Center for Advanced Construction Materials

Sustainable and Eco-efficient Cementitious Composites Using Waste Cellulose Fibers

By:

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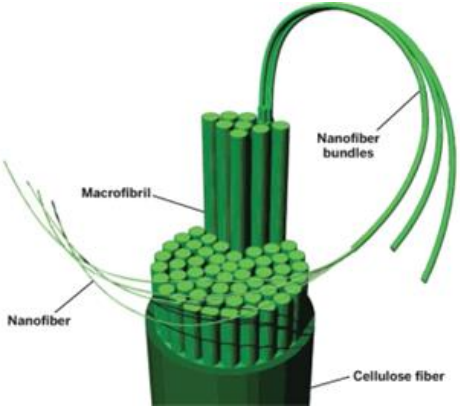
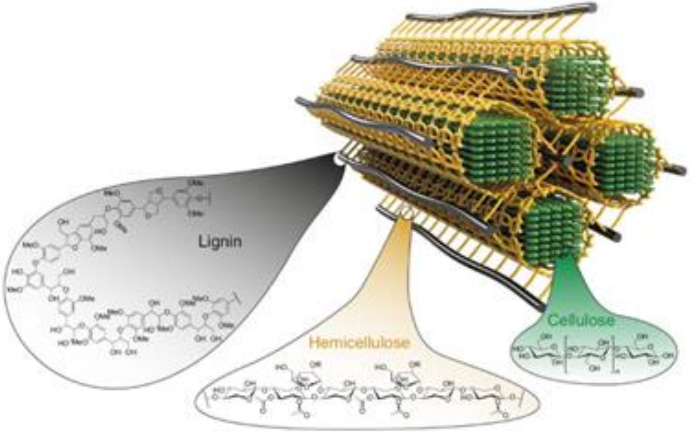
Properties, Advantages and Challenges



Marc Delgado-Aguilar et al. (2015)



Simone Brethauer et al. (2020)

Intrinsic Properties of Cellulose Fibers

- ✓ High Tensile Strength (~250-1200 Mpa)
- ✓ Low Thermal Conductivity (<0.072 W/m.K)
- ✓ High Water Retention/Release Capacity (300wt.%<)
- ✓ Light Weight

Advantages

Abundant Resources

Fast Renewability

Low Cost

Low Carbon Footprint

Challenges

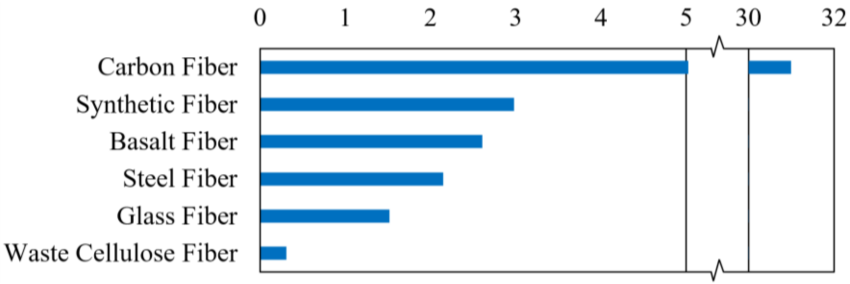
Effective Dispersion

Unstability of Fibers in Alkaline Environments

Research Significance and Objectives

➢ ~10% is being recycled

Incineration of Waste Cellulose Fibers



GWP of 1Kg of various types of fibers used for reinforcement of construction materials

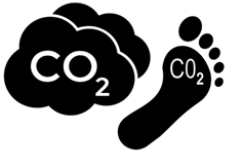
Objectives:

- ✓ Improving Mechanical Properties
- ✓ Controlling the Shrinkage
- ✓ Reducing the Carbon Footprint

Eco-Efficient Concrete

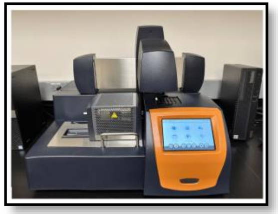
Conventional Cellulose Fiber → Waste Cellulose Fiber

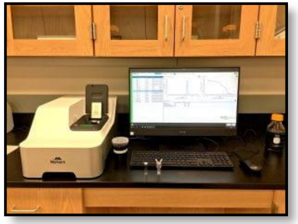
-76%

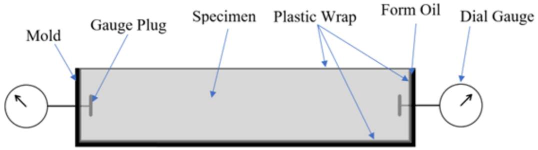


Outline

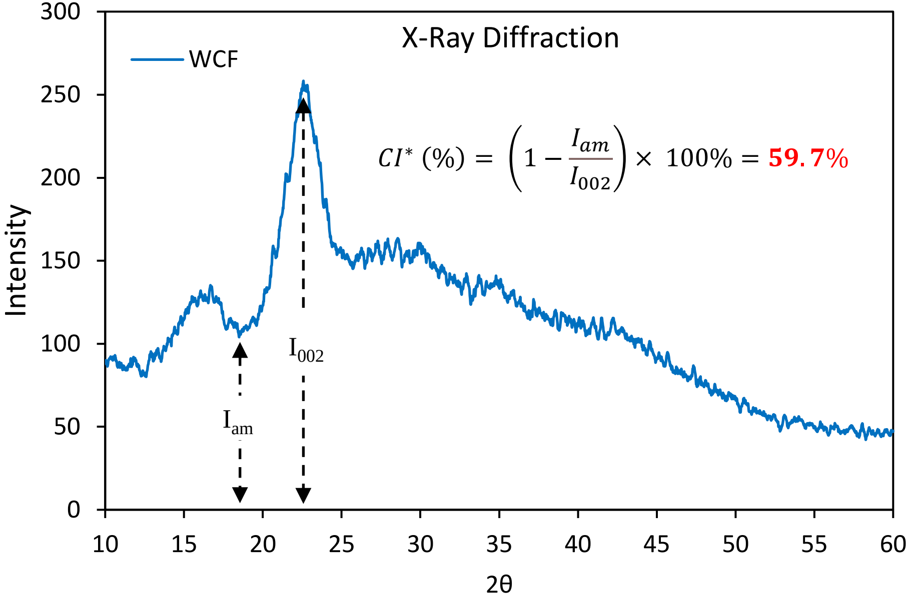
- ❑ Characterization of Waste Cellulose Fibers (Pulped Wheat Straw)
  - ➢ Crystallinity Index (XRD)
  - ➢ Cellulose Content (TGA)
  - ➢ Water Retention Capacity (WRC) and Water Release Rate (WRR)
- ❑ Effective Dispersion Method
- ❑ Microstructural Analysis of WCF Paste at 2 wt.%WCF to:
  - ➢ Investigate the effects of WCF on the kinetics of hydration reactions (isothermal calorimetry)
  - ➢ Study the effects of WCF on the development of hydration products (TGA)
  - ➢ Observe the morphology and fiber-matrix interfacial adhesion (SEM)
- ❑ Effects of WCF on the Autogenous Shrinkage of Cementitious Mortars at 0.15-0.25 wt.%WCF
- ❑ Mechanical Properties of WCF reinforced Cementitious Mortars
- ❑ Carbonation Curing as a Protective Approach for the Integrity of Fibers
- ❑ Conclusions

