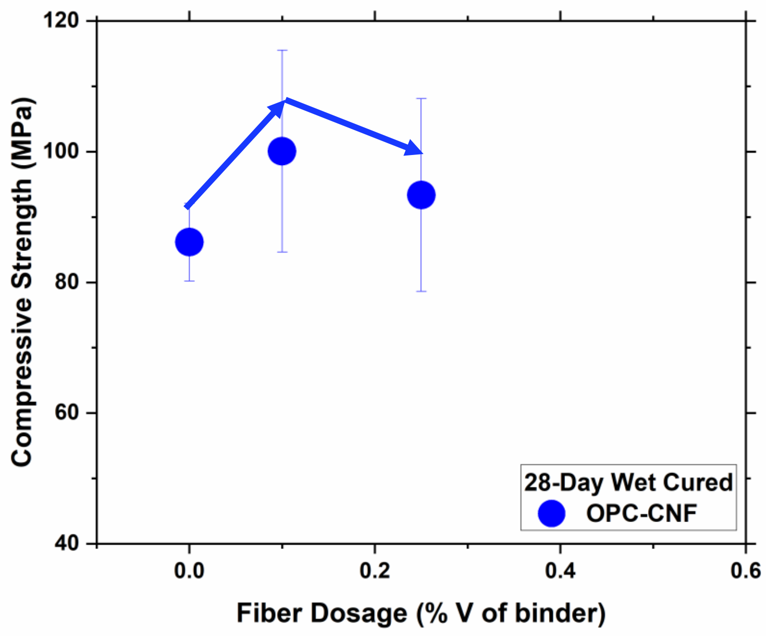


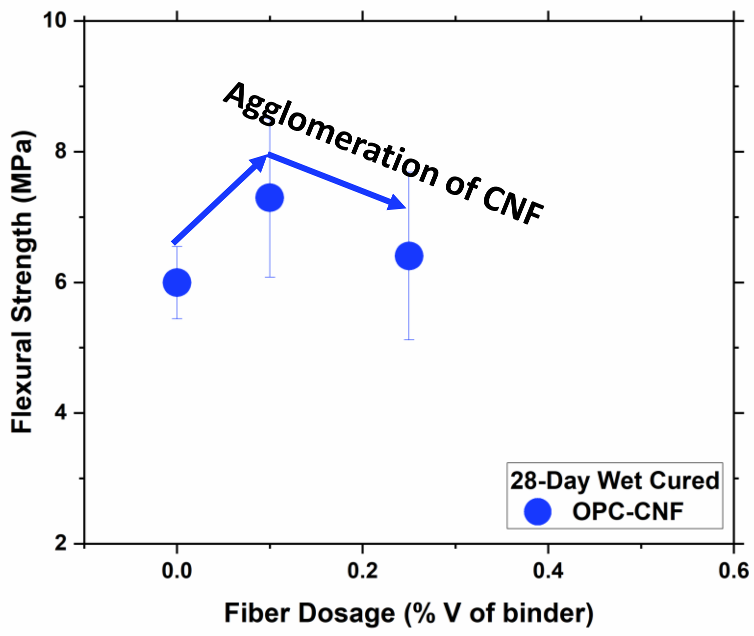


Experimental Program (Compressive & Flexural Strength)

OPC-CNF

- Compressive and flexural strength increases ≤ 0.10%.
- Concentration > 0.10%, agglomeration starts and work as a weak point.

