DuRe-Transp

Tier 1 University Transportation Center for Durable and Resilient Transportation Infrastructure

UTA Center for Advanced Construction Materials

Development of Net-Zero Embodied Carbon Concrete Using Carbon- and Cellulose- based Byproducts and Nanomaterials

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aci VIRTUAL CONCRETE CONVENTION
The world's gathering place for advancing concrete

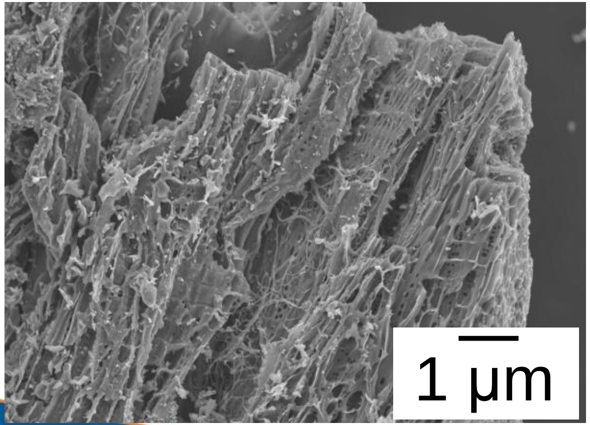
ACI Fall Convention 2024
Decoupling of Concrete Production from Embodied Carbon Emissions through Nanotechnology, Part 2 of 2
Philadelphia, PA, USA November 3-6. 2024

UTA

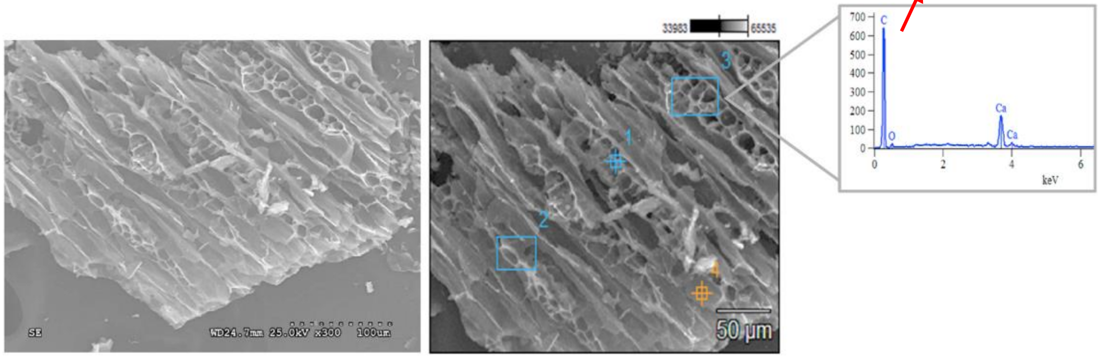
Controlling the Carbon Footprint of Concrete: Development of Sustainable, Eco-efficient Concrete Using Agricultural Waste/Byproducts

Biochar

- ✓ Unique 3D porous structure
- ✓ Extremely high stoichiometric CO_2 uptake potential (≈60%)

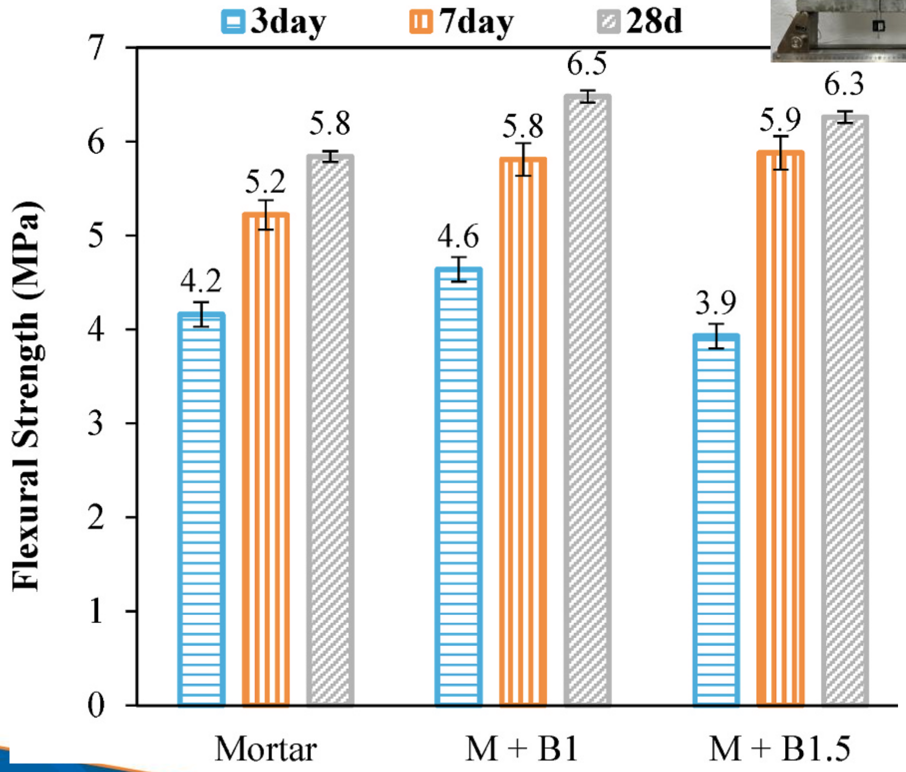


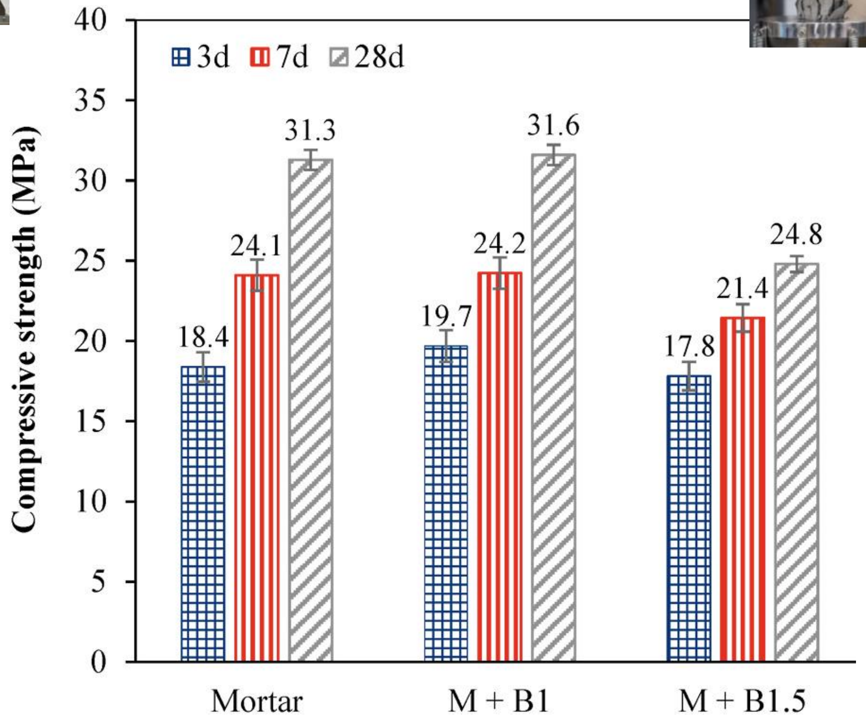
Oxygen-to-carbon ratio = 0.08



Konsta-Gdoutos, M.S. et al. 2023 Cement and Concrete Composites, 140, p. 105078
Konsta-Gdoutos, M.S. et al. 2023 Construction and Building Materials, 392, p. 132021