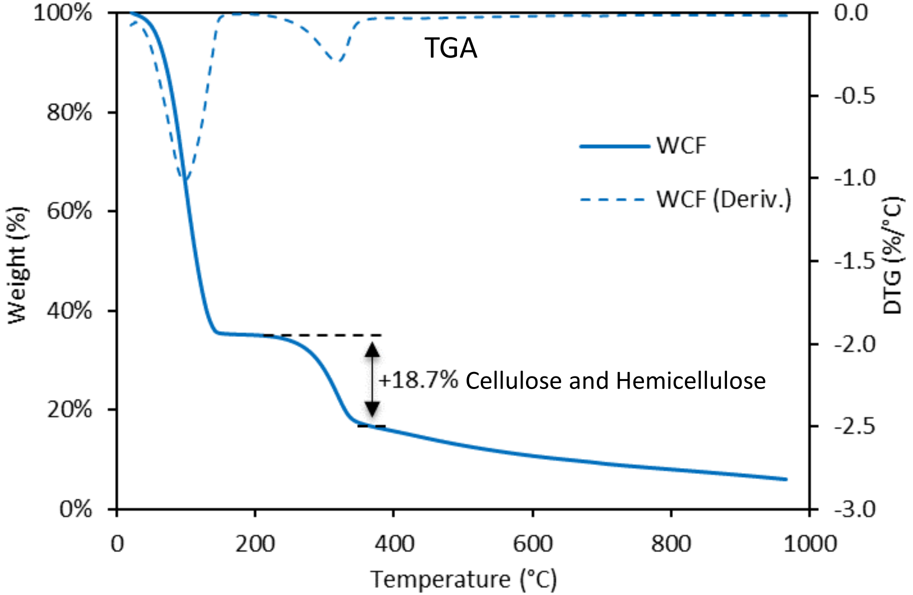






Characterization of WCF – XRD and TGA





** L. Segal, J. J. Creely, A. E. Martin, and C. M. Conrad, "An Empirical Method for Estimating the Degree of Crystallinity of Native Cellulose Using the X-Ray Diffractometer," Textile Research Journal, vol. 29, no. 10, pp. 786–794, Oct. 1959, doi: 10.1177/004051755902901003.*

- Result suggest the presence of amorphous regions in the WCFs' molecular structure

- The amount of cellulose content and degree of crystallinity of fibers' molecular structure contribute to the rigidity, strength, moisture absorption and thermal conductivity of cellulose fibers that make them suitable for high value composite applications

Characterization of WCF – Water Retention Capacity and Release Rate

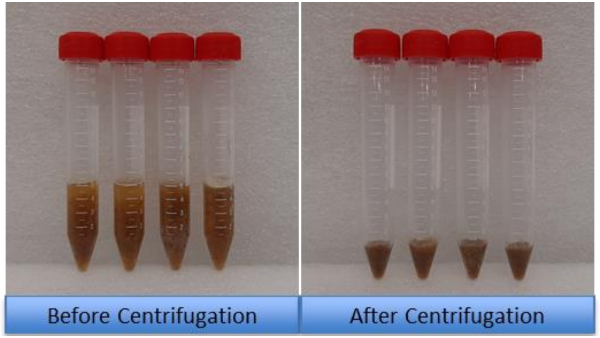
ISO 23714:2014

$$\text{WRC}\,(\%) = \frac{M_1 - M_0}{M_0} \times 100\% = \color{red}{\mathbf{947\%}}$$

$$\text{WRR}\,(\%) = \frac{M_1 - M_2}{M_1 - M_0} \times 100\%$$

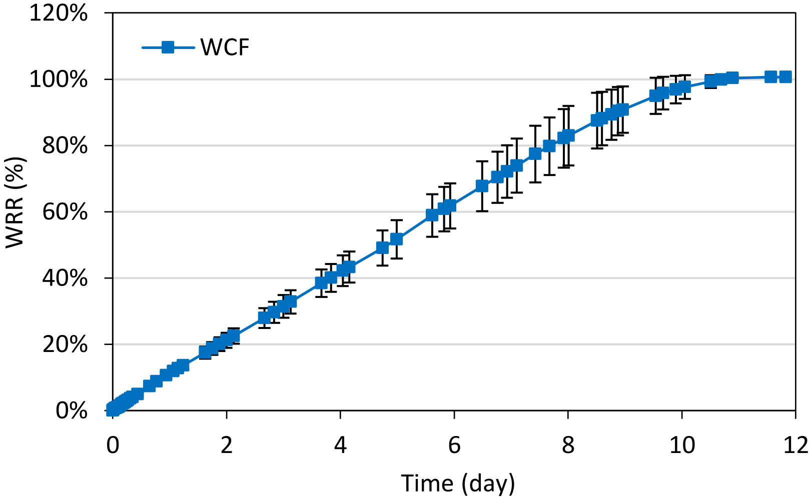
Where:

