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Center for Advanced Construction Materials

Carbon-Negative Concrete with Enhanced Resiliency and Ductility Using Sustainable Carbon-Based Agricultural Byproducts and Nanomaterials

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

ACI Spring Convention 2023
Nanotechnology for Concrete with Low Carbon Footprint
April 2 - 6, 2023, Hilton San Francisco Union Square, San Francisco, CA

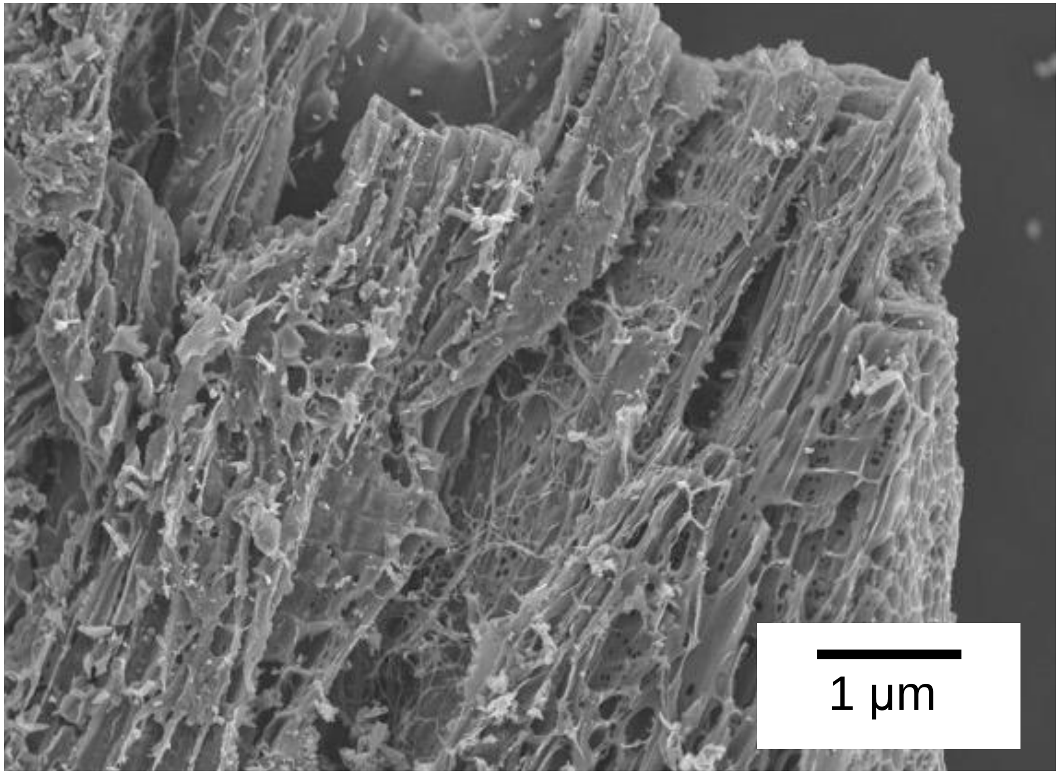
CO_2 Emissions and Sequestration of Concrete

	OPC Concrete	Carbonated OPC Concrete
CO_2 emissions (lbs/yd^3) From manufacturing process	590	590
CO_2 sequestration (lbs/yd^3)	10	360

+580 CO_2 lbs/yd3

+230 CO_2 lbs/yd3

Agricultural Byproducts – Biochar



SEM picture of porous biochar

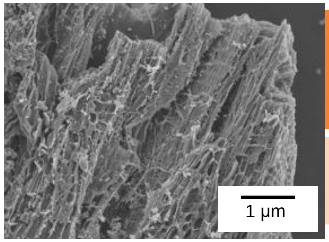
Biochar

- ✓ Unique 3D porous structure
- ✓ High stoichiometric CO_2 uptake potential (15-25%)

Experimental Program

28-day Cement Mortars
w/c/s: 0.485
OPC Type I
Sand ASTM C779
Biochar: 1.0 wt%

4 x 4 x 16 cm³ Prisms



SEM picture of porous biochar

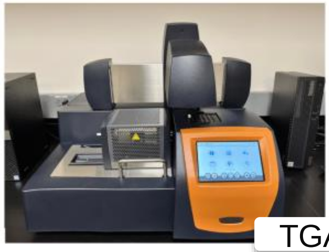
	Particle size (μm)	Bulk density (g/cm³)	Purity (%)
Biochar	20 – 250	0.55	90

CO_2 curing
CO_2 12% v/v (100% purity)
65% RH
74 °F (23 °C)

CO_2 Diffusion

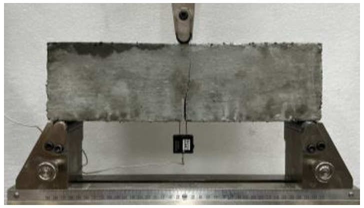

FTIR

CO_2 uptake and mineralization (%)

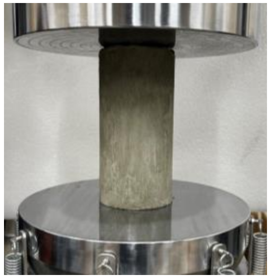

TGA – ASTM C1872 - 18

Mechanical Properties

- Modulus of Elasticity
- Strain energy absorption capability (flexural toughness)

