UTA
Center for Advanced Construction Materials

The role of graphene-based nanomaterials for enhancing CO_2 uptake and mineralization in engineered concrete

Maria S. Konsta-Gdoutos[1], Panagiotis A. Danoglidis[2]

[1]*Professor of Civil Engineering, Associate Director, Center for Advanced Construction Materials*
maria.konsta@uta.edu

[2]*Assistant Professor of Research, Department of Civil Engineering, Center for Advanced Construction Materials*
panagiotis.danoglidis@uta.edu

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

2D Graphene Nanoplatelets in Concrete

2 – 3x higher specific surface area
than the surface area of cementitious grains

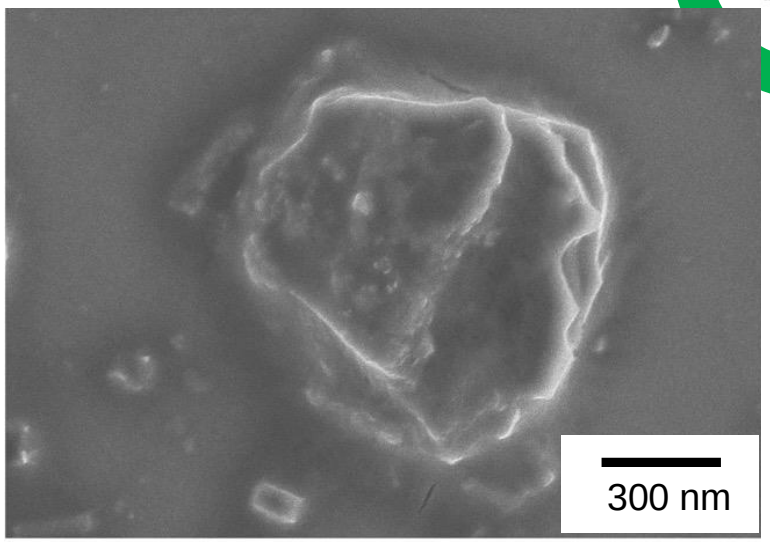
Functionalized surface area
with carboxyl and hydroxyl groups

↓

Platform for surface chemistry

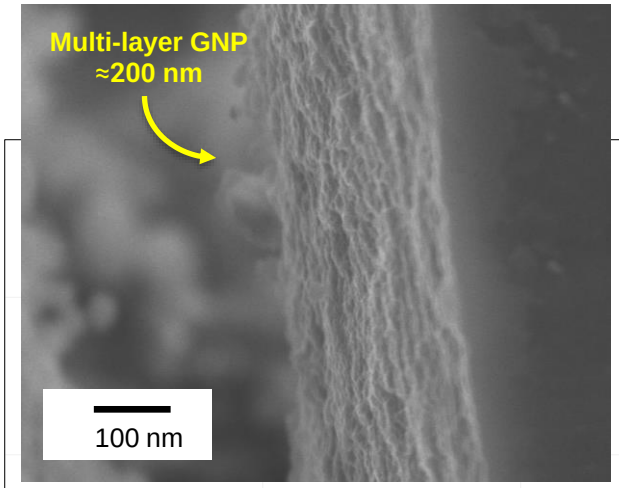
↓

Higher kinetics



✓ Control the interfacial processes at the nanostructured C-S-H/graphene interfaces