- M_0: Mass of Dried Fibers, 0.15 g
- M_1: Mass of Fibers After Centrifugation
- M_2: Mass of Fibers After Moisture Loss Over Time



Experiment's Procedure:

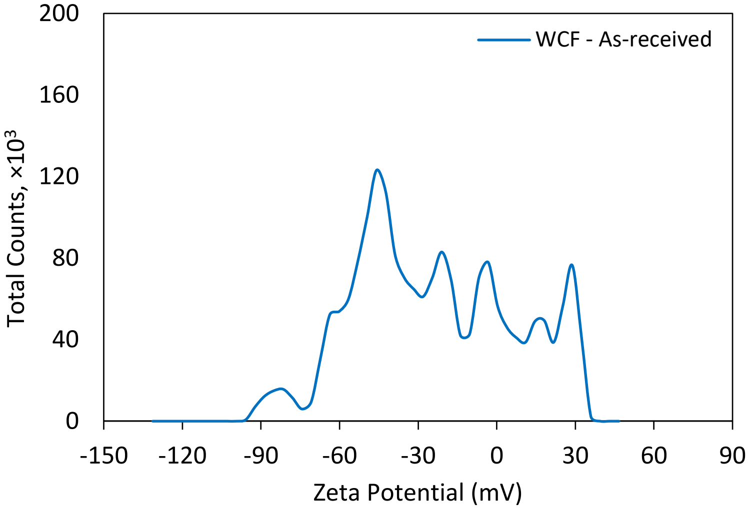
1. 5 ml of water was added to 0.15gr of fibers WCF and kept in room condition for 10 days
2. Samples were centrifuged with centrifugation force of 3000g for 1 hr
3. Excess water was removed, and remaining mass was recorded over time in the oven at 32°C until fibers were fully dried.