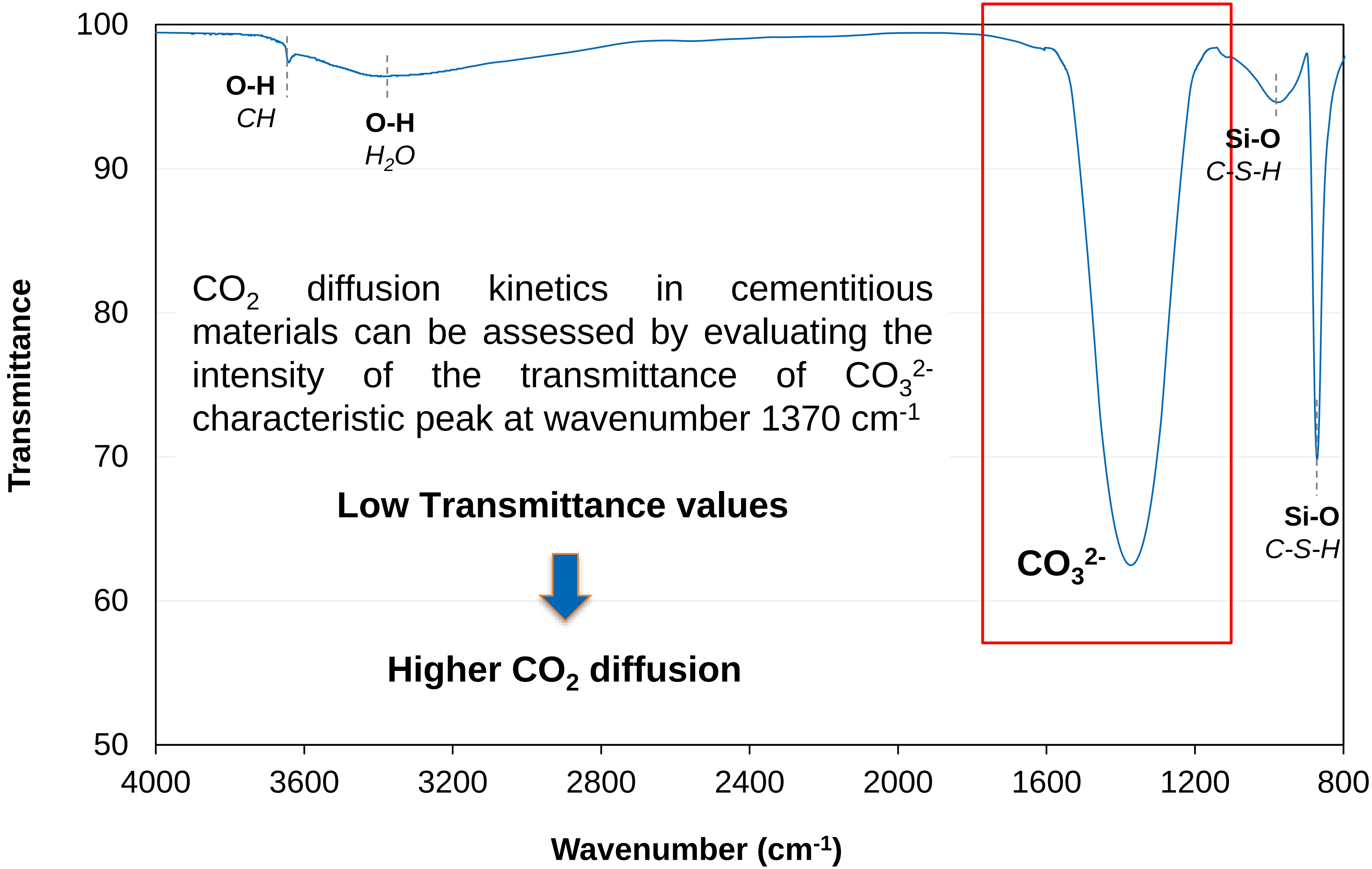


Linear Elastic Fracture Mechanics
ASTM C1609 - 19a
ACI 544R
RILEM TC 162



Uniaxial Compression
ASTM C39

CO_2 Diffusion Kinetics in Concrete
28-days



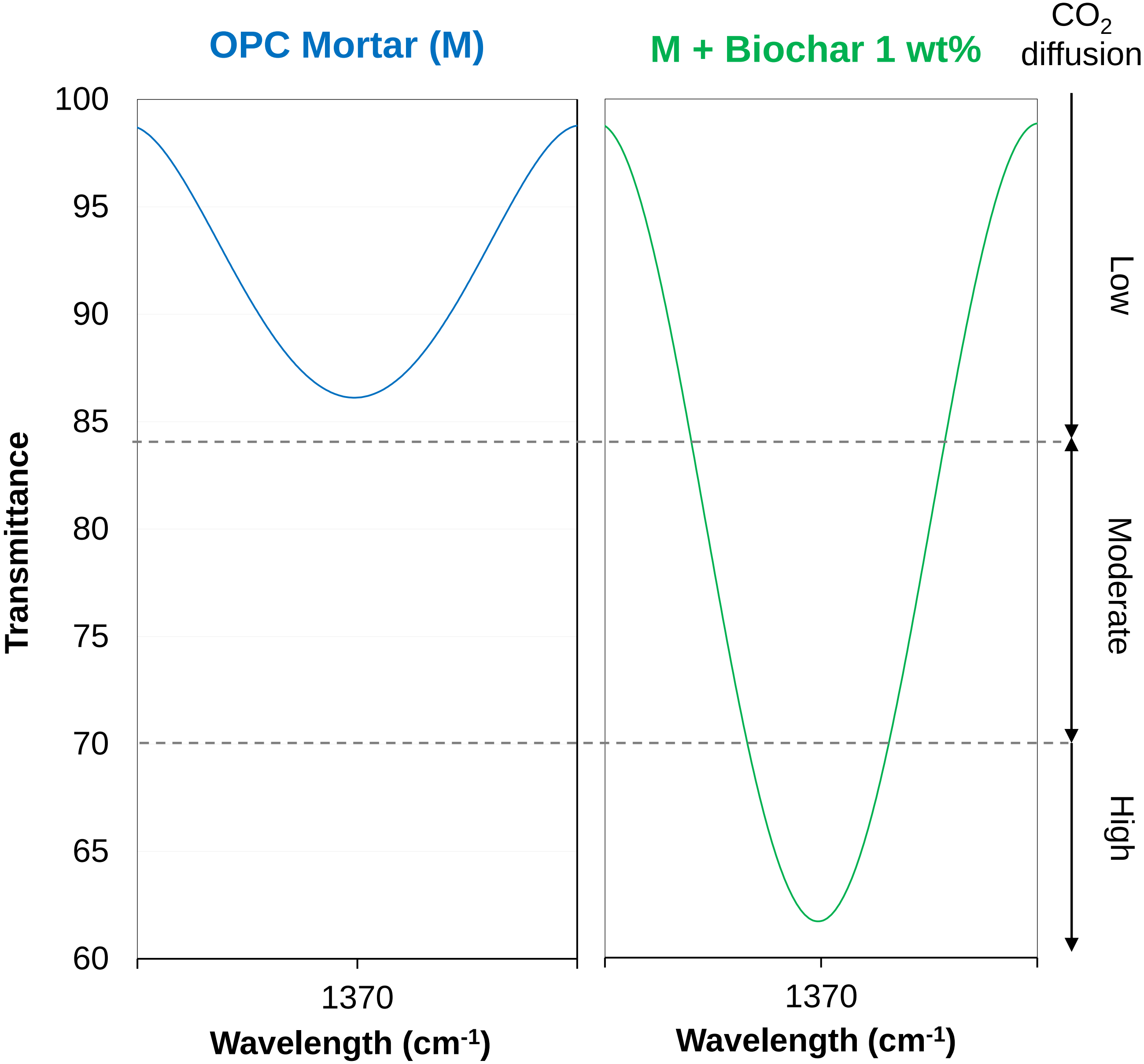
CO_2 diffusion kinetics in cementitious materials can be assessed by evaluating the intensity of the transmittance of CO_3^{2-} characteristic peak at wavenumber 1370 cm^{-1}