Mechanical Properties of Biochar Concrete



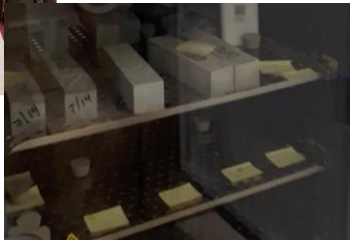


B1: Biochar 1 wt%
B1.5: Biochar 1.5 wt%

Mishra, G., Danoglidis, P.A., Shah, S.P., Konsta-Gdoutos, M.S. 2023 Cement and Concrete Composites, 140, p. 105078
Mishra, G., Danoglidis, P.A., Shah, S.P., Konsta-Gdoutos, M.S. 2023 Construction and Building Materials, 392, p. 132021

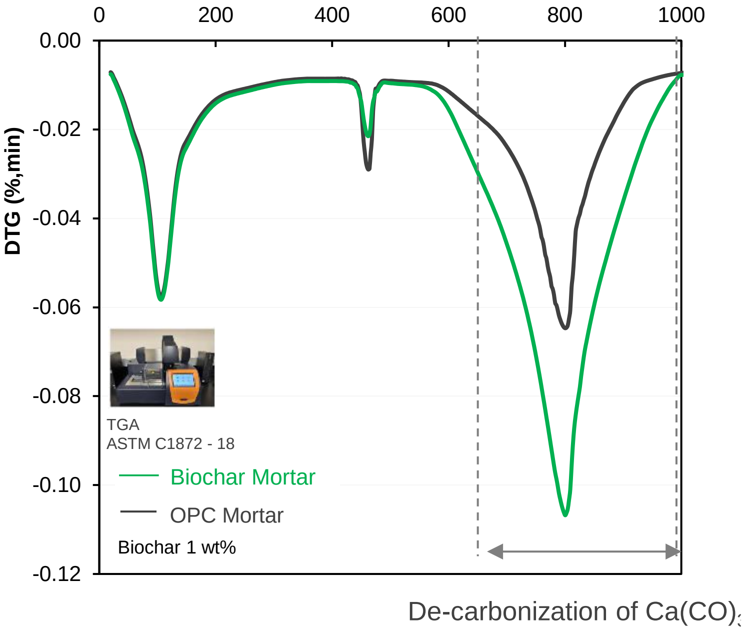
CO_2 Mineralization Capacity of Biochar Concrete

Carbonation - 7 Days
CO_2 12% v/v
65% RH
74 ºF (23 ºC)

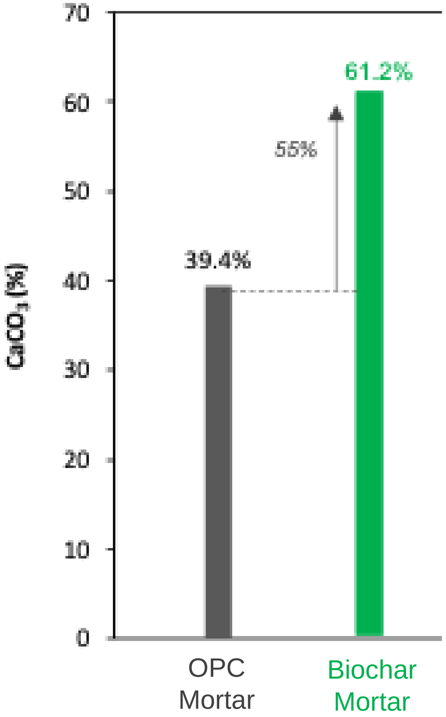


Simulation of CO_2 sequestration capacity of concrete exposed to outdoor conditions in metropolitan areas (400 – 430 ppm) for 3 years

RILEM 281-CCC "Carbonation of concrete"



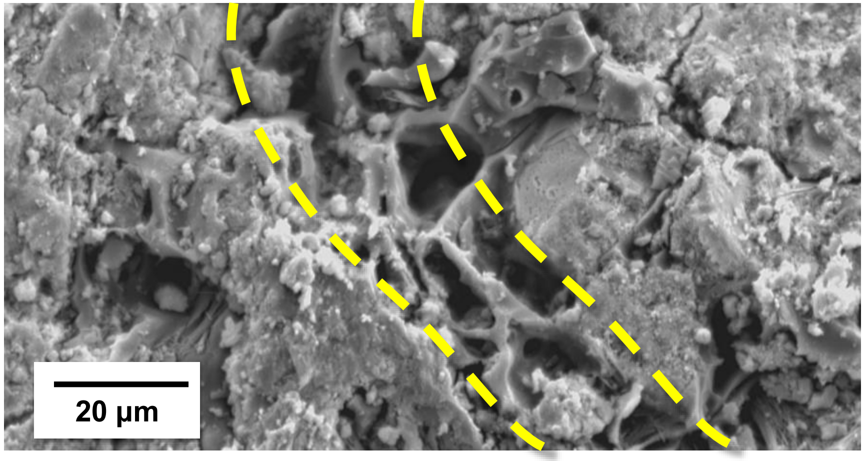
$$CaCO_3 = \frac{W_{525} - W_{900}}{W_{525}} \times 2.27 \times 100$$



Mishra, G., Danoglidis, P.A., Shah, S.P., Konsta-Gdoutos, M.S. 2023 Cement and Concrete Composites, 140, p. 105078