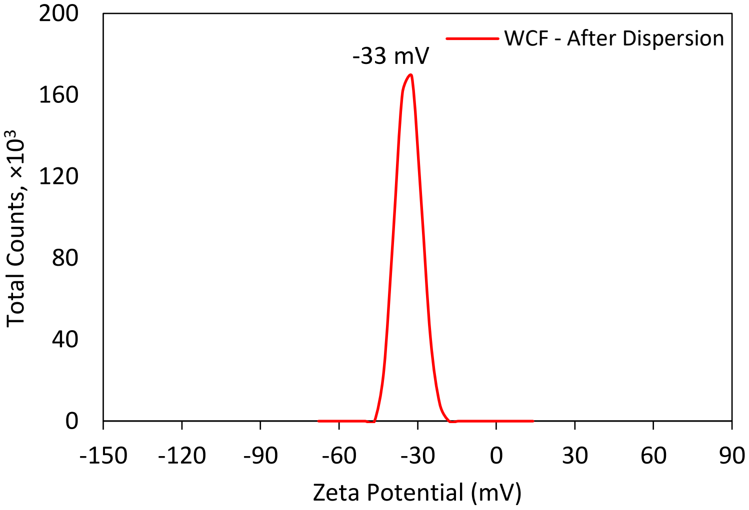


Dispersion

Pulped Wheat Straw

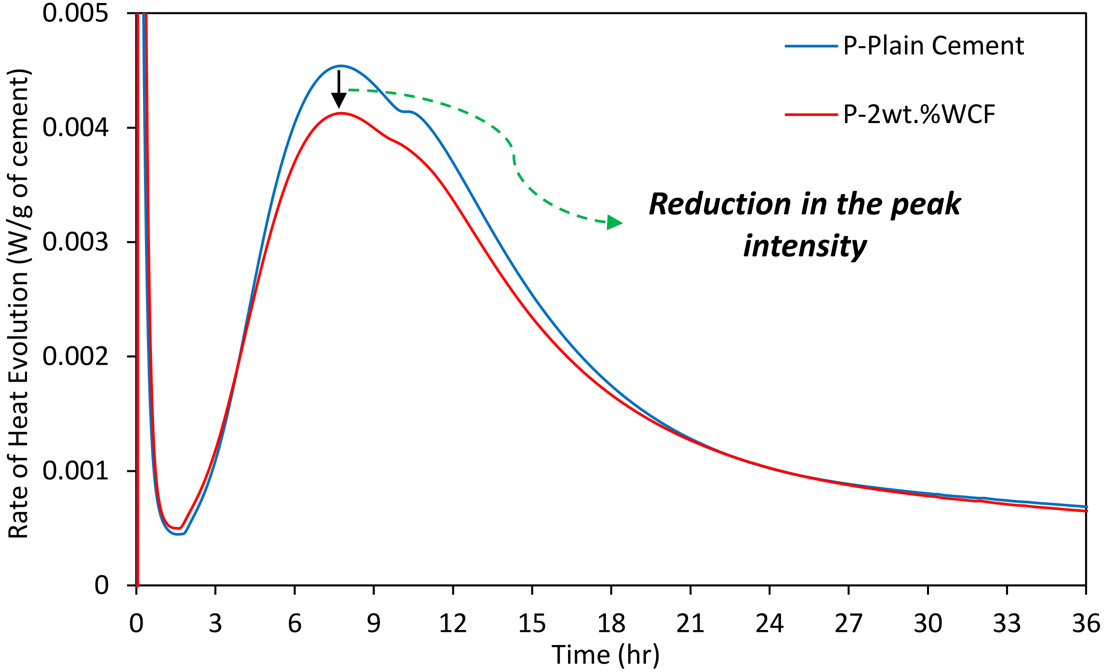
Shear Mixer





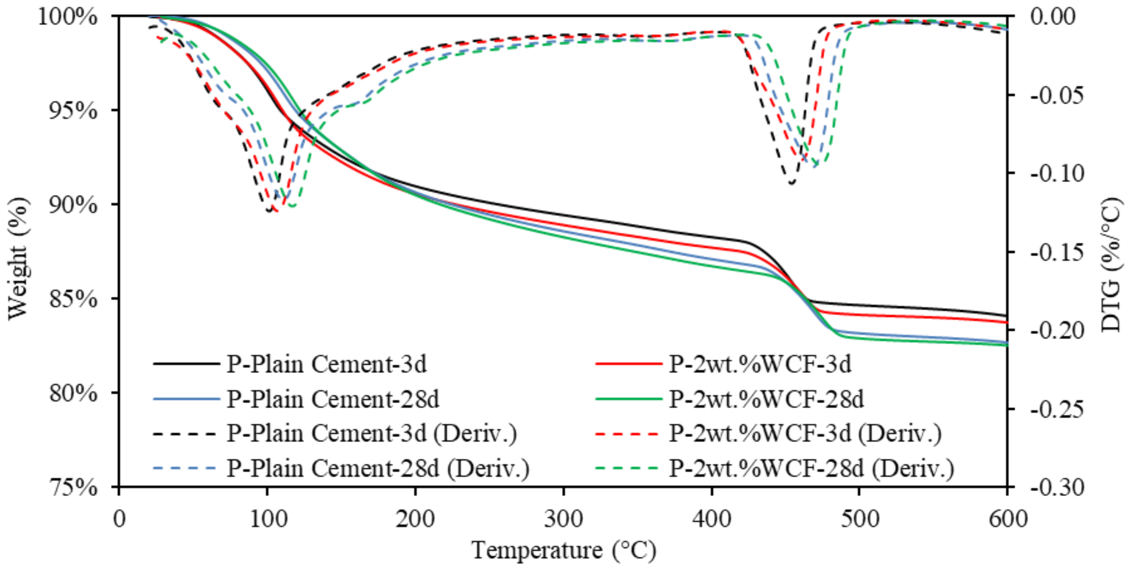
Shah, S.P., Konsta-Gdoutos, M.S. and Metaxa, Z.S., Northwestern University, 2016. *Highly-dispersed carbon nanotube-reinforced cement-based materials*. U.S. Patent 9,365,456.

Microstructural Analysis of WCF Paste (w/c=0.4) – Isothermal Calorimetry



- WCF did not change the rate of hydration reactions
- The reduction in the peak intensity can be attributed to the lower thermal conductivity of WCF (<0.072 W/m.K) compared to cement paste (0.9-1.35 W/m.K)

Microstructural Analysis of WCF Paste (w/c=0.4) – Thermogravimetric Analysis



Material	3 Days		28 Days	
	Plain cement	2wt.%WCF	Plain cement	2wt.%WCF
Bound Water (%) (105°C-400°C)	7.16	7.93	9.48	10.22
$Ca(OH)_2$*(%) (400°C-520°C)	15.17	14.92	16.62	16.15

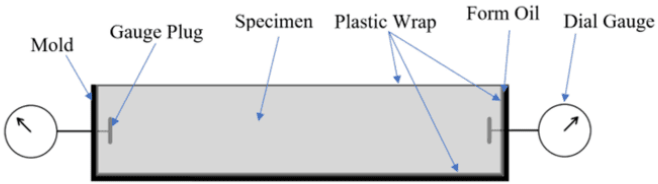
$$^{*}Ca(OH)2\,(\%) = weight\ change\ (\%) \times \frac{74}{18}$$

Where:

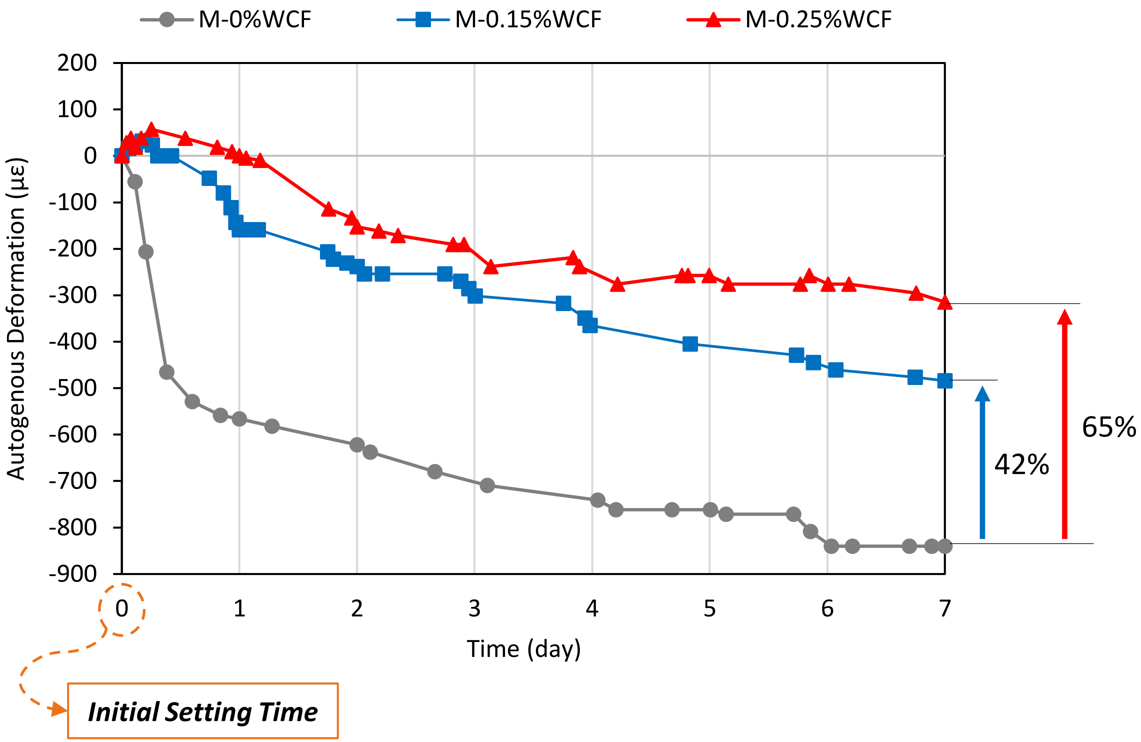
78: *Molecular weight of calcium hydroxide*