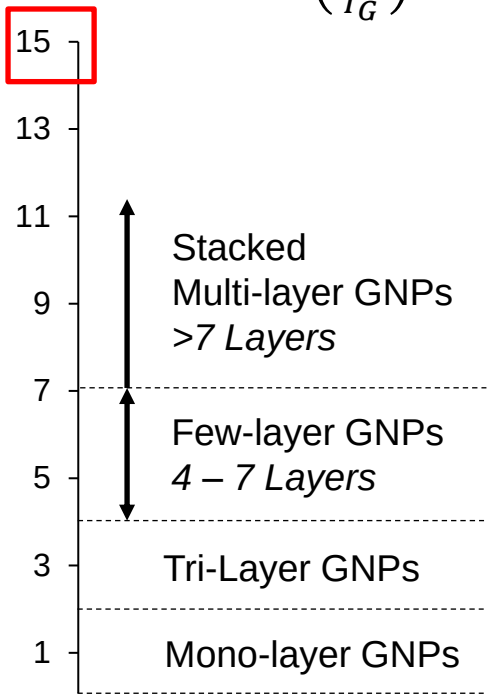
“As received” GNPs



SEM image of ”As received” GNPs showing **15 layers** of stacked graphene sheets

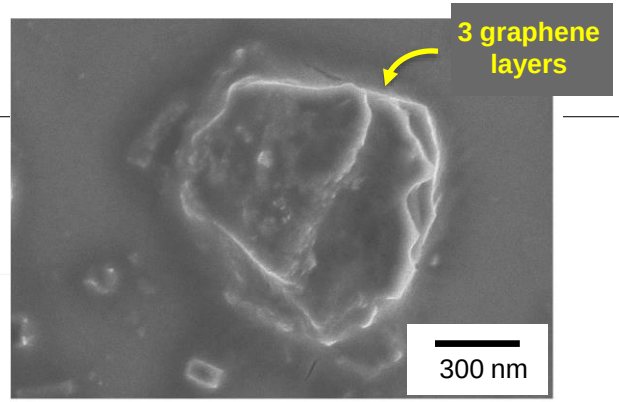
Number of Graphene Layers

$$N = 0.14\left(\frac{I_{2D}}{I_G}\right)^{-4.62}$$



	Number of Layers	Thickness (nm)	Lateral Dimension (μm)
GNPs	13 - 16	200	2

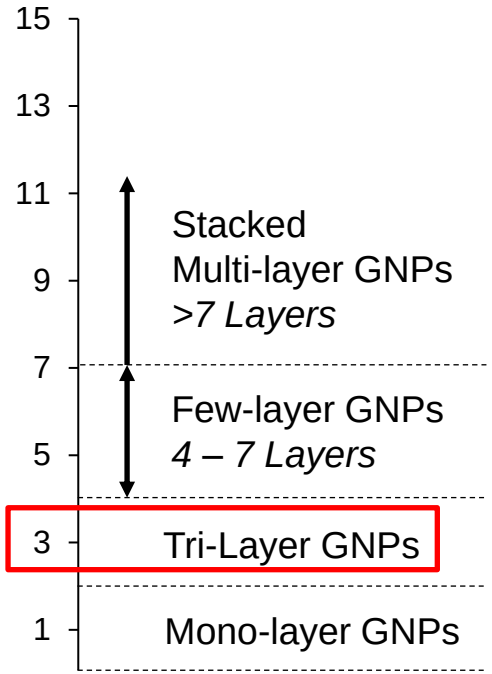
Exfoliated Tri-layer GNPs in Suspension



SEM image of exfoliated tri-layer GNP

Number of Graphene Layers

$$N = 0.14\left(\frac{I_{2D}}{I_G}\right)^{-4.62}$$



	Number of Layers	Thickness, (nm)	Lateral Dimension (μm)
GNPs	13 - 16	200	2

Materials and Experimental Program

	Number of Layers	Thickness, (nm)	Lateral Dimension (μm)
GNPs	13 - 16	200	2

Exfoliation of GNPs

- Controlled Ultrasonication Energy Method

28-day Cement Pastes and Mortars

w/c/s: 0.485
OPC Type I
Sand ASTM C779
GNPs: 0.15 vol%

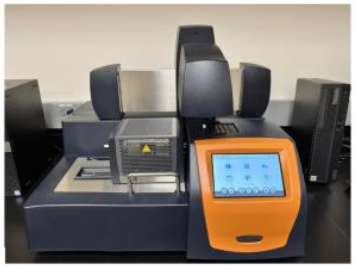
CO_2 curing

CO_2 12% v/v (100% purity)
65% RH
74 ^oF (23 ^oC)

Quantitative evaluation of CO_2 uptake and mineralization

Macro-scale

Thermogravimetric analysis
Quantitative evaluation of CO_2 uptake and mineralization