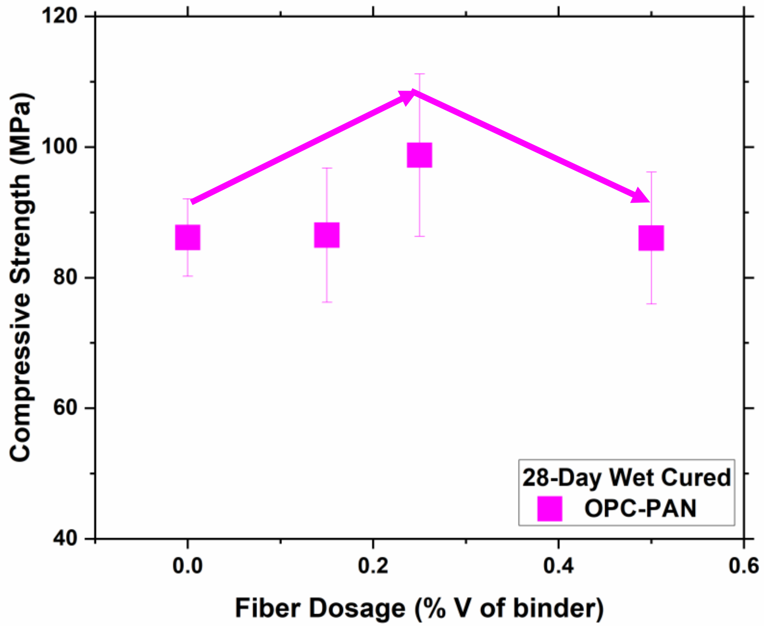


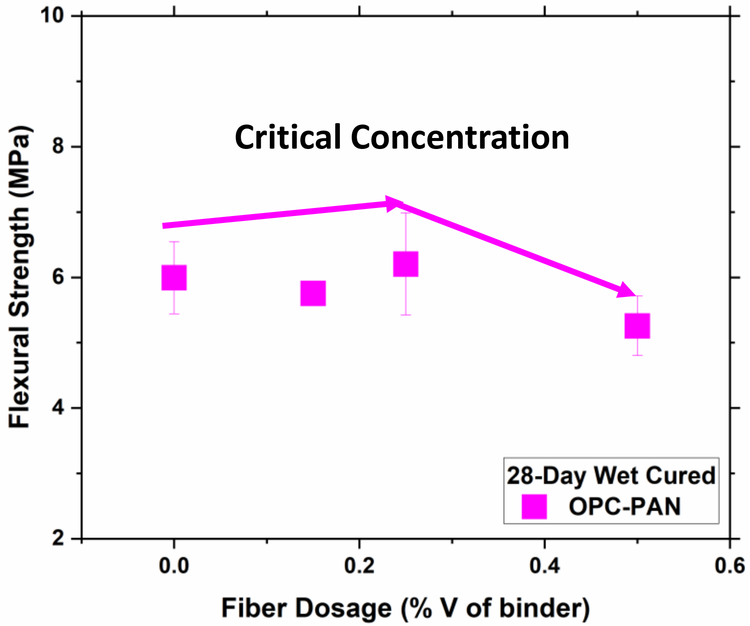


Experimental Program (Compressive & Flexural Strength)

OPC-PAN

- Compressive and flexural strength increases ≤ 0.25%.
- 0.25% is the critical concentration for PAN fibers.