18: *Molecular weight of water*

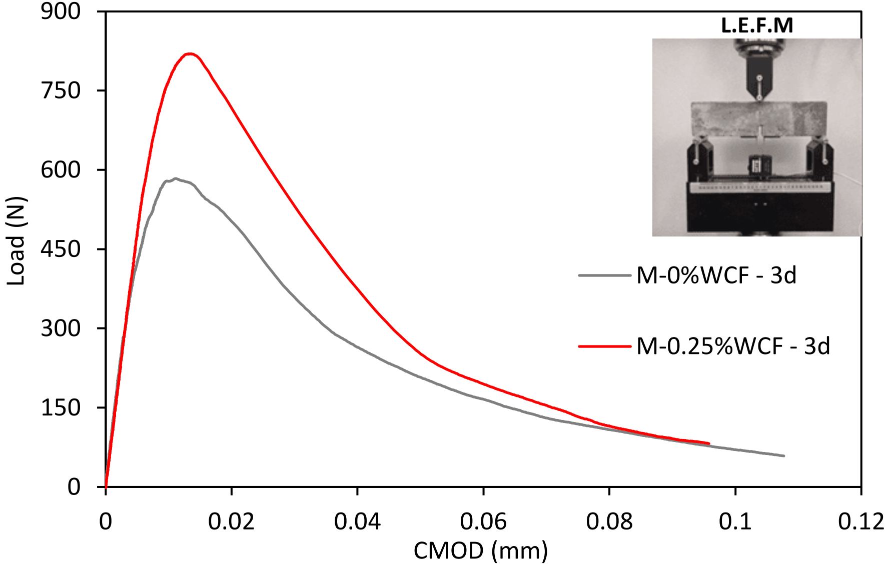
Effects of WCF on the Autogenous Shrinkage of WCF Mortar

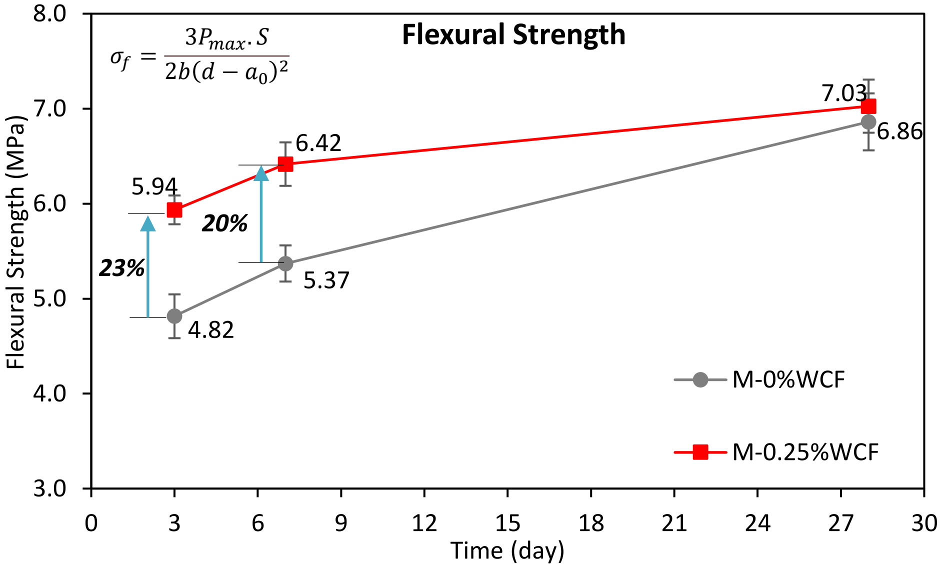


Name	w/c	WCF content (wt.% of cement)
M-0%WCF	0.25	0
M-0.15%WCF	0.25	0.15%
M-0.25%WCF	0.25	0.25%