Low Transmittance values

Higher CO_2 diffusion

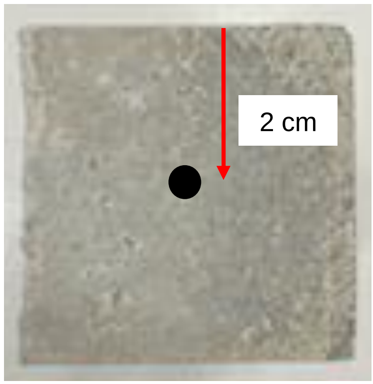
CO_2 Diffusion in Biochar OPC Concrete

28-days of Carbonation



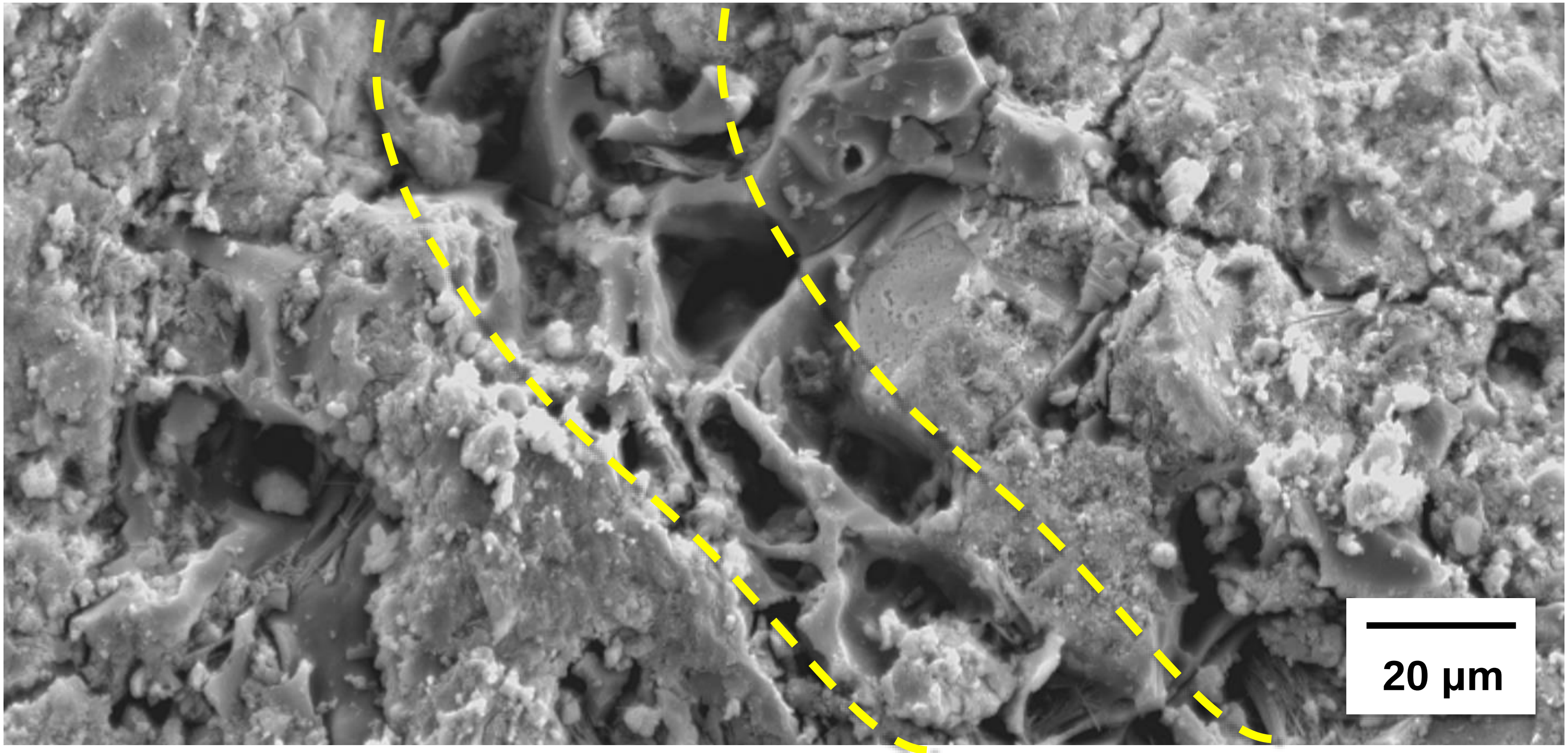
M + Biochar 1 wt% exhibits transmittance peak values at the wavelength of 1370 cm^{-1} around 62

High CO_2 diffusion



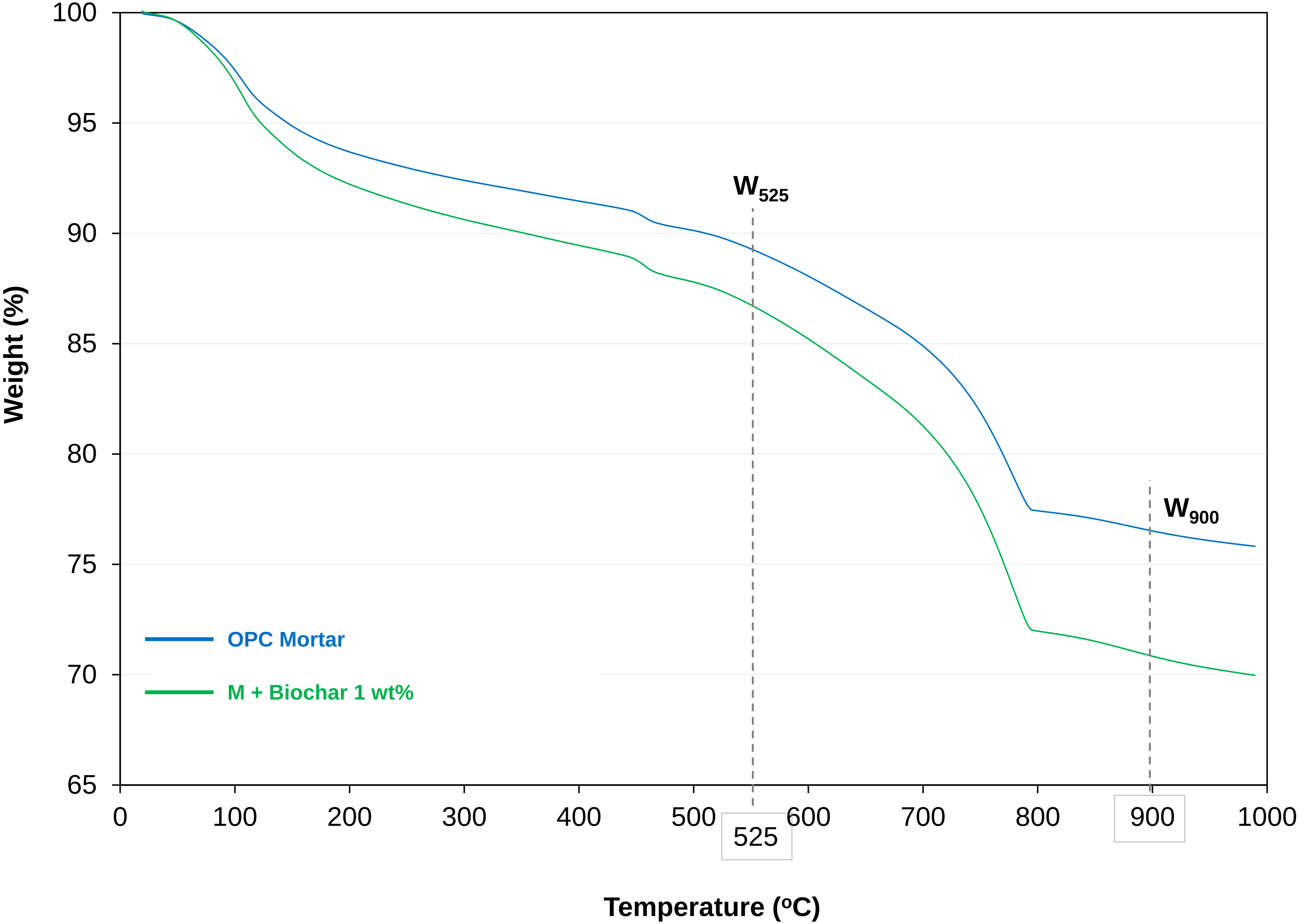
4x4 cm^2 Cross sectional area of mortar prism