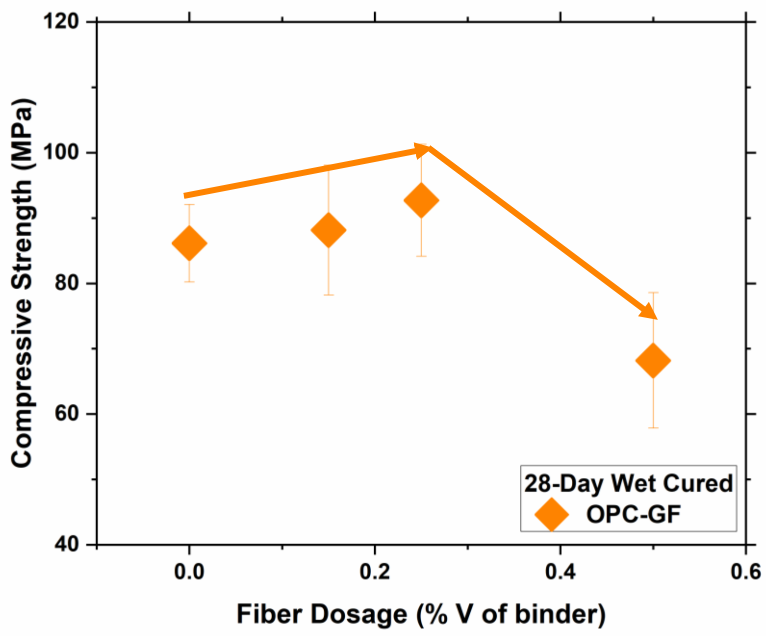


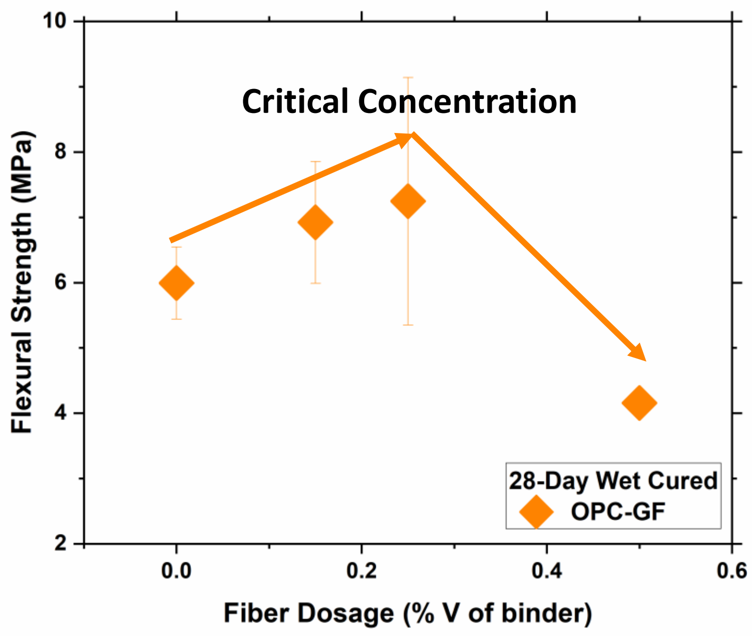


Experimental Program (Compressive & Flexural Strength)

OPC-GF

- Compressive and flexural strength increases ≤ 0.25%.
- 0.25% is the critical concentration for GF fibers.

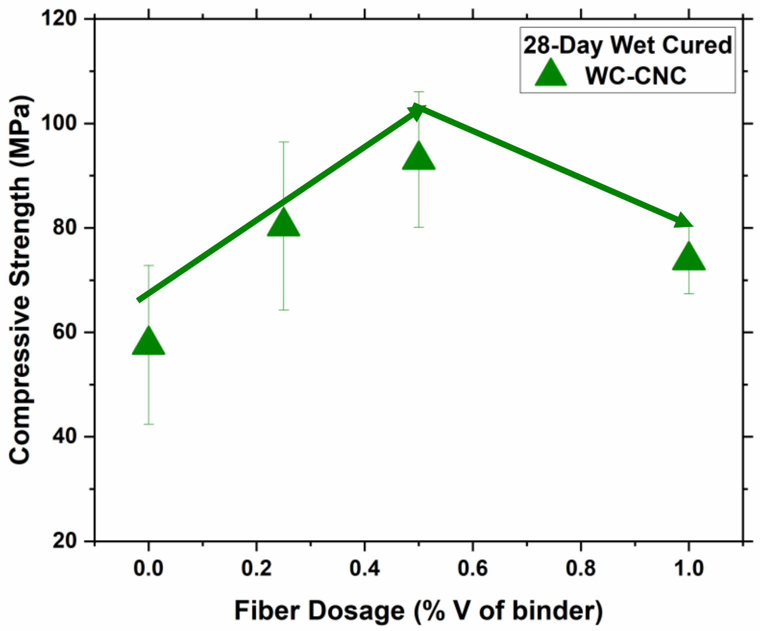


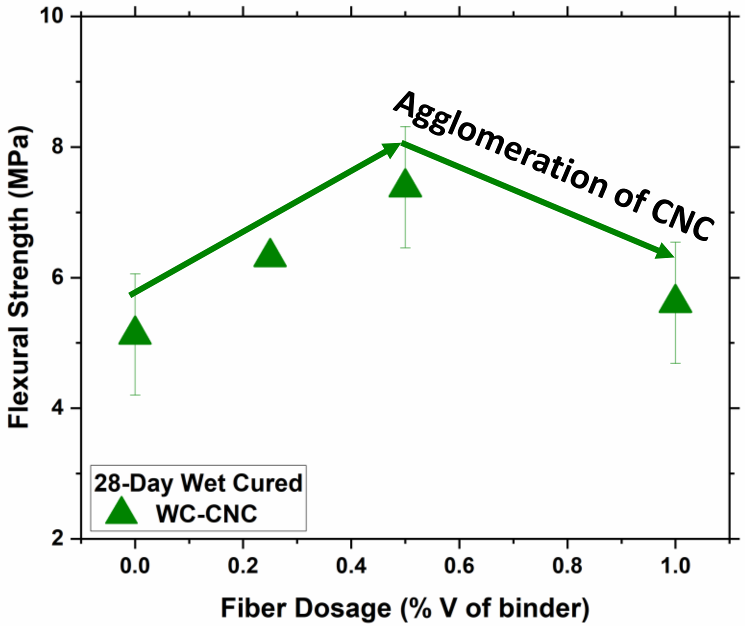


Experimental Program (Compressive & Flexural Strength)

WC-CNC

- Compressive and flexural strength increases ≤ 0.50%.
- Concentration > 0.50%, agglomeration starts and work as a weak point.