✓ OPC Mortar (M)
✓ M + GNPs exfoliated
✓ M + GNPs as received

ASTM C1872 - 18

Nano-scale

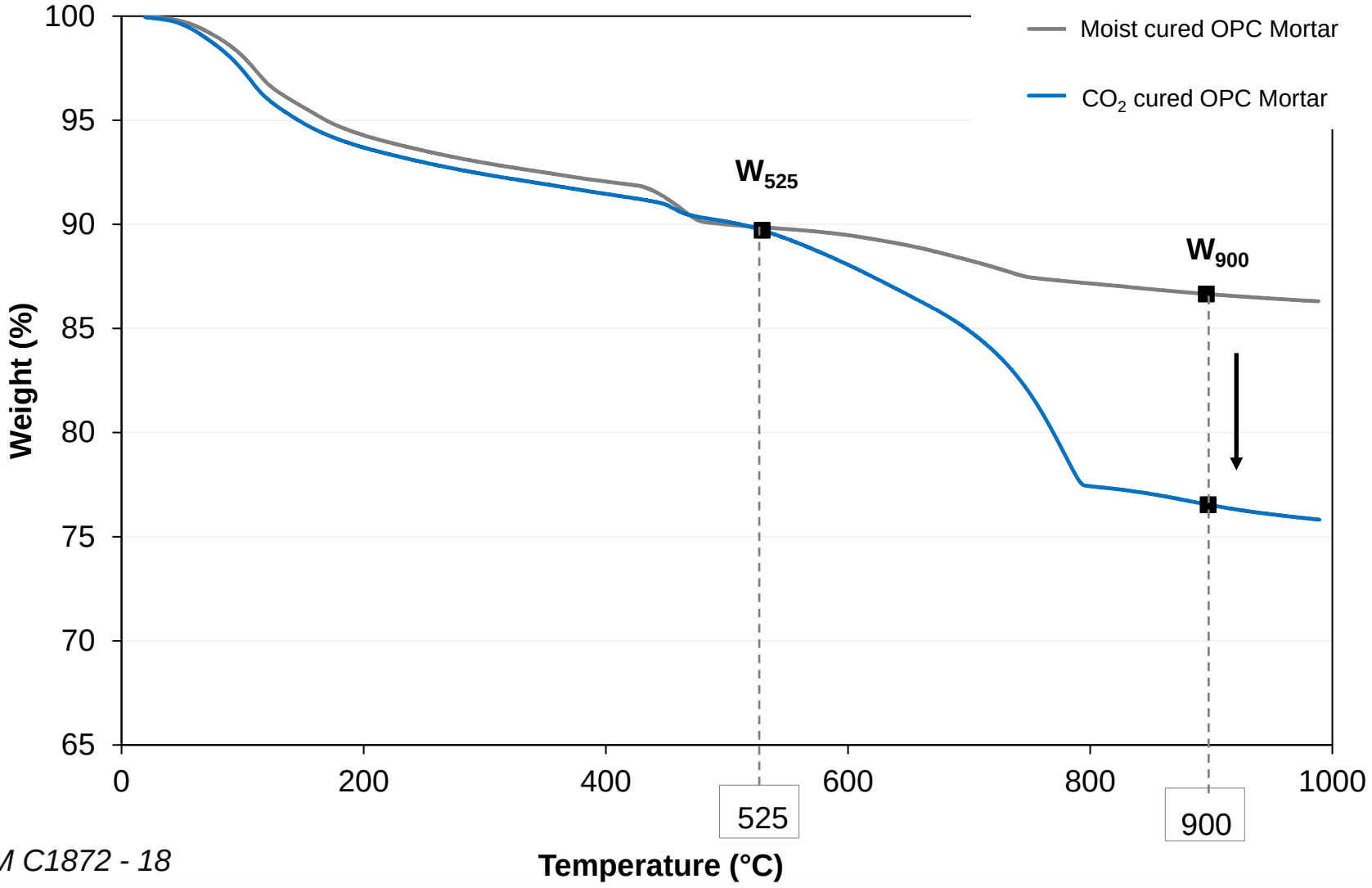
NanoIR AFM (Sub-10 nm)
Chemical Imaging/Mapping on

GNP reinforced cement pastes

Specimens
Diameter: 1.2" (30 mm)
Height: 0.6" (14mm)