Channels for CO_2 Diffusion in Biochar Concrete

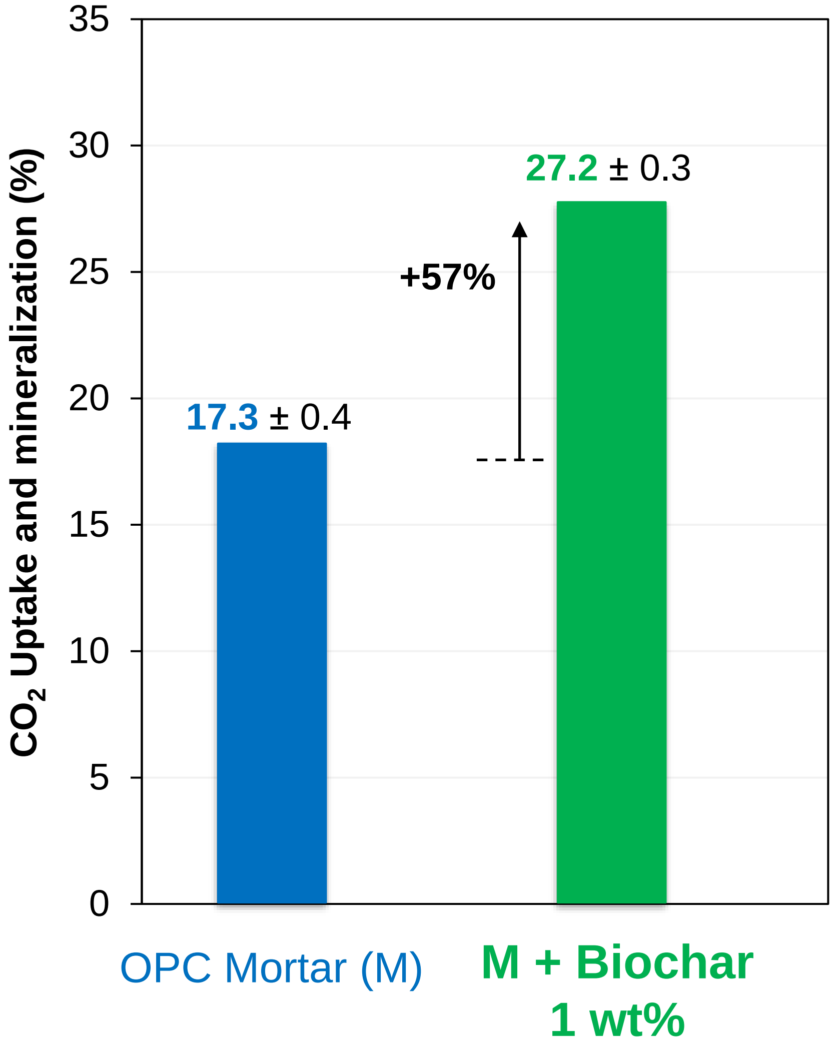


Porous biochar channels for CO_2 diffusion

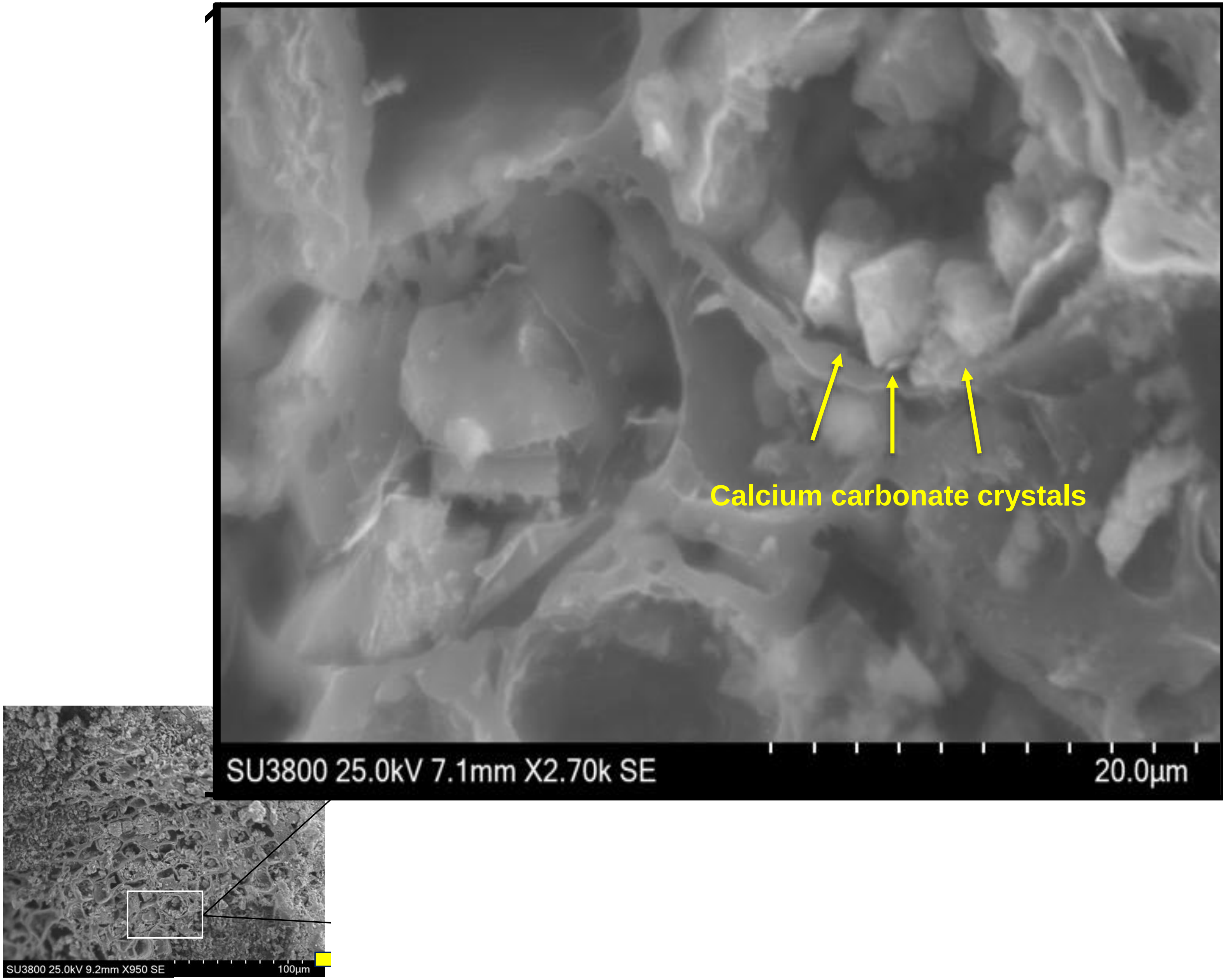
Thermogravimetric Analysis of 28-day Biochar Mortar specimens