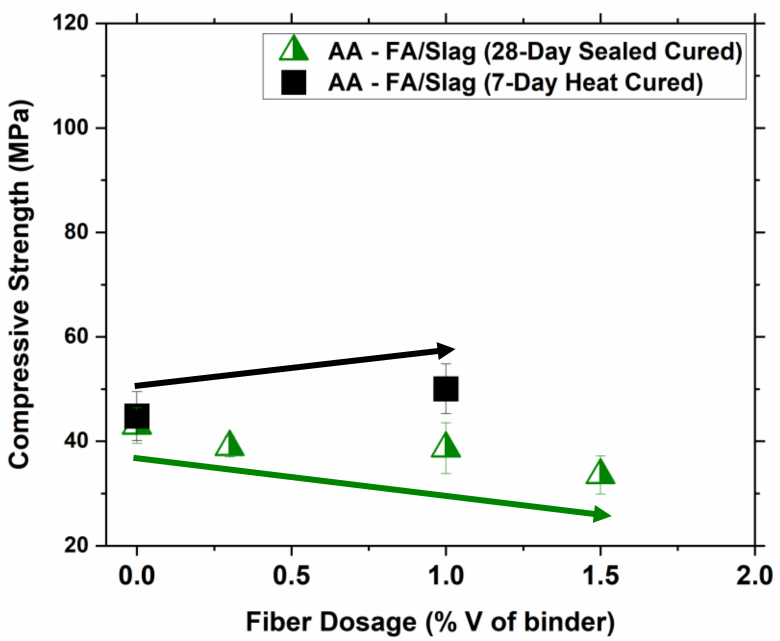


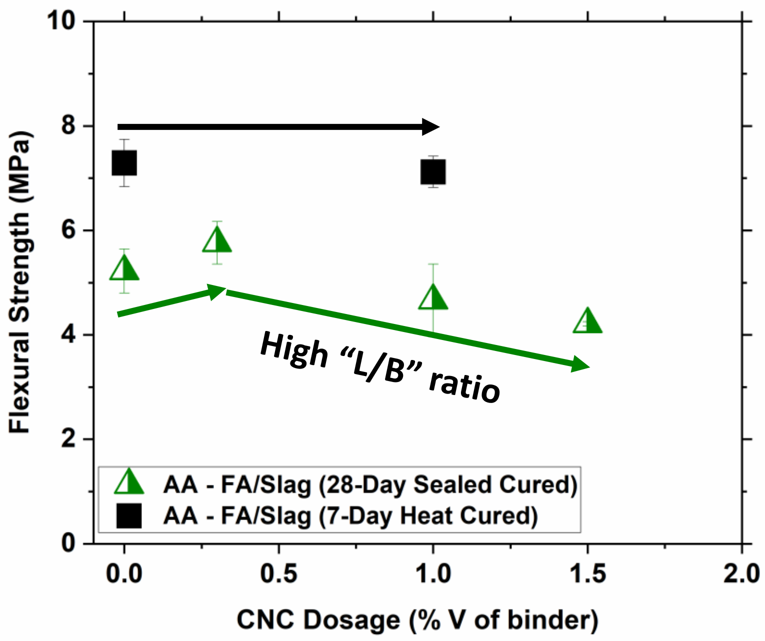


Experimental Program (Compressive & Flexural Strength)