Carbonated Biochar Concrete-SEM images

Porous biochar provides channels for
CO_2 diffusion within concrete



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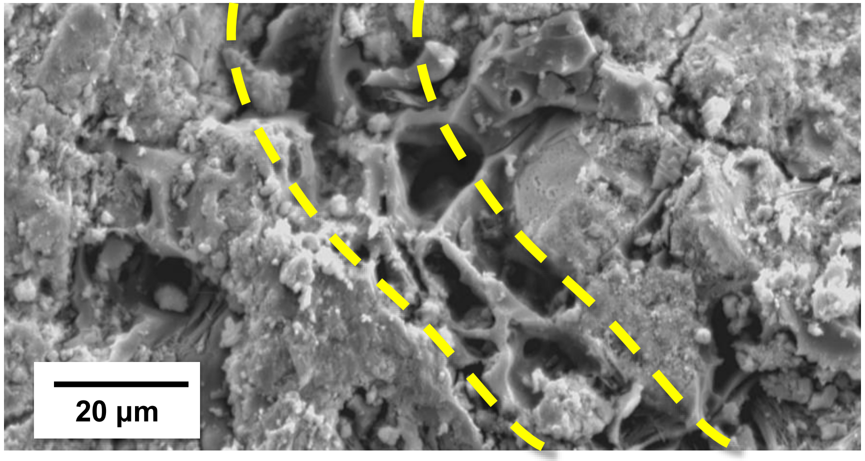
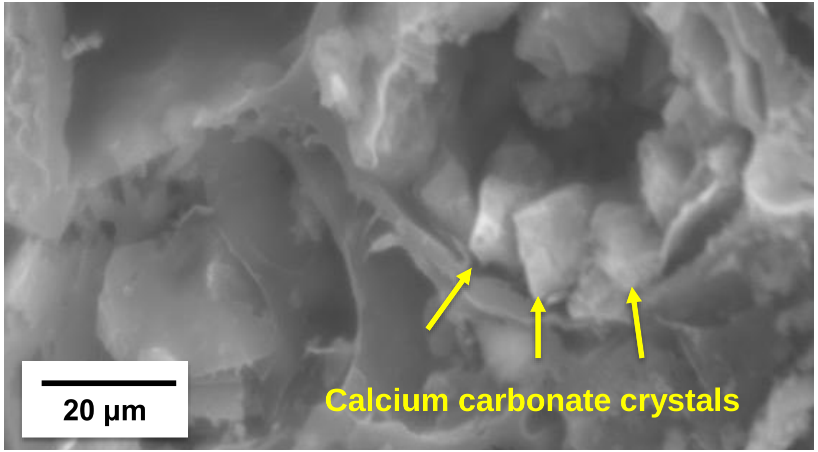


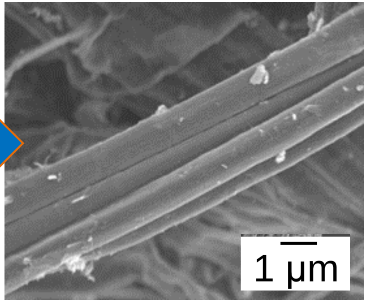
Precipitation of calcium carbonate crystals in Biochar concrete



Mishra, G., Danoglidis, P.A., Shah, S.P., Konsta-Gdoutos, M.S. 2023 Cement and Concrete Composites, 140, p. 105078

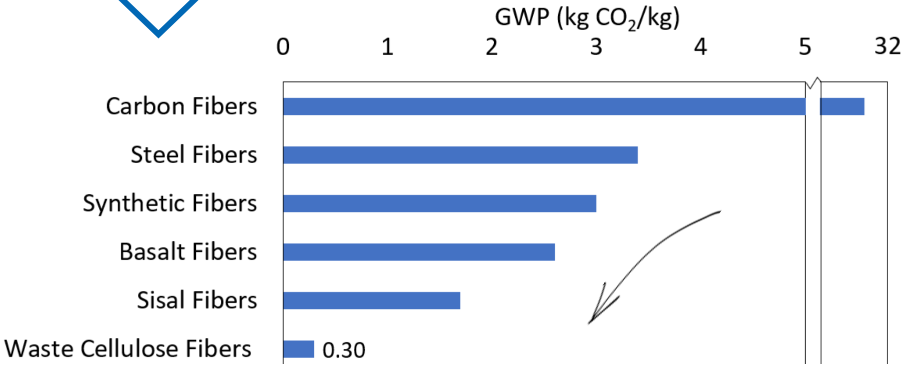
Eco-Efficient Concrete Using Waste Cellulose Fibers