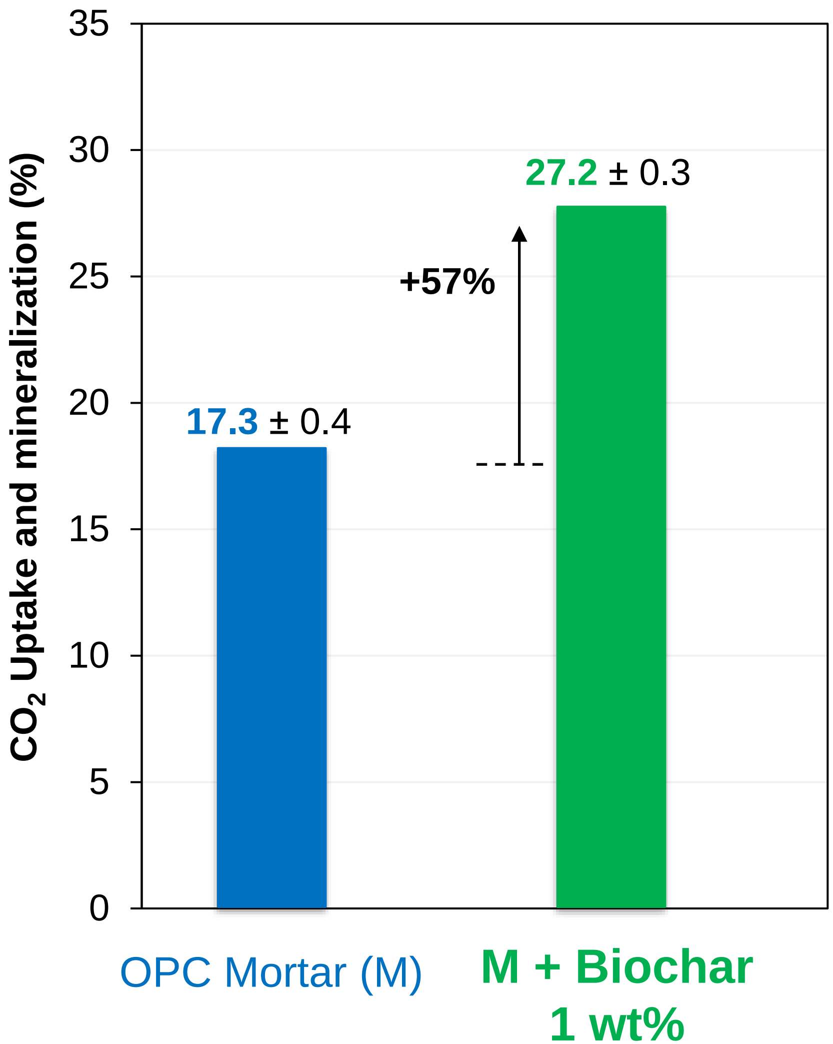
CO_2 Uptake and Mineralization of Biochar Mortar



Precipitation of Calcium Carbonates in Biochar



CO_2 Emissions – Sequestration of Biochar Mortar

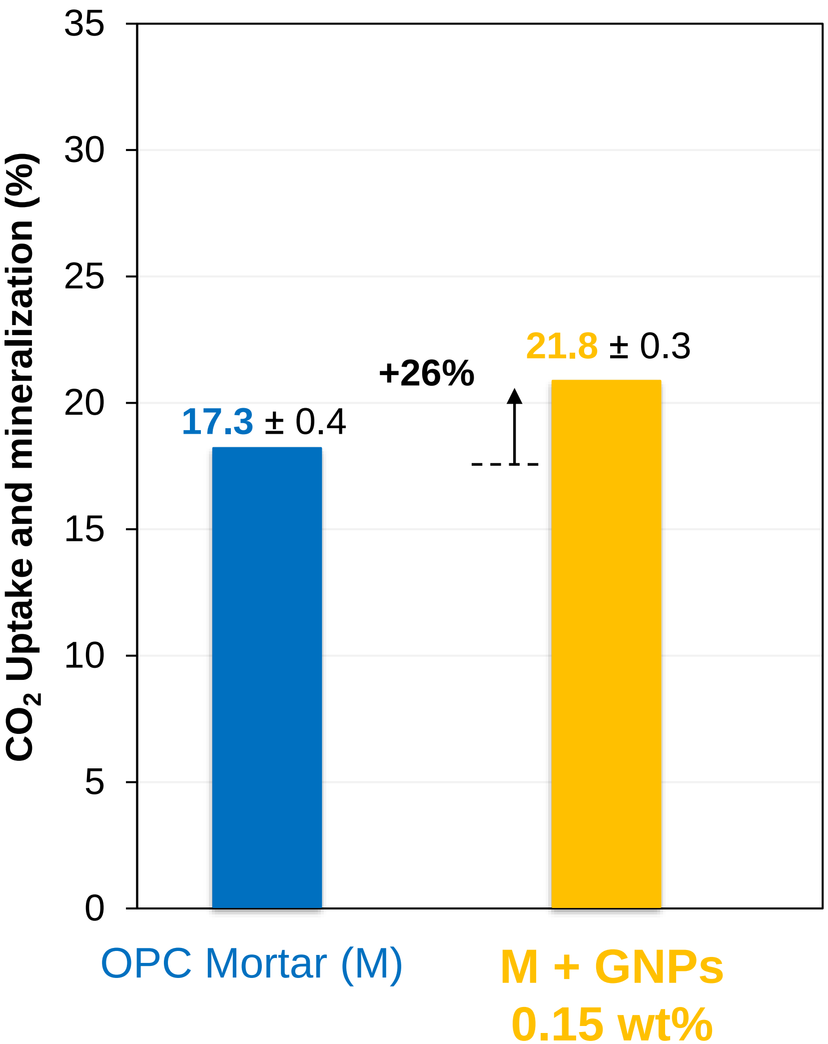


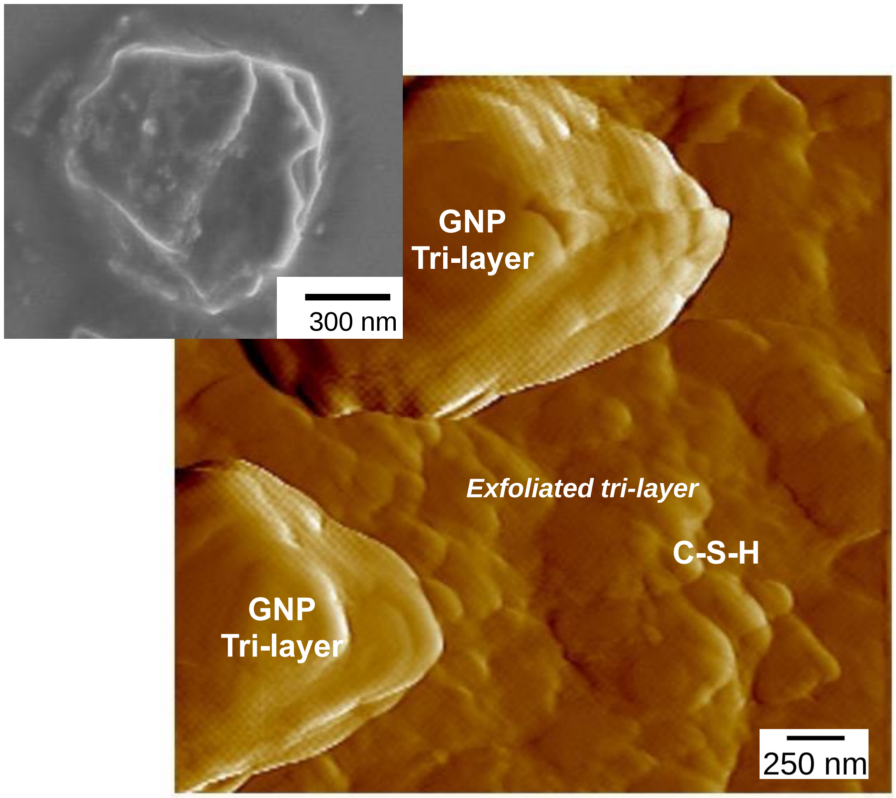
	OPC Mortar	Mortar + Biochar
CO_2 emissions (lbs/yd^3)	590	590
CO_2 sequestration (lbs/yd^3)	10	590 - 595