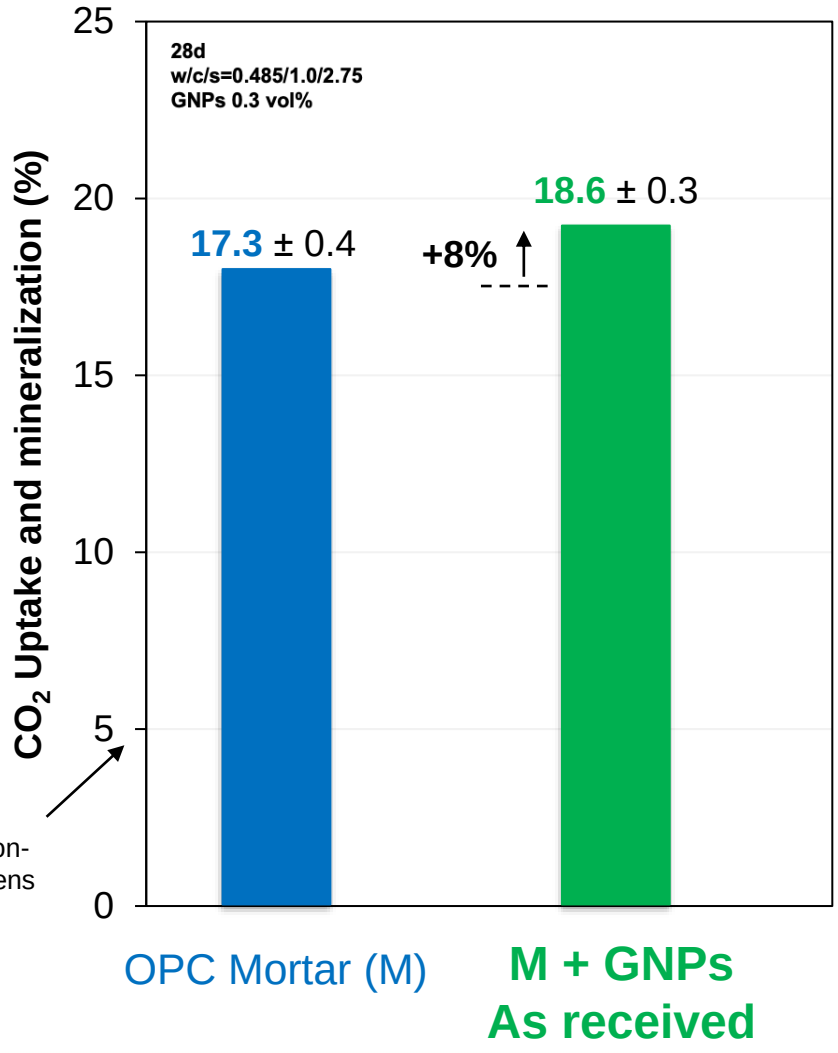
Thermogravimetric Analysis of 28-day OPC Mortars