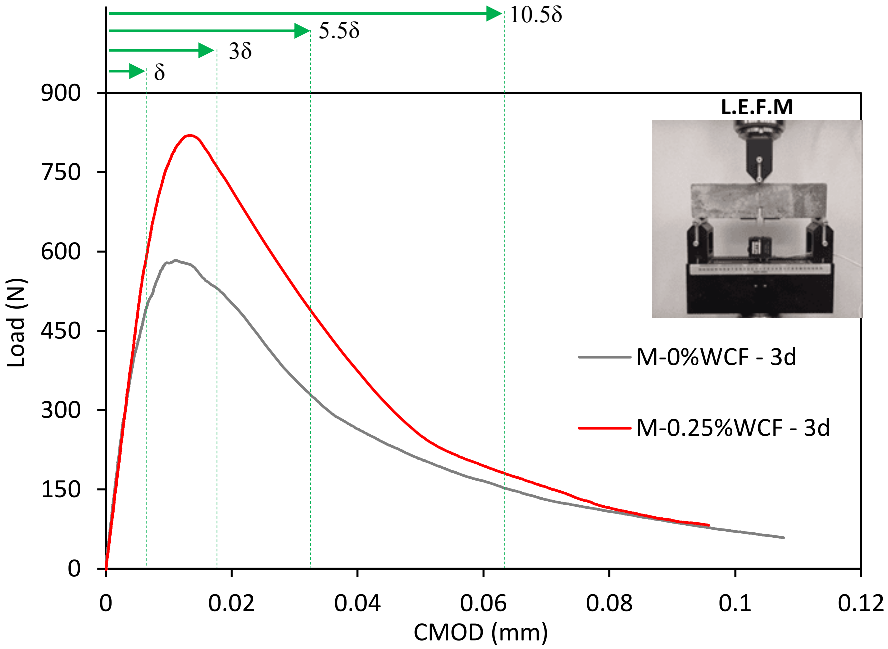


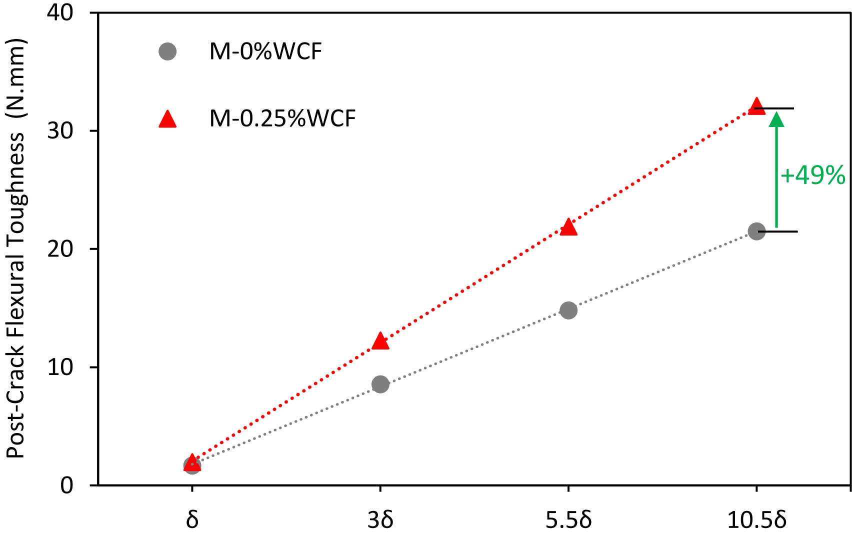
Mechanical Properties of WCF Mortar (w/c=0.25)



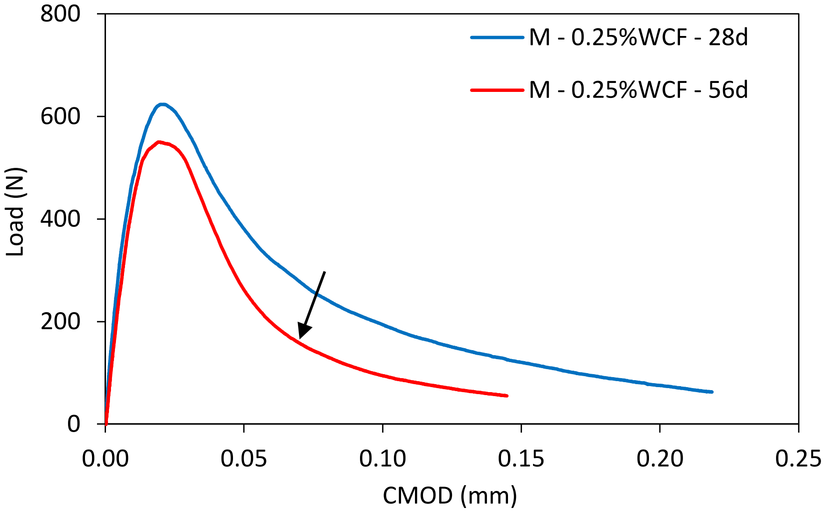


Mechanical Properties of WCF Mortar (w/c=0.25)



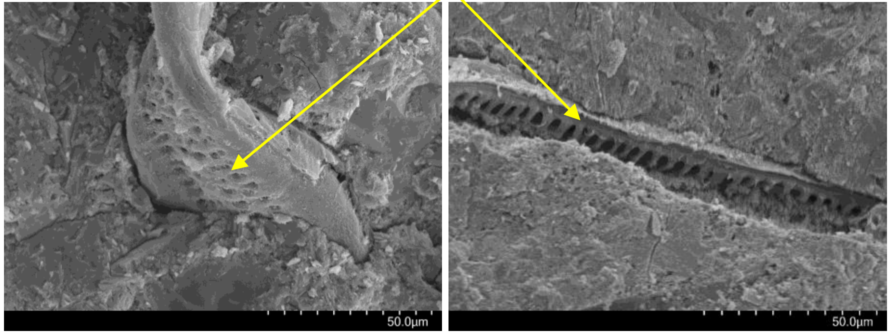


Microstructural Analysis of WCF Paste (w/c=0.4) – SEM

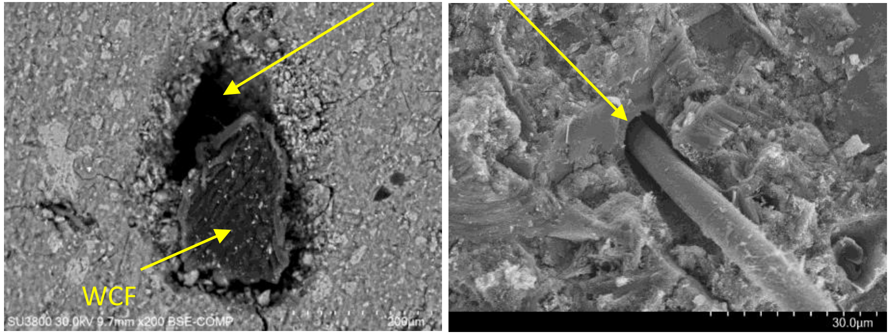


Solution?

Disintegration of Cellulose Fibers



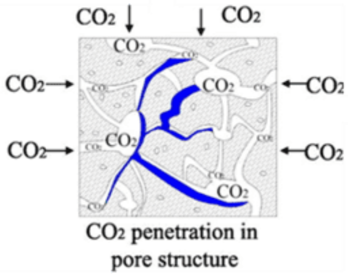
Loss of Interface Adhesion



Protective Measures to the Integrity of Cellulose Fibers

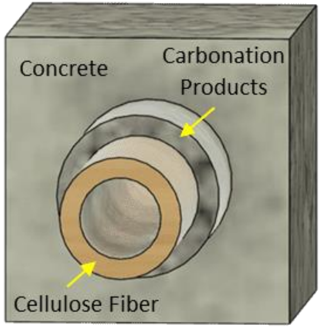
Conventional Protective Methods	*Advantages*	*Disadvantages*
1) Modifying the matrix (i.e., SCMs)	Extended durability of fibers and matrix	a) Use of additional materials b) Unclear effects on ITZ
2) Modifying the cellulose fibers (i.e., chemical treatment)	Extended durability of fibers	a) Use of additional material b) Unclear effects on ITZ c) Additional cost d) Increased carbon footprint