+580 CO_2 lbs/yd^3

– 5 CO_2 lbs/yd^3

Effect of GNPs on the CO_2 Uptake and Mineralization Capacity of Mortar

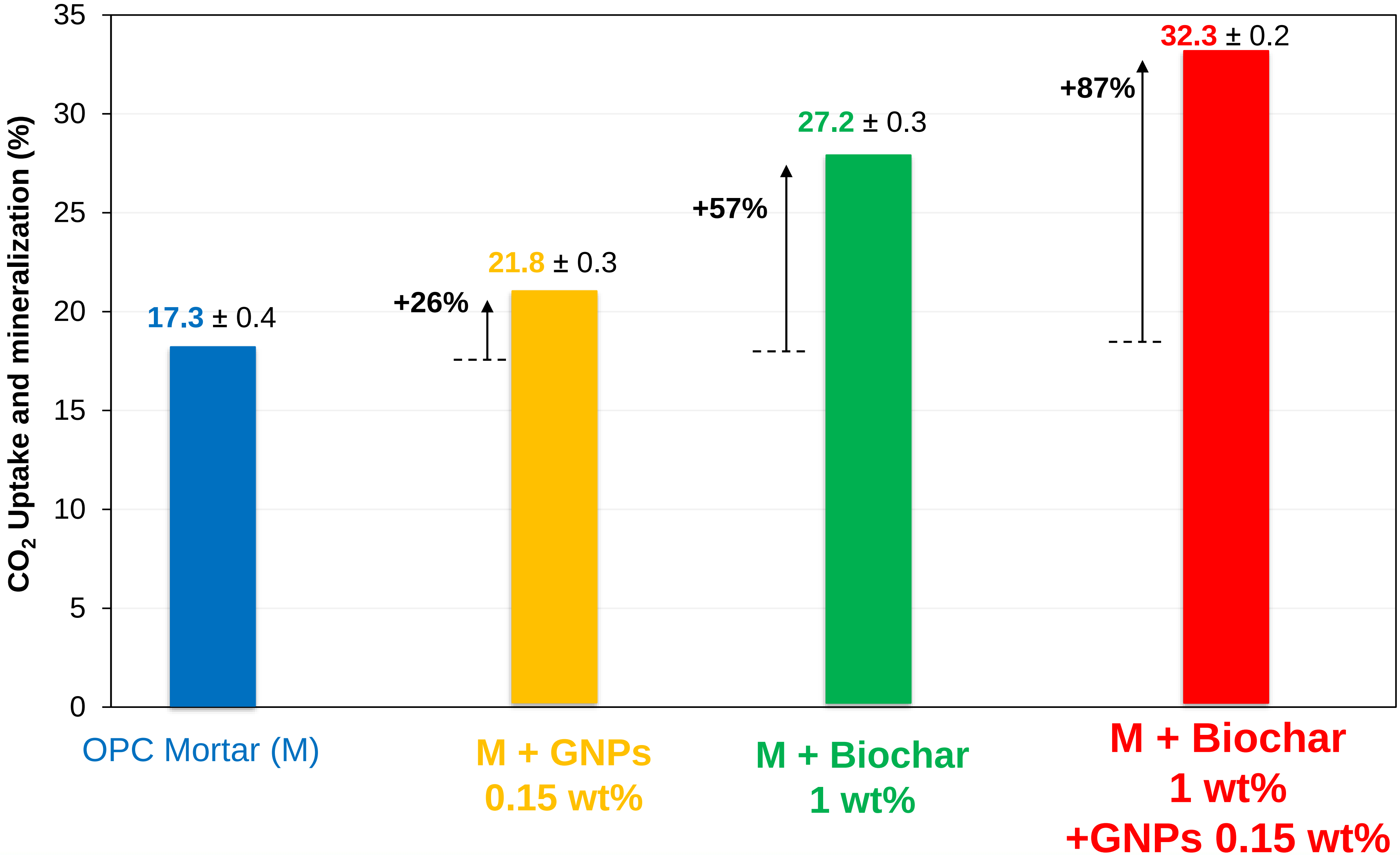




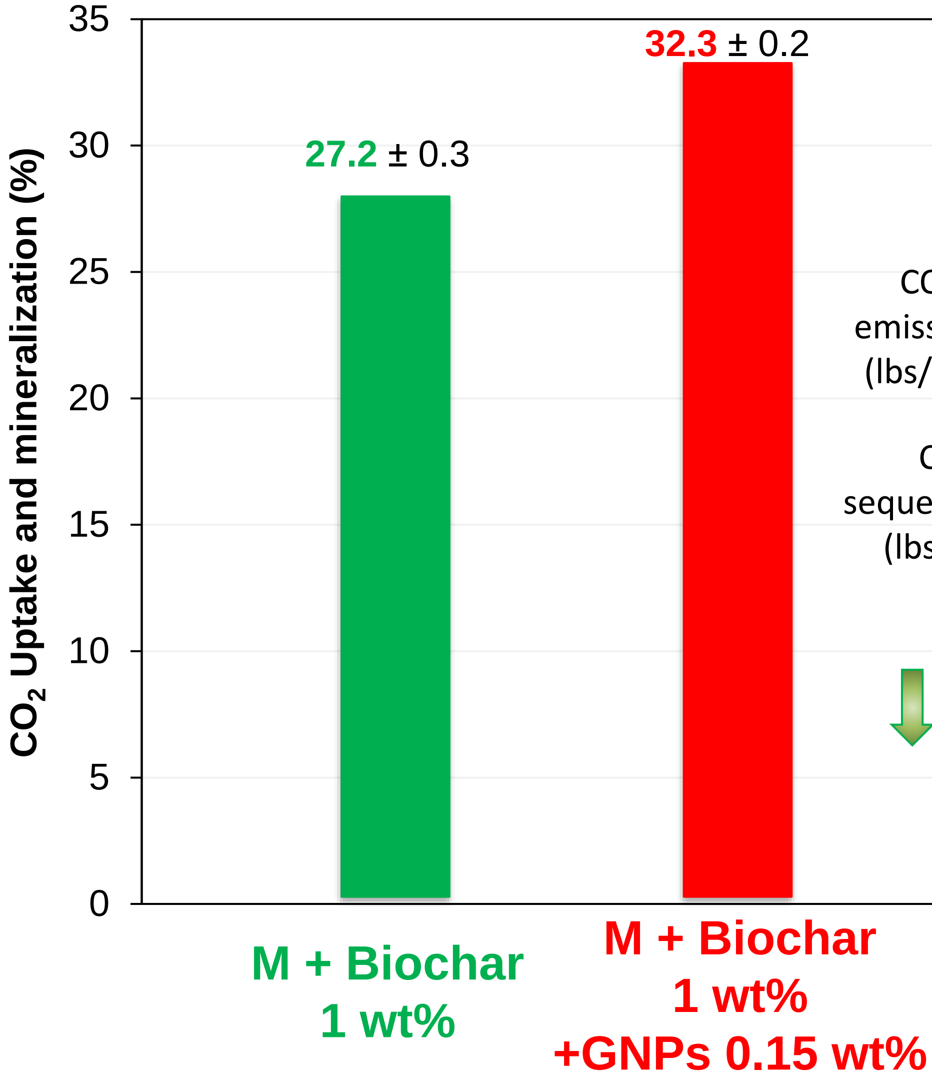
GNP surface area: 500 -2500 m^2/g

	Thickness (nm)	Lateral Dimension (μm)	Purity (%)
GNPs *Tri-layer*	15	2	99

CO_2 Uptake and Mineralization ($CaCO_3$) of GNP - Biochar Mortar



CO_2 Emissions – Sequestration of GNP - Biochar Mortar

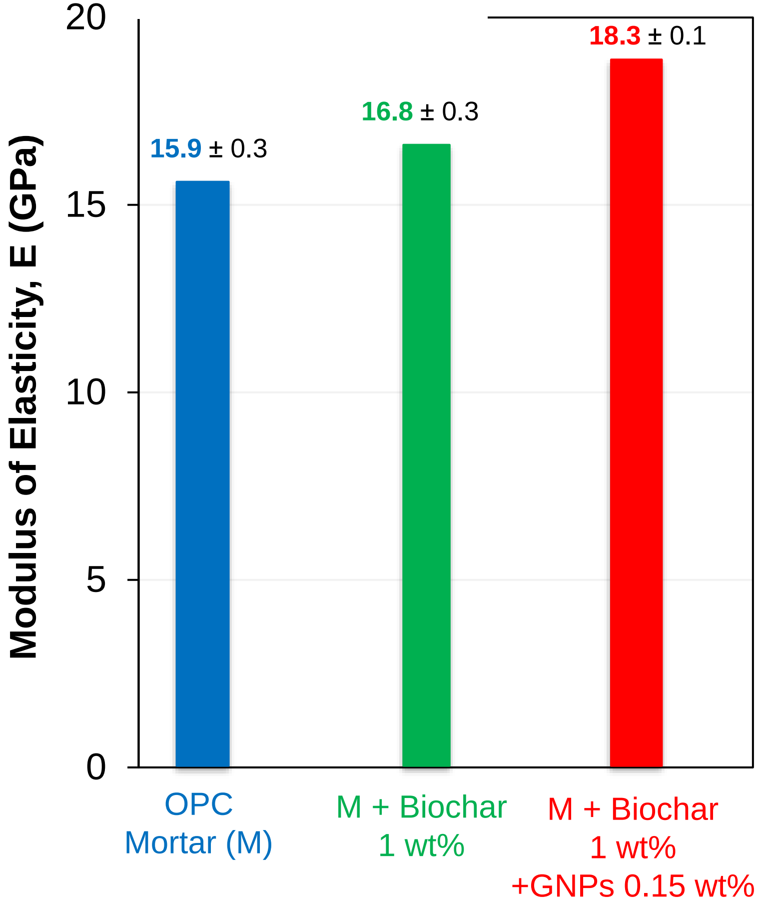


	Biochar Mortar	GNP-Biochar Mortar
CO_2 emissions (lbs/yd^3)	590	590
CO_2 sequestration (lbs/yd^3)	590 - 595	630 - 645
	– 5 CO_2 lbs/yd^3	– 55 CO_2 lbs/yd^3