Moist Cured and CO_2 Cured OPC Mortars



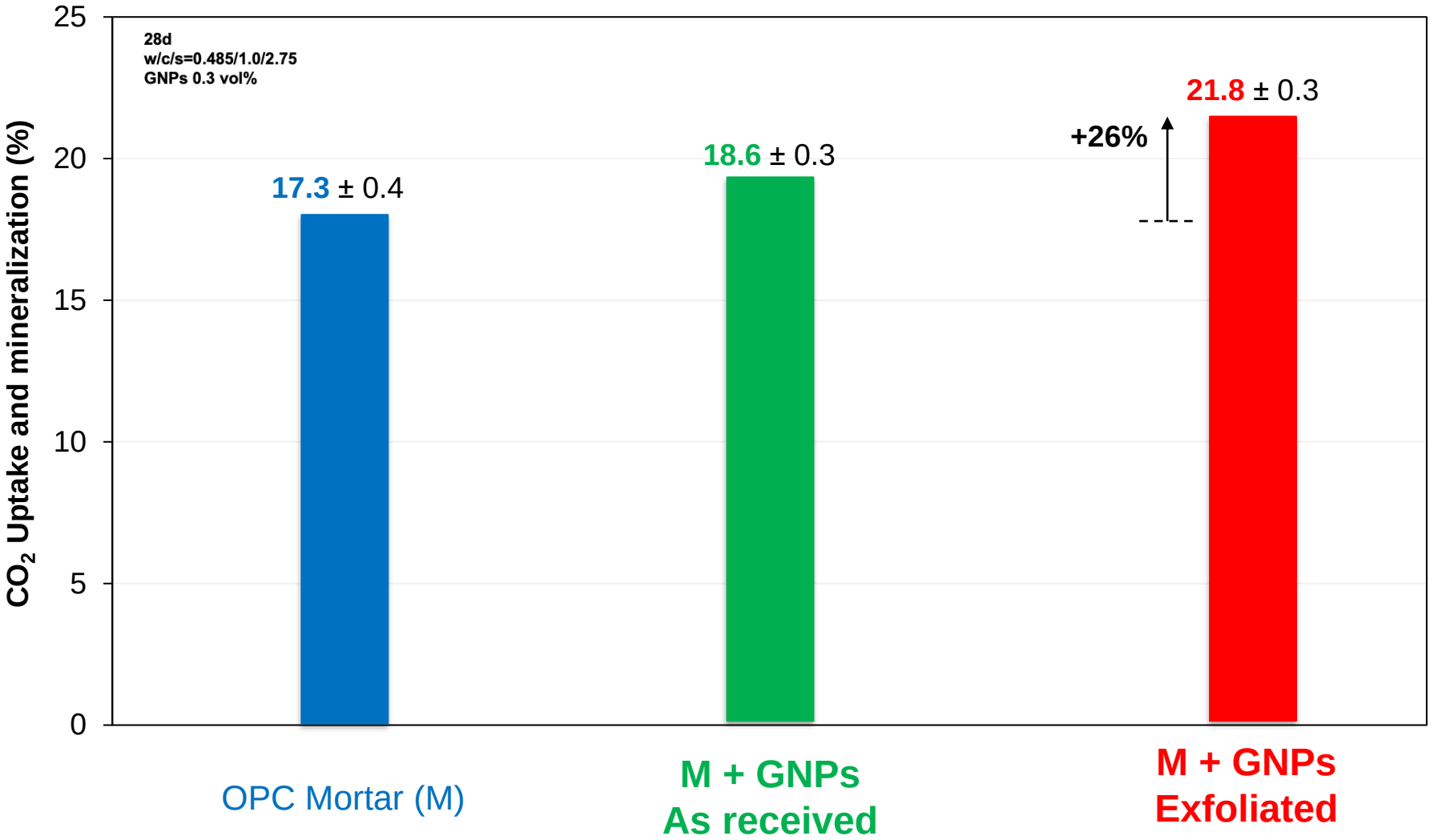
ASTM C1872 - 18

CO_2 Uptake and Mineralization of 