Proposed Method: Carbonation Curing



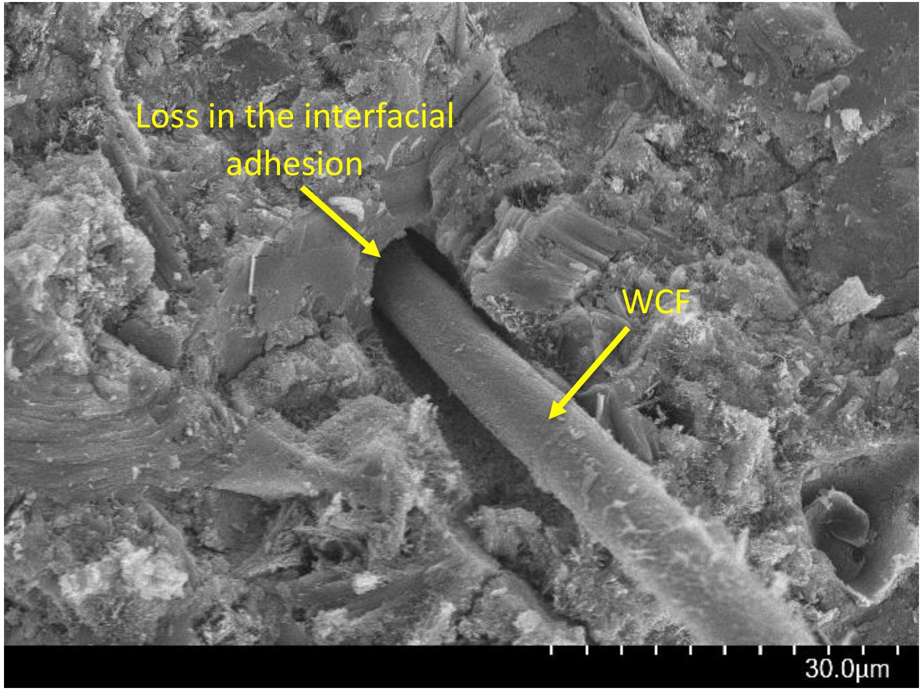
CO_2 Reacts with Hydrated and Unhydrated Phases