Cellulose Fibers



Incineration of Waste Cellulose Fibers

➢ ~10% is being recycled



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

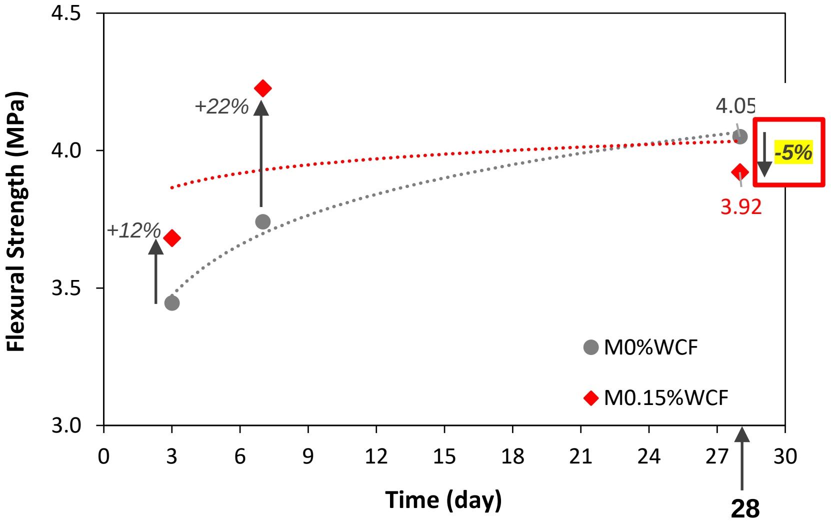
Abundant Resources

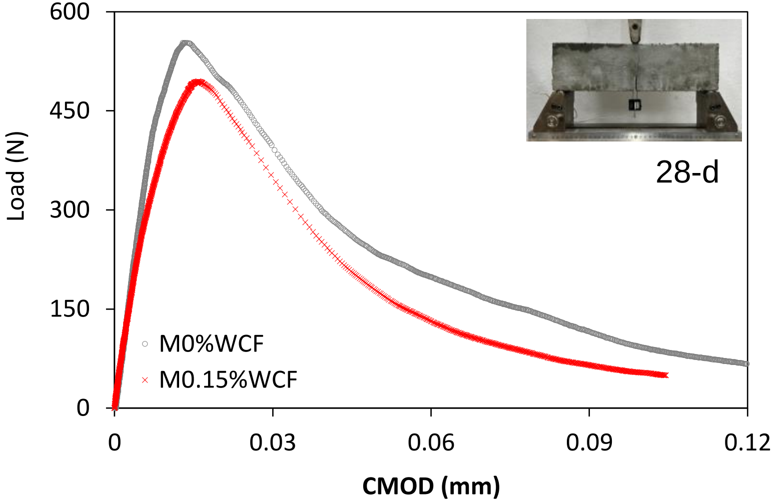
Fast Renewability

Low Cost

Low Carbon Footprint

Mechanical Properties of WCF-Concrete

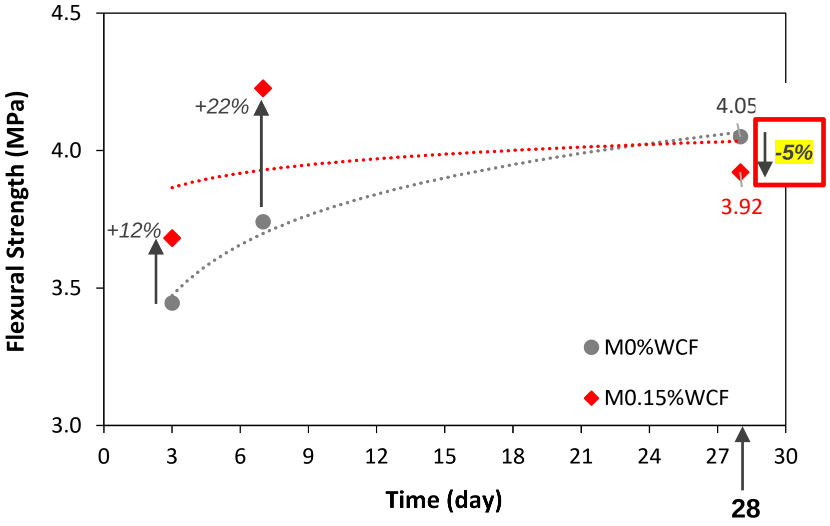


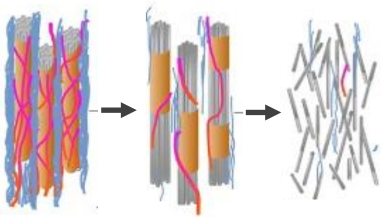


Deterioration of the mechanical properties of the 28-day WCF-Concrete specimens:

- -5% Flexural Strength and Young's Modulus
- -10% Tensile Energy Strain Absorption Capacity

Mechanical Properties of WCF-Concrete

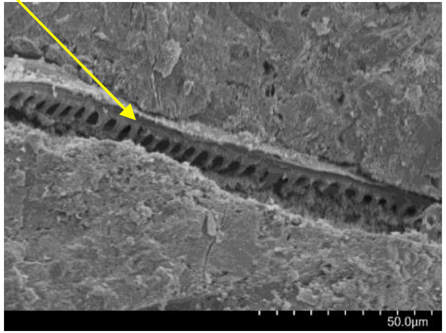




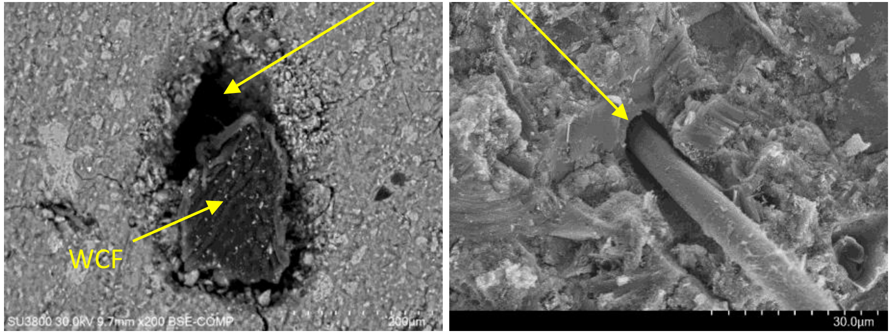
Embrittlement/Loss of Elasticity

Cellulose Fibers, Polypropylene Fibers, Basalt Fibers, Polyamide Fibers

Disintegration of WCF



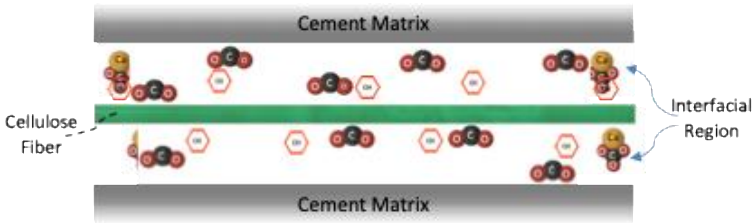
Loss of Interfacial Bonding

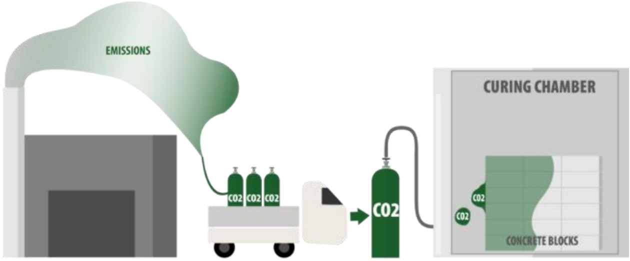


Deterioration of the mechanical properties of the 28-day WCF-Concrete specimens:

- -5% Flexural Strength and Young's Modulus
- -10% Tensile Energy Strain Absorption Capacity

Carbonation Curing of WCF-Concrete





Curing Conditions

1. Carbonation, *6% and RH=65%*
2. Conventional Curing, *RH=95%, 3 days*
   + Carbonation, *6% CO_2 and RH=65%*

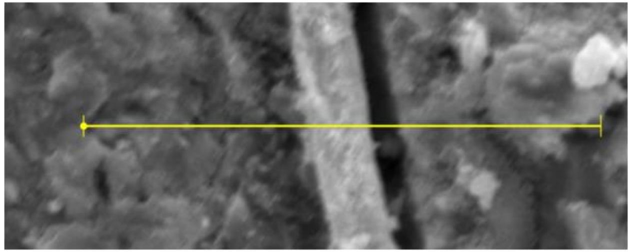
Preferential Formation of Carbonation Products at the fiber-matrix interface

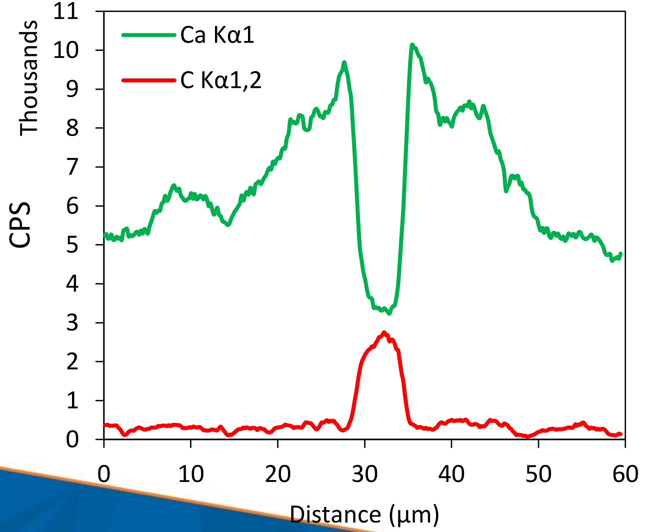
Selectively reduce the alkalinity at fiber-matrix interfacial area