Modulus of Elasticity of Carbonated GNP – Biochar Mortar

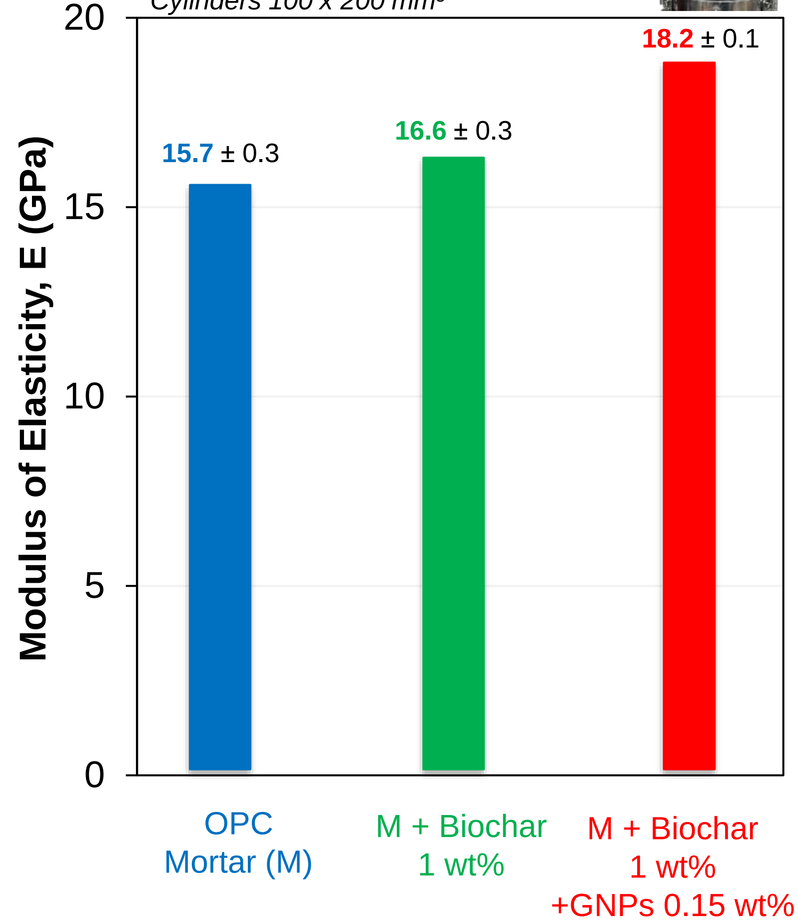
3 Point Bending

28d
Notched 100 x 100 x 350 mm³

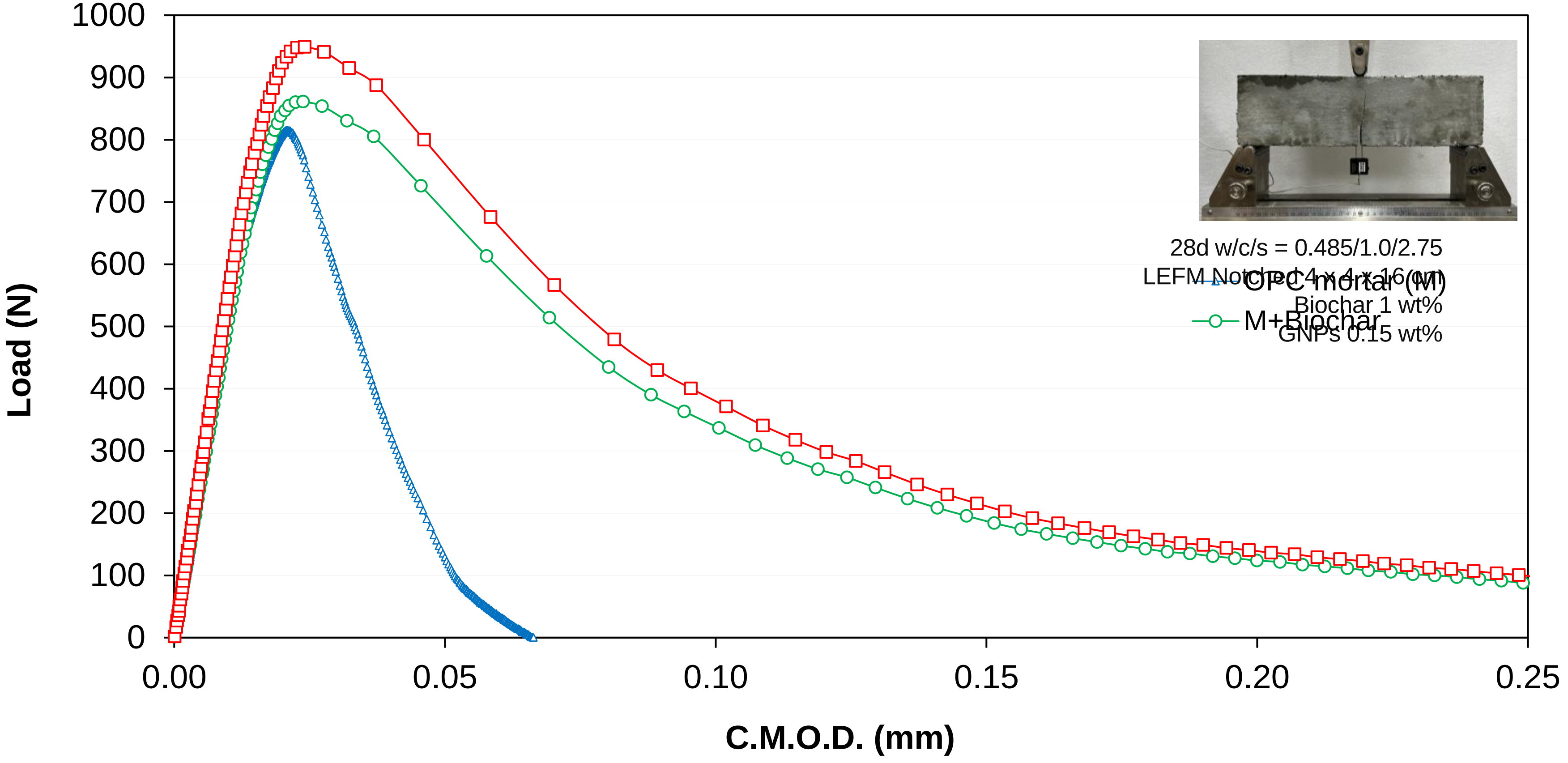


Uniaxial Compression

28d
Cylinders 100 x 200 mm³



Ductility of Carbonated Mortars
Strain Energy Absorption Capability



Flexural toughness (N-mm)

OPC Mortar (M)	**40 N-mm**	M + Biochar 1 wt%	**115 N - mm**	M + Biochar 1 wt% +GNPs 0.15 wt%	**125 N - mm**

ASTM C1609
ACI 544R Report on Fiber Reinforced Concrete

2x Higher Ductility of CO_2 cured GNP Reinforced Biochar-OPC Mortar

CO_2 cured OPC Mortar | **GNP Reinforced Biochar-OPC Mortar**

Fractured surface showing the (a) linear crack propagation of CO_2 cured OPC mortar and (b) the tortuous crack pathway of CO2 cured GNP reinforced biochar OPC mortar

Flexural toughness (N-mm)

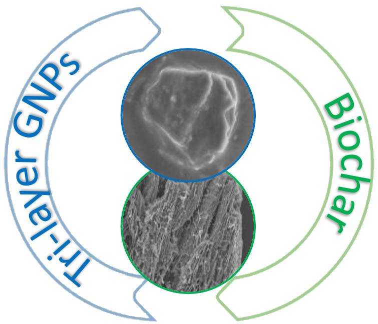
OPC Mortar (M)	**40 N-mm**
M + Biochar 1 wt%	**115 N - mm**
M + Biochar 1 wt% +GNPs 0.15 wt%	**125 N - mm**

✓ Angular and fibrillar morphology of biochar

✓ Hexagonal, honeycomb-like structure of GNPs