AA-CNC

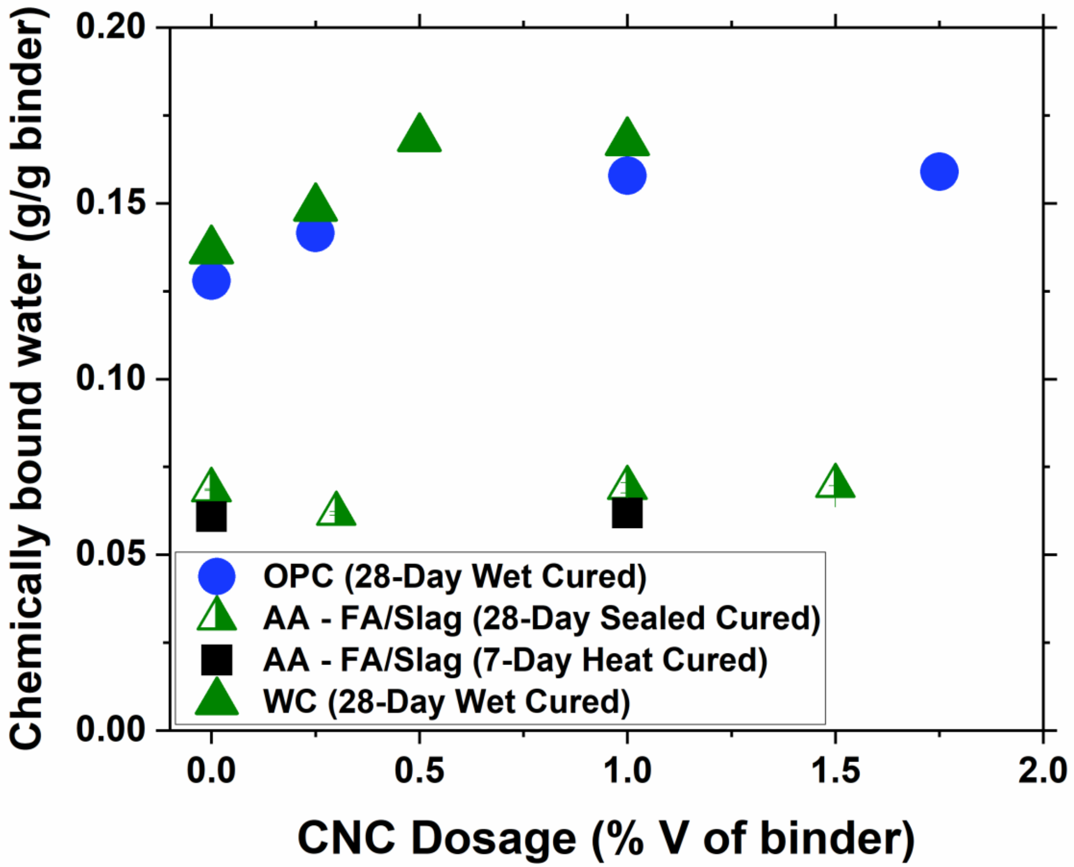
- For seal-cured samples, compressive and flexural strength decreases.
- For heat-cured samples, increase in compressive is noticed.