Prevention of fiber hydrolysis

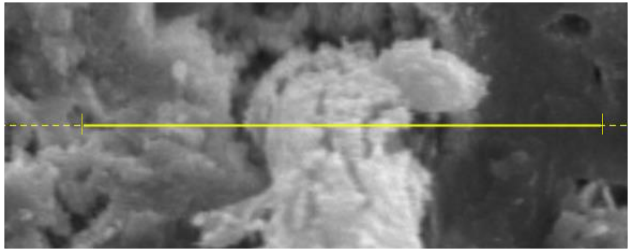
Reducing the Alkalinity at WCF-Matrix Interface

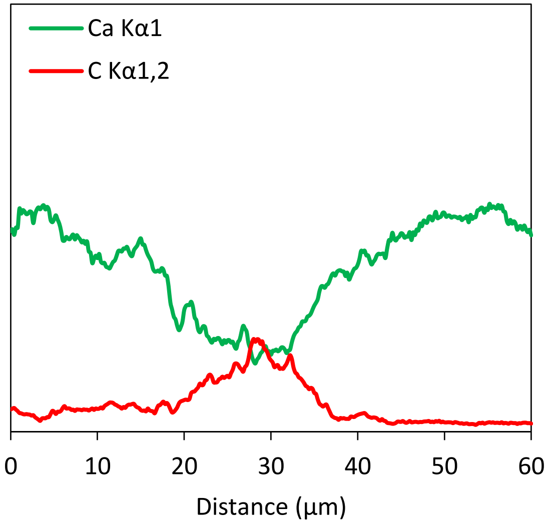
28-Day Conventional Curing
RH 95%





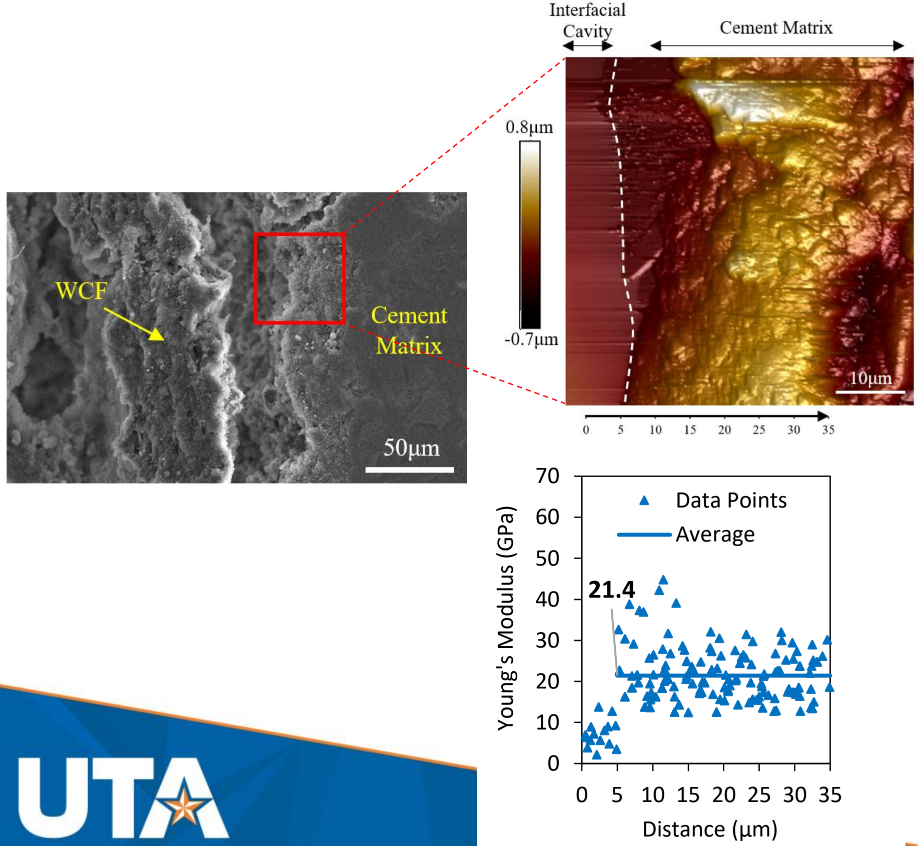
28-Day Carbonation
6% CO_2, RH 65%



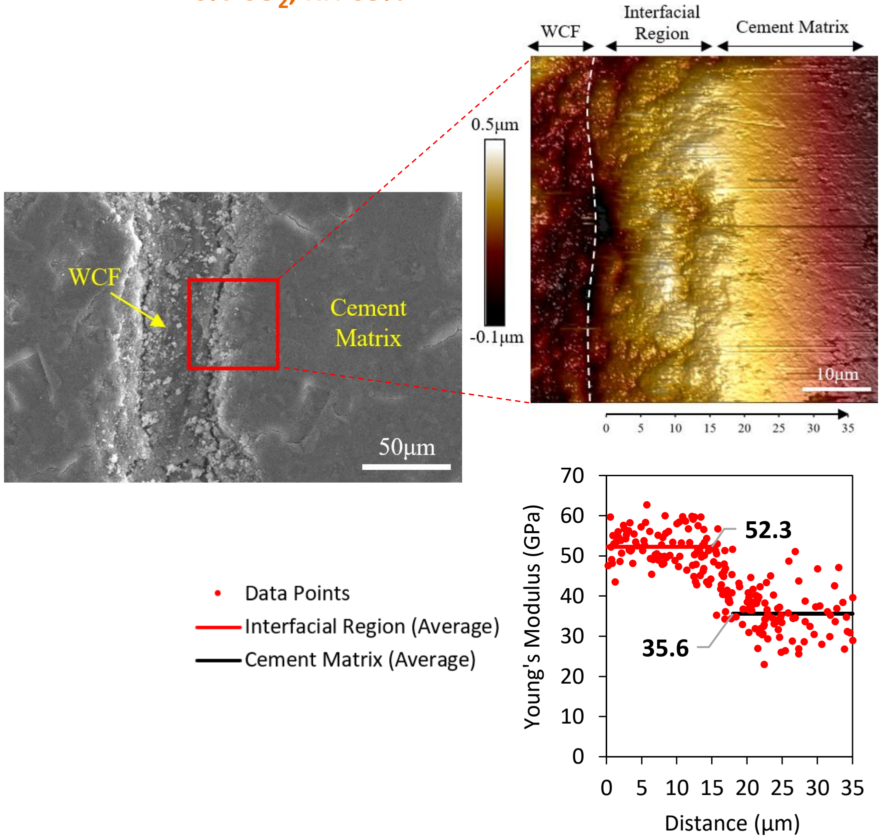


Increased Modulus of the WCF/Matrix Interface

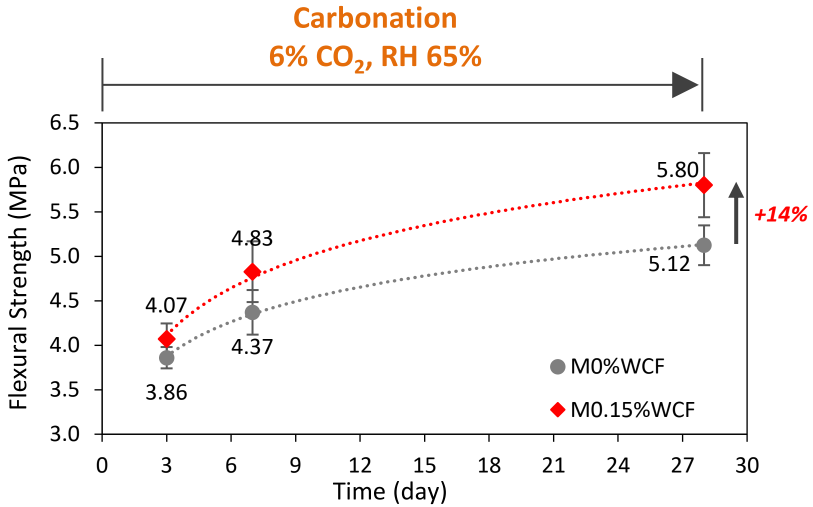
28-Day Conventional Curing
RH 95%