contribute to the development of more tortuous and articulated crack paths resulting in a more ductile behavior of the CO_2 cured composite

Conclusions



✓ GNPs 0.15 wt%

Extraordinary surface area and hexagonal structure

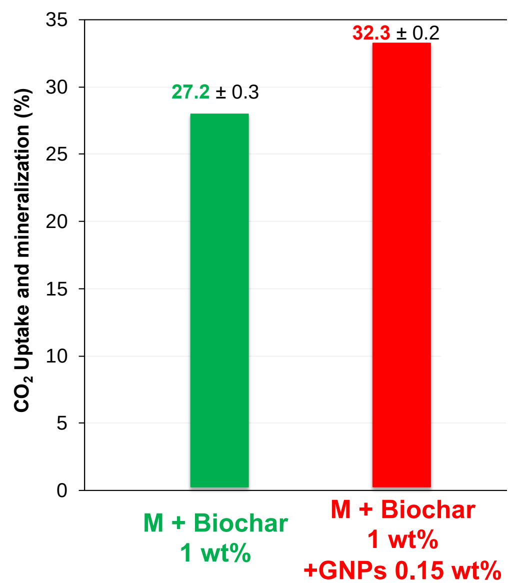
✓ Biochar 1.0 wt%

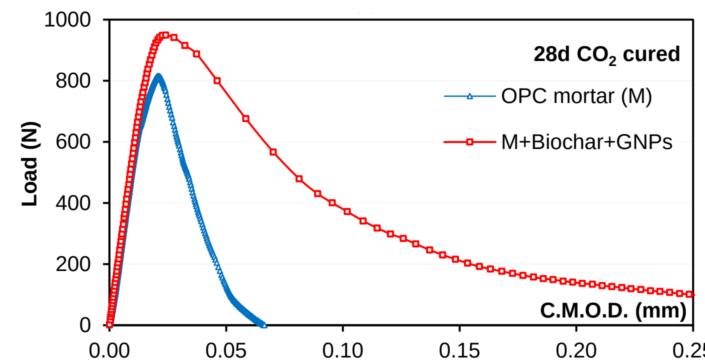
Unique 3D porous structure and fibrillar morphology

	Biochar Mortar	GNP-Biochar Mortar
O_2 sions /yd³)	590	590
CO_2 estration s/yd³)	590 - 595	630 - 645
	– 5 CO_2 lbs/yd³	– 55 CO_2 lbs/yd³

Higher CO_2 Diffusion Kinetics

+87% CO_2 Storage and Mineralization





Enhanced Resiliency

✓ +16% Modulus of Elasticity

Enhanced Ductility

✓ >2x higher toughness indices

Due to the development of more tortuous crack paths

Acknowledgements

Center for Advanced Construction Materials

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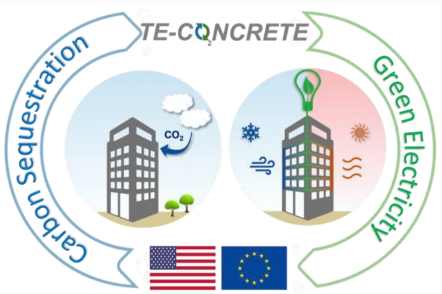

Advancing International Partnerships in Research for Decoupling Concrete Manufacturing and Global Greenhouse Gas Emissions

National Science Foundation

Partnerships for International Research and Education (PIRE)

Thank you!

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