$CaCO_3$

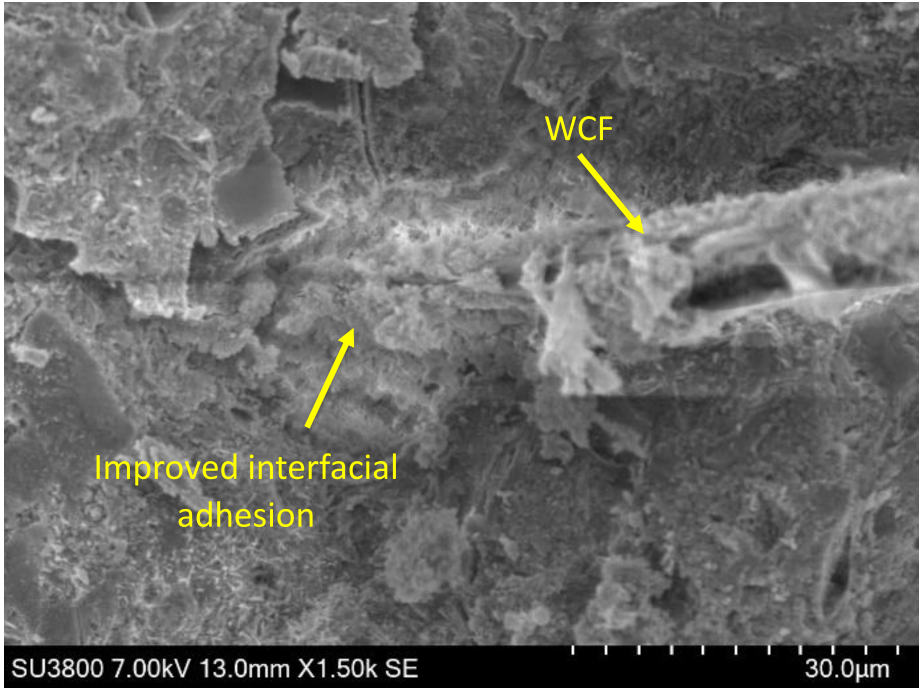


Microstructural Analysis of WCF Paste – SEM

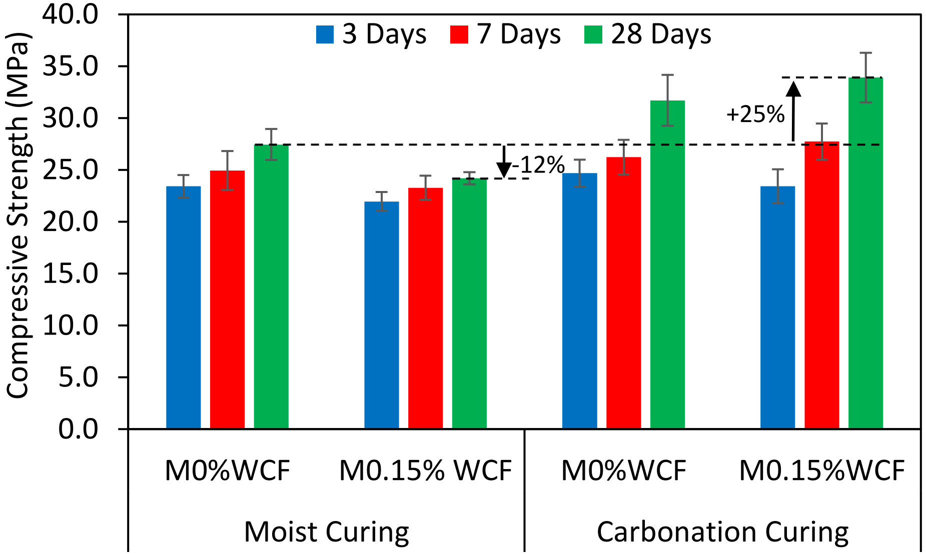
Moist Curing

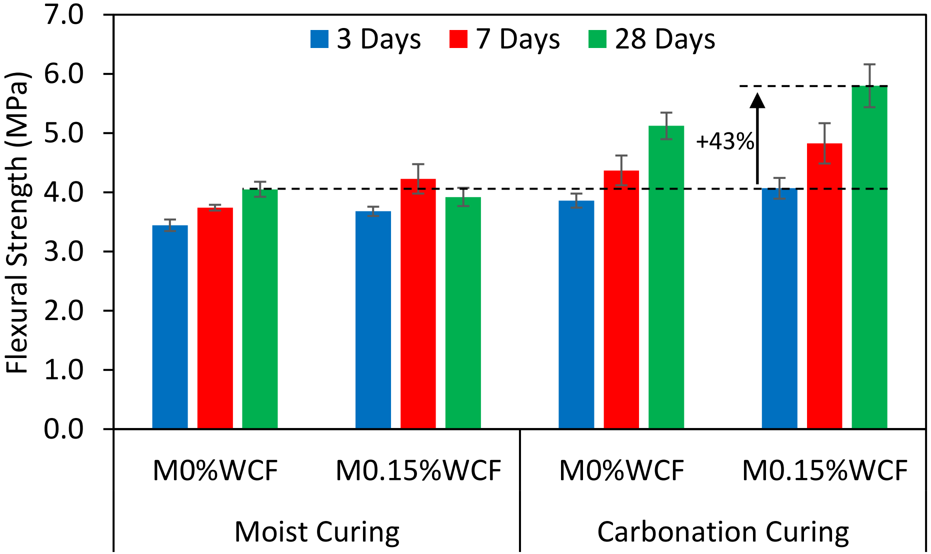


Carbonation Curing



Mechanical Properties of WCF Mortars (w/c=0.4)





Curing Condition	Modulus of Elasticity (GPa)	
	M0%WCF	M0.15%WCF
Moist Curing	20.12	17.38
Carbonation Curing	24.76	26.96

+55%

Conclusions

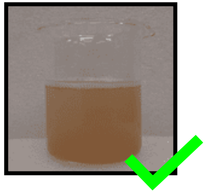
Cement

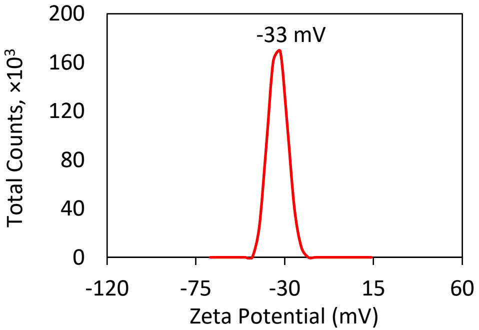
Aggregate

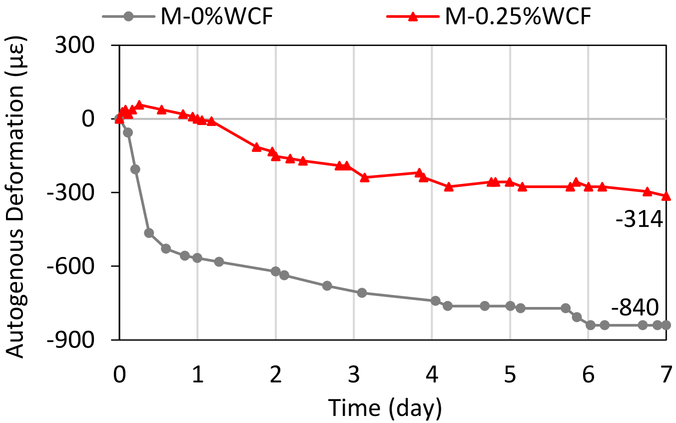
WCF

Eco-efficient Concrete

- Improved Shrinkage Performance
- Enhanced Mechanical Properties
- Low Carbon Footprint
- Low Cost







- ✓ Water Retention Capacity ≈ +950%
- ✓ Reduction in Autogenous Shrinkage ≈ 65%

Conclusions

Cement

Aggregate

WCF

Eco-efficient Concrete

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- Enhanced Mechanical Properties
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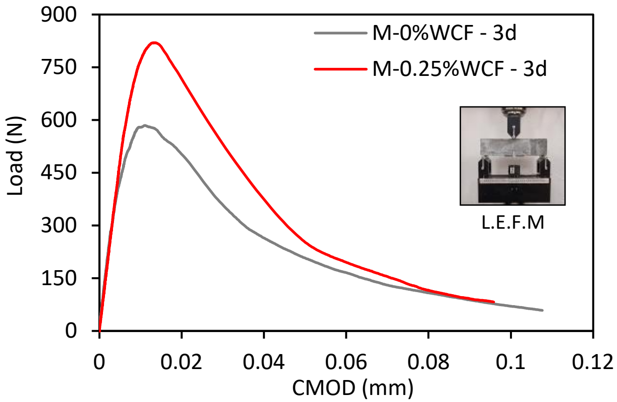
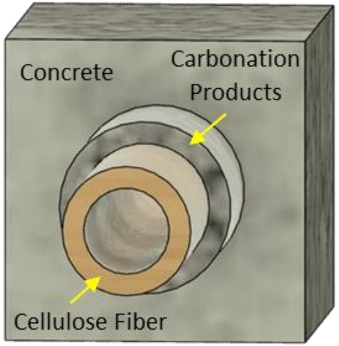


- ✓ Flexural strength ≈ +25%
- ✓ Energy absorption capacity ≈ +50%



Carbonation Curing as Protective Approach:

- ✓ Improved interfacial adhesion
- ✓ Flexural strength ≈ +50%
- ✓ Compressive strength ≈ +25%
- ✓ Increased carbon uptake

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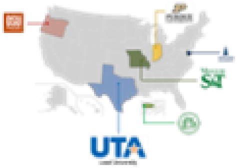

Thank you…!

UTA