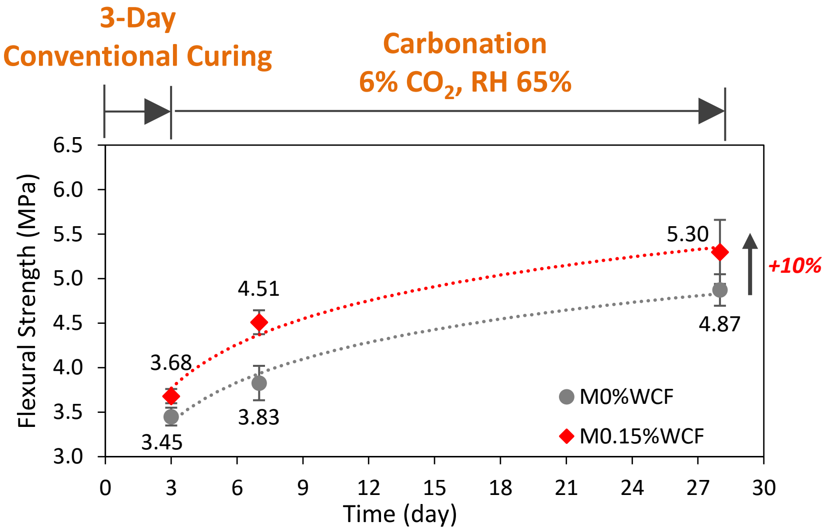
28-Day Carbonation
6% CO_2, RH 65%



Mechanical Properties of Carbonated WCF - Concrete



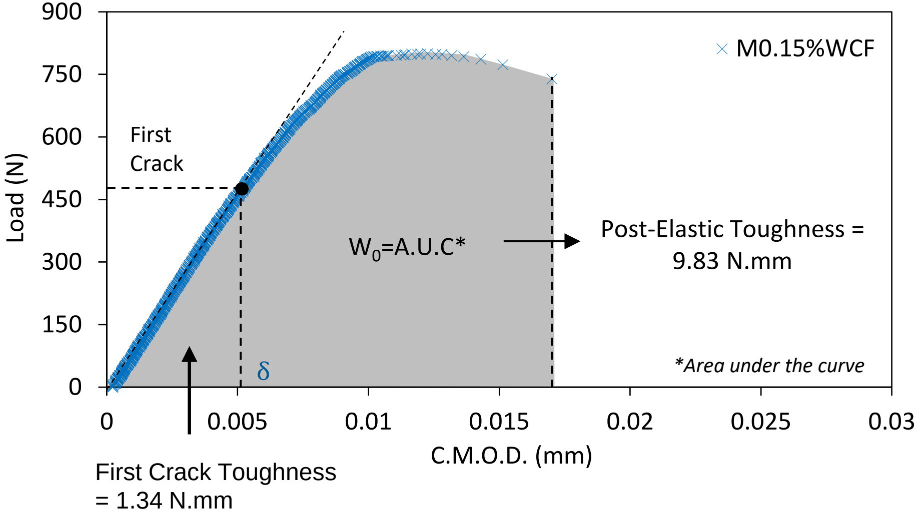
28-Day Specimens	Compressive Strength (MPa)	Modulus of Elasticity (GPa)
M0%WCF	31.72	21.34
M0.15%WCF	33.91 +7%	24.27 +14%



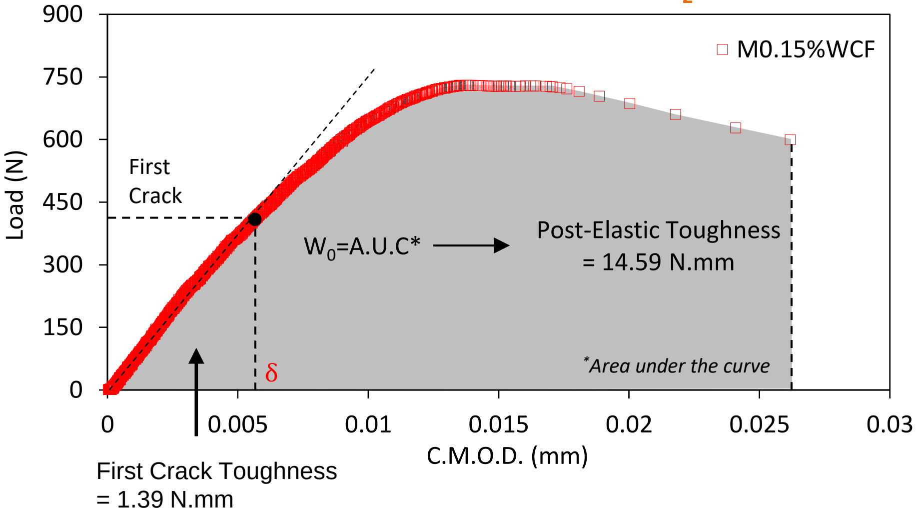
28-Day Specimens	Compressive Strength (MPa)	Modulus of Elasticity (GPa)
M0%WCF	29.43	17.38
M0.15%WCF	31.72 +7%	19.82 +14%