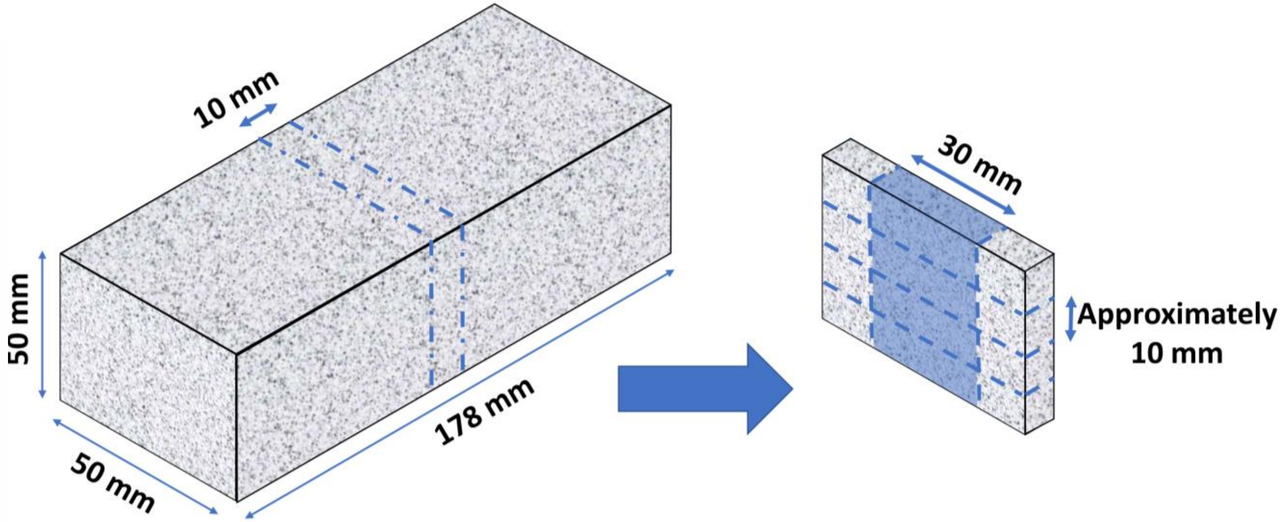


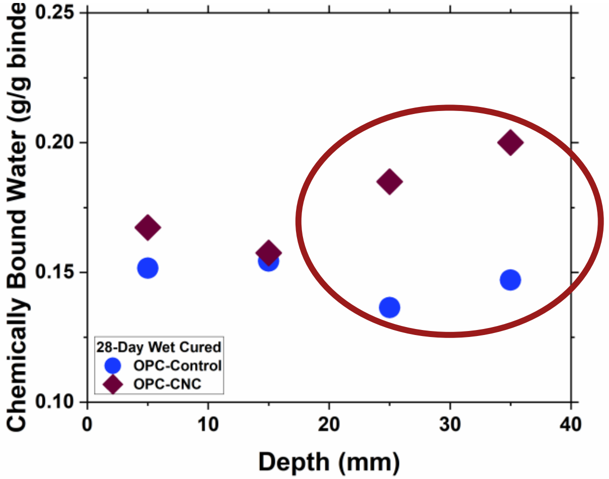


Heat curing increases flexural strength of AA samples.

Experimental Program (Internal Curing Potential of CNC)







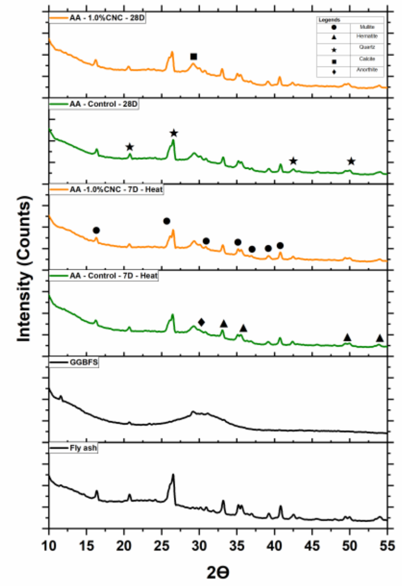
Conclusion

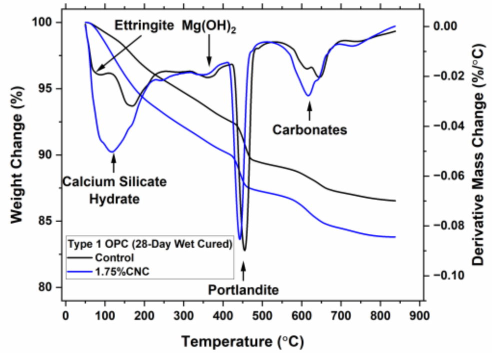
- The critical concentration for different fibers were determined.
- Heat-curing of AA systems results in better mechanical performance compared to seal-cured systems.
- CNC works as a viscosity modifying agent for AA systems.
- CNC improves the degree of hydration of OPC and WC systems.
- CNC promotes internal curing.

Binder	Fiber	Curing Condition	Critical Concentration (%)
OPC	CNC	Wet-cured	1.00
	CNF	Wet-cured	0.10
	PAN	Wet-cured	0.25
	GF	Wet-cured	0.25
AA	CNC	Seal-cured	0.30
	CNC	Heat-cured	1.00
WC	CNC	Wet-cured	0.50

Future Work

- The mass transport properties will be evaluated based on
  - Porosity and
  - Bulk Electrical Resistivity
- The microstructure will be investigated using
  - **X-Ray Diffraction (XRD)** to characterize the phase composition.
  - **Scanning Electron Microscopy (SEM)** to characterize the microstructure.
  - **Energy-dispersive X-ray (EDX) Spectroscopy** to determine elemental composition.





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Thank You!

Abdullah Al Fahim

fahim@temple.edu

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