28-day Carbonated Specimens



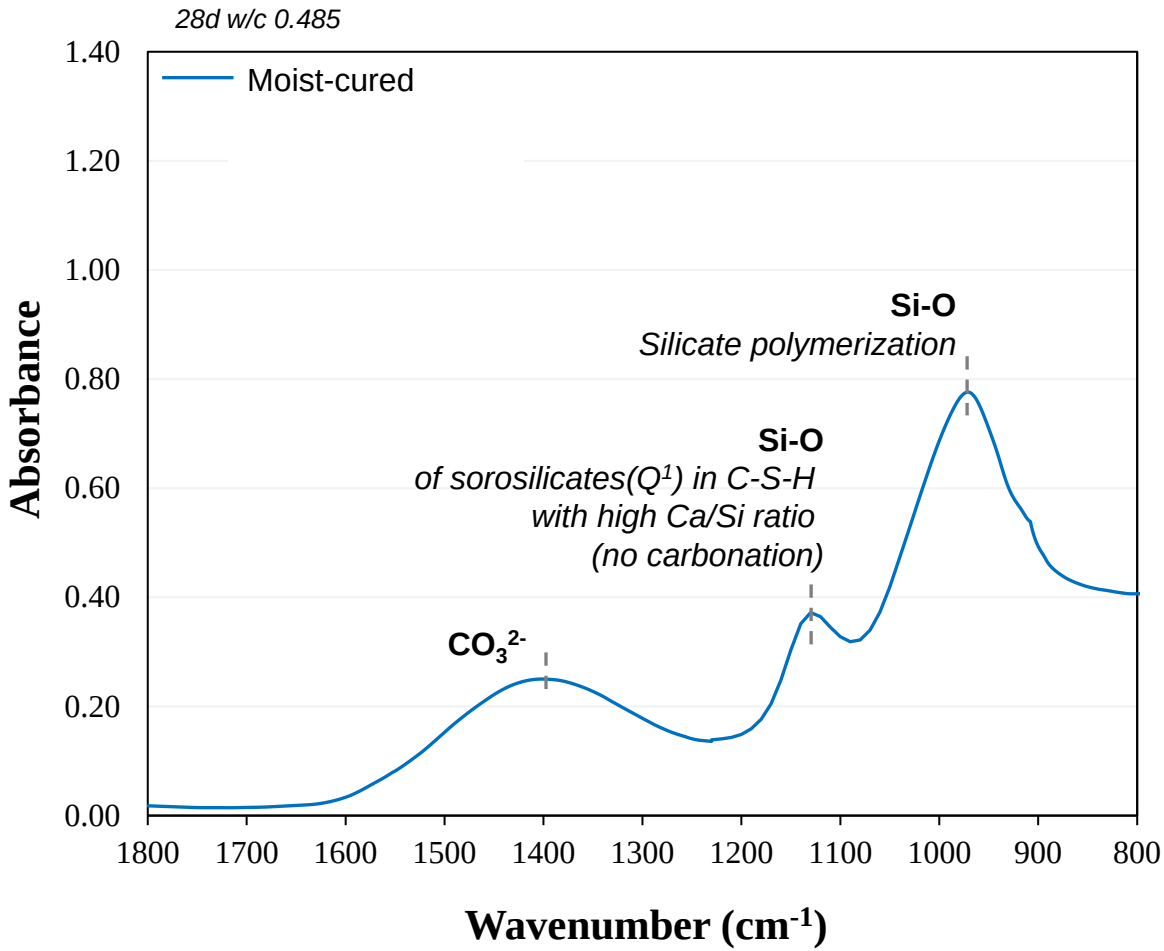
CO_2 uptake and mineralization of non-carbonated specimens