Ductility of Carbonated WCF - Concrete

28-Day Carbonation
6% CO_2, RH 65%



3-Day Conventional Curing + 25-Day Carbonation
6% CO_2, RH 65%

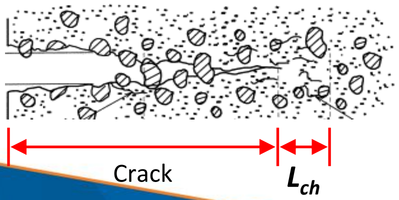


Fracture Energy:

$$G_f = \frac{W_0 + 2P_w\delta_0}{b(d - a_0)}$$

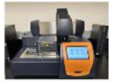
Fracture Process Zone Length:

$$l_{ch} = \frac{E.G_f}{\sigma_f^{\,2}}$$



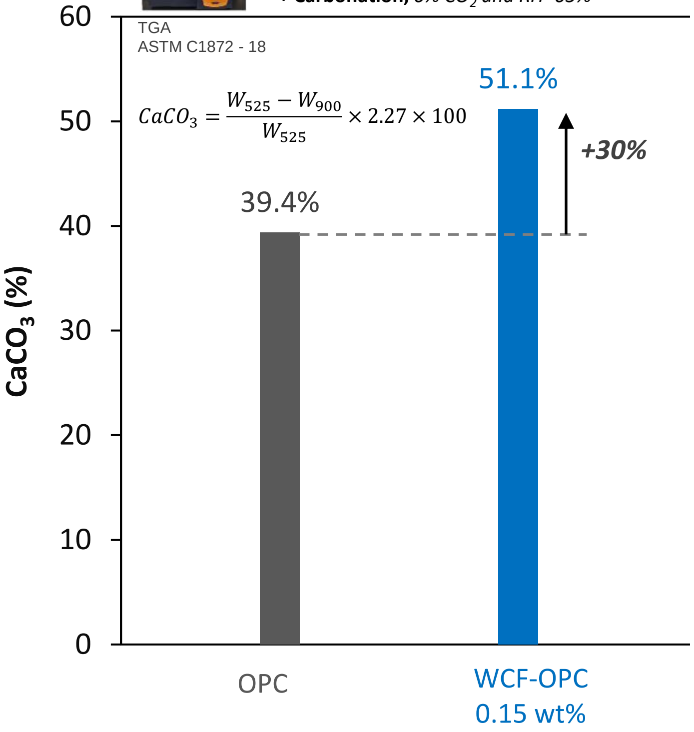
Curing Condition	G_f (N/mm)		l_{ch} (mm)	
Moist curing (3d) + Carbonation at 6% CO_2	14.61	~+50%	66.89	+46%
Carbonation Curing at 6% CO_2	9.85		45.76	

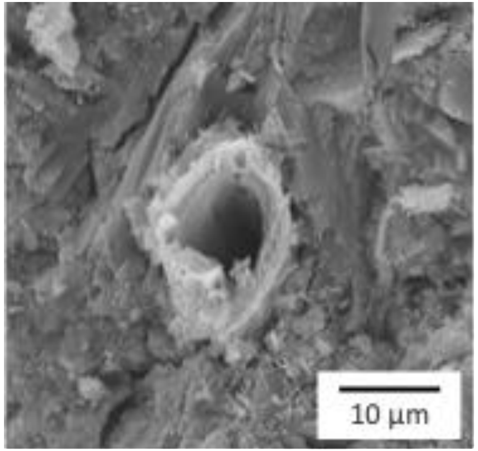
Dual Purpose Carbonation: Increase the Carbon Mineralization Capacity of WCF Reinforced Concrete

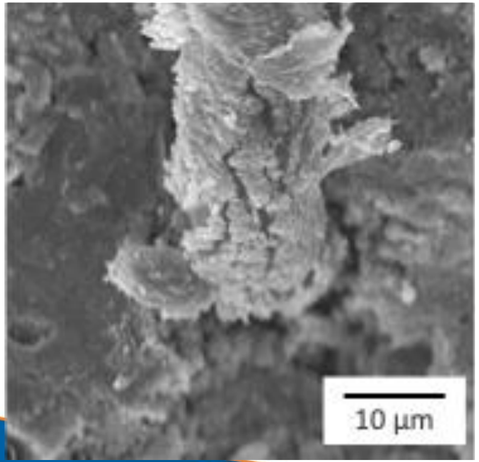


Conventional Curing, *RH=95%, 3 days*

+ Carbonation, *6% CO_2 and RH=65%*





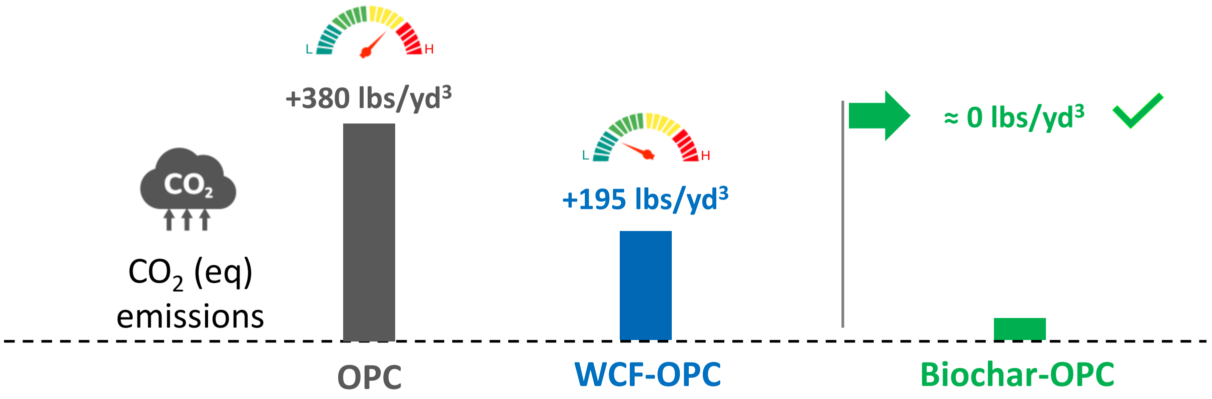


Similarly to the biochar, the tubular Morphology of WCF provides channels for enhanced mineralization

Formation of calcium carbonates in the WCF/Matrix interface

Carbon Footprint of Eco-Efficient Concrete

From Carbon Emitter to Net-Zero Carbon Concrete

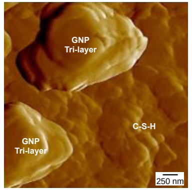


	OPC	WCF-OPC	Biochar-OPC
Emitted CO_2 (lbs/yd^3)	590	590	590
Sequestered CO_2 (lbs/yd^3)	210	395	580