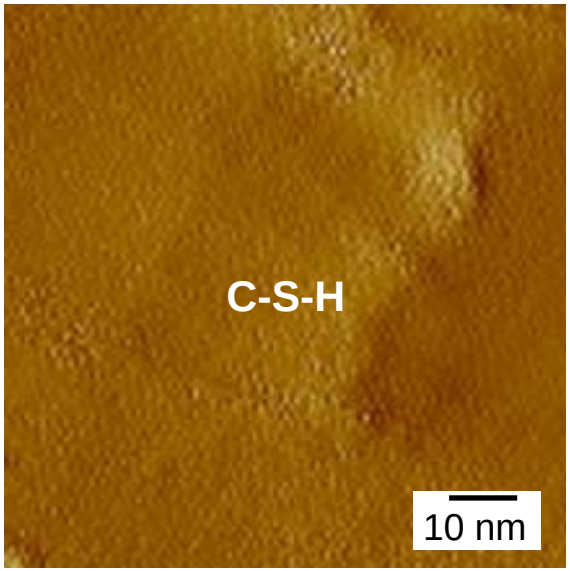
CO_2 Uptake and Mineralization of 28-day Carbonated Specimens



Sub-10nm IR Spectrum of Cement Paste

Moist-cured specimens

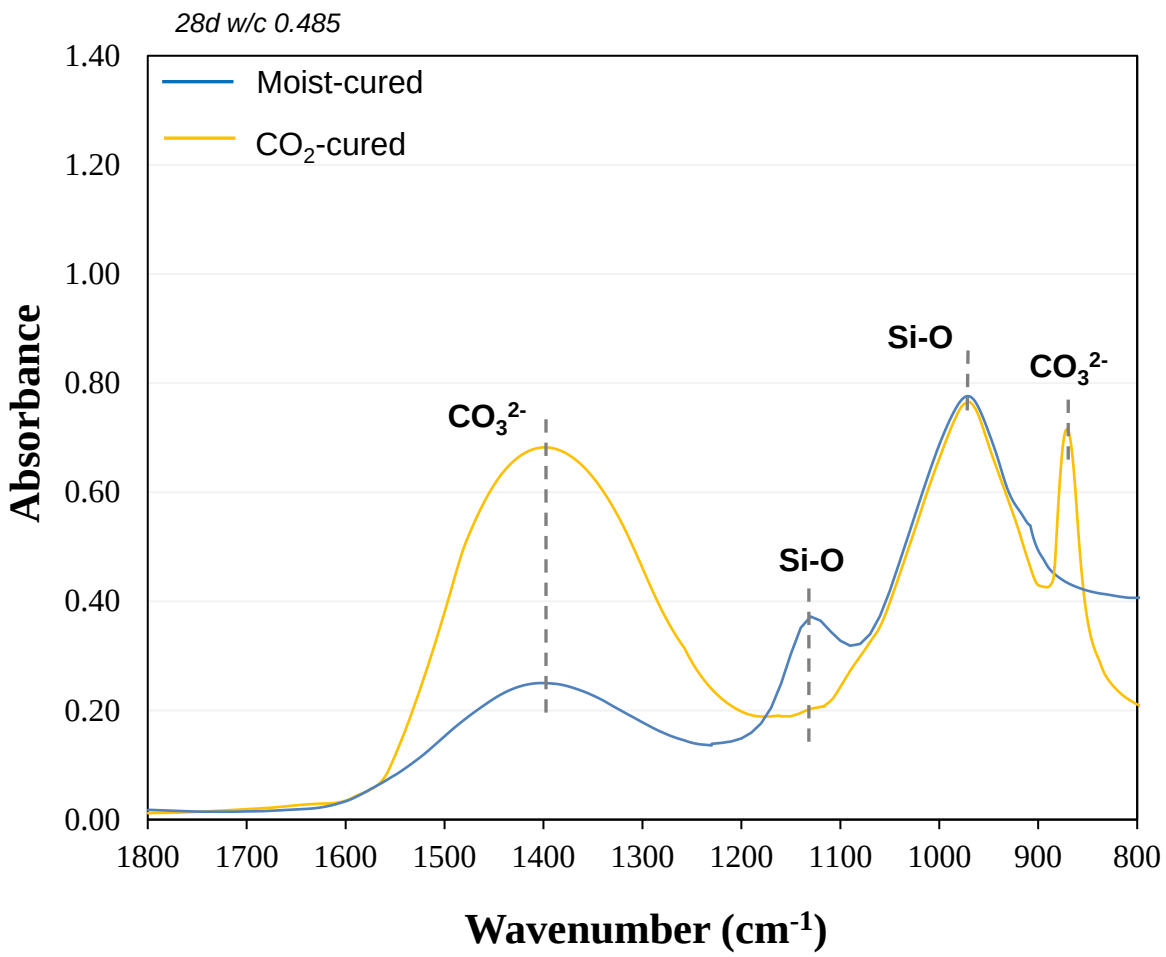


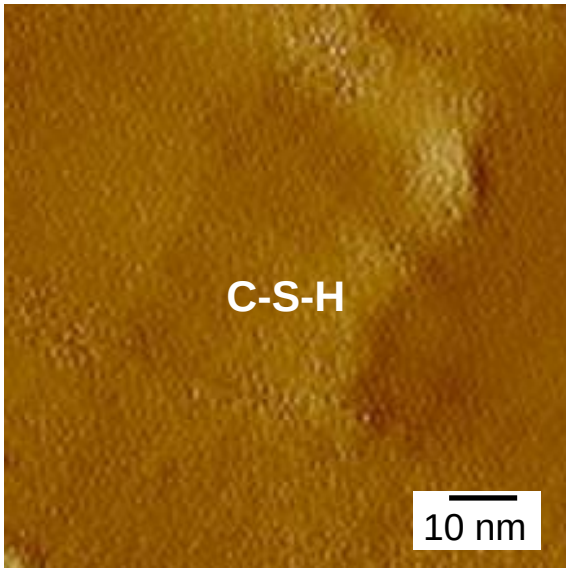


Moist-cured Cement Paste

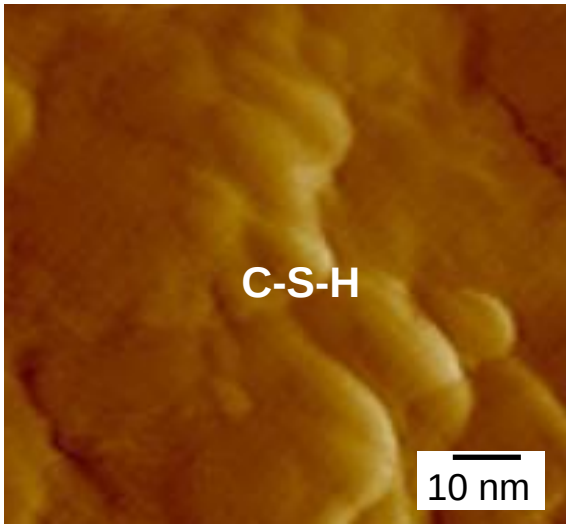
Sub-10nm IR Spectrum of Cement Paste

CO_2-cured specimens



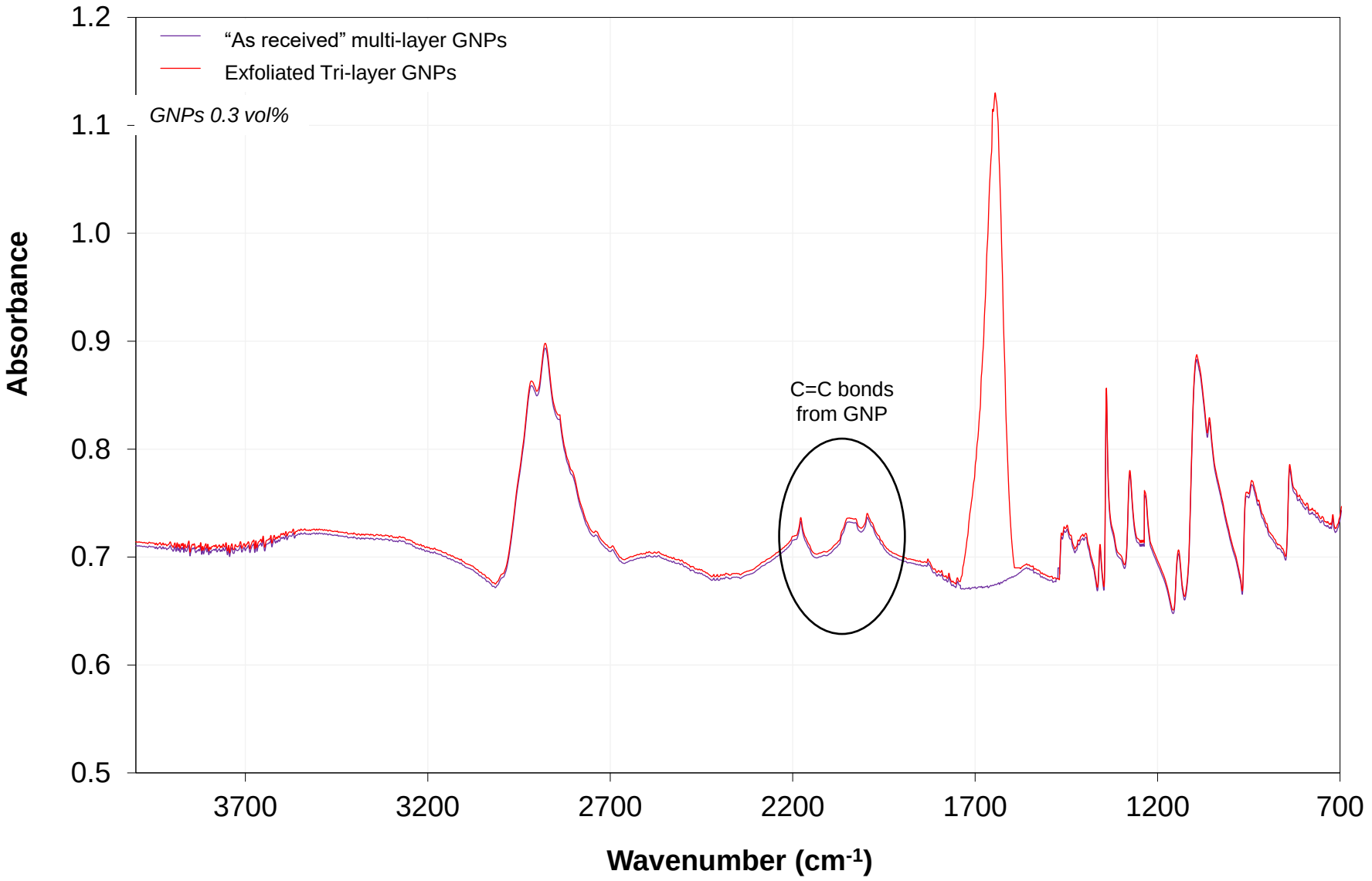


Moist-cured Cement Paste