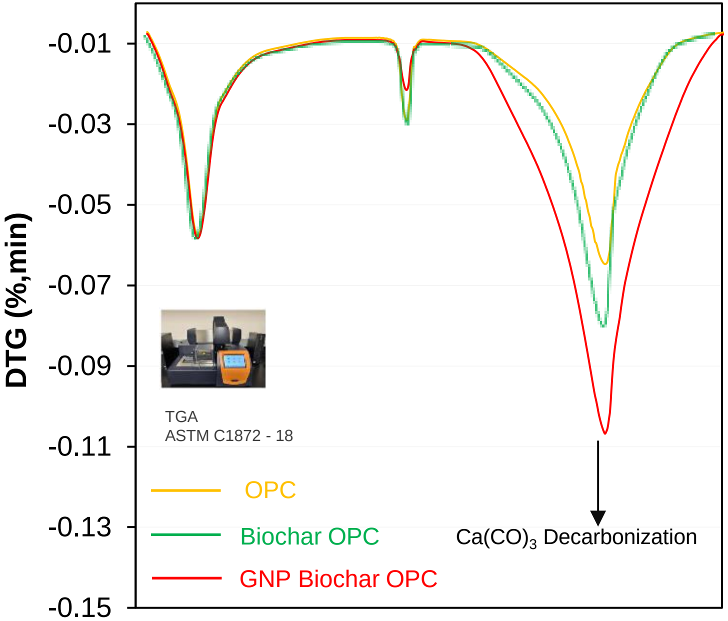
CO_2 Sequestration of GNP Reinforced Biochar - OPC

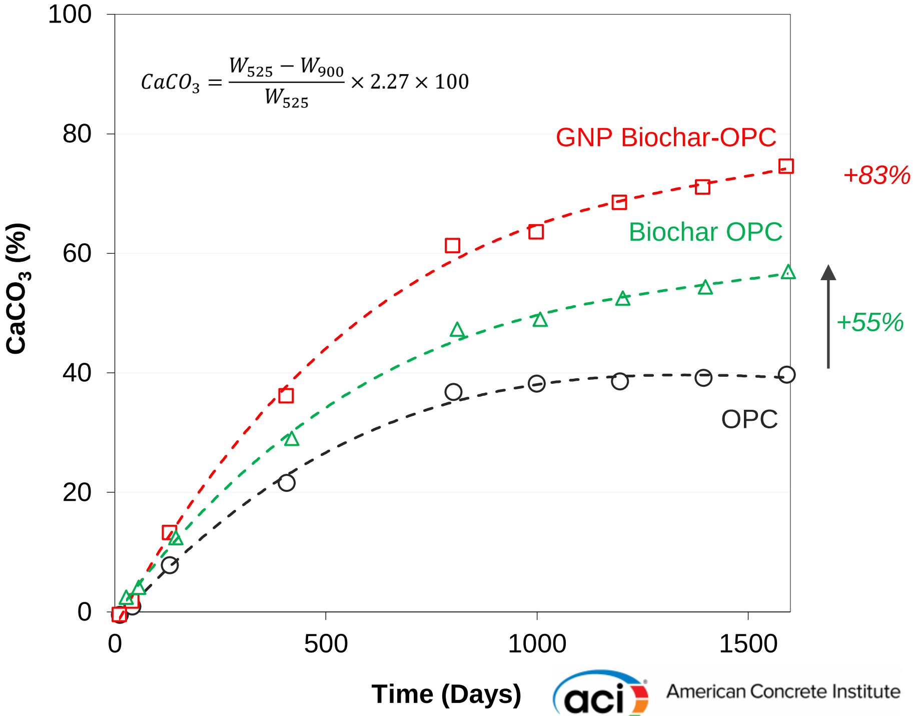
Biochar
- Specific Surface Area: 450 m^2/g
- Carbon Content: 75%

GNPs
- Specific Surface Area: 750 m^2/g
- Carbon Content: 99%

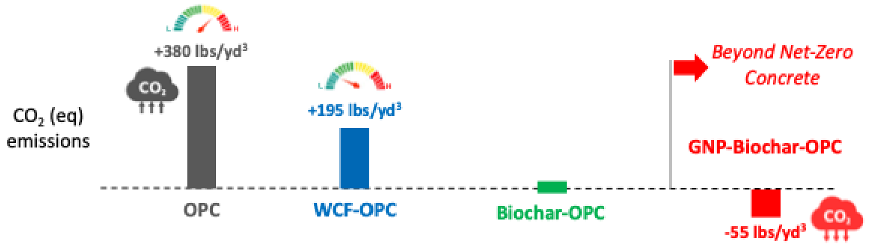


Replacing cement with **Biochar**
and reinforcing it with few-layer **Graphene Nanoplatelets (GNPs)**

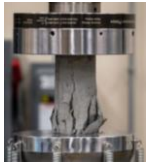




Conclusions



	OPC Mortar	OPC + WCF 0.15wt%	OPC + Biochar 1wt%	OPC + Biochar 1wt% + GNPs 0.15wt%
CO_2 Emission (lbs/yd³)	590	590	590	590
CO_2 Sequestration (lbs/yd³)	210	395	600	645



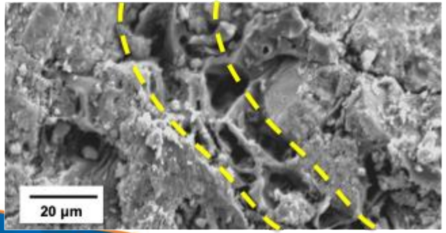
Enhanced Resiliency

- ✓ +15% First crack strength
- ✓ +16% Modulus of Elasticity

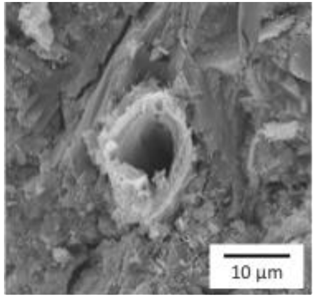
Enhanced Ductility

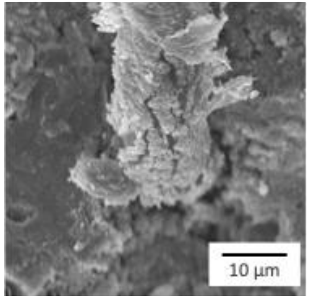
- ✓ 1.5x higher toughness
- ✓ 1.4x higher fracture energy

Biochar-OPC



WCF-OPC





Acknowledgements

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Advancing International Partnerships in Research for Decoupling Concrete Manufacturing and Global Greenhouse Gas Emissions

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Thank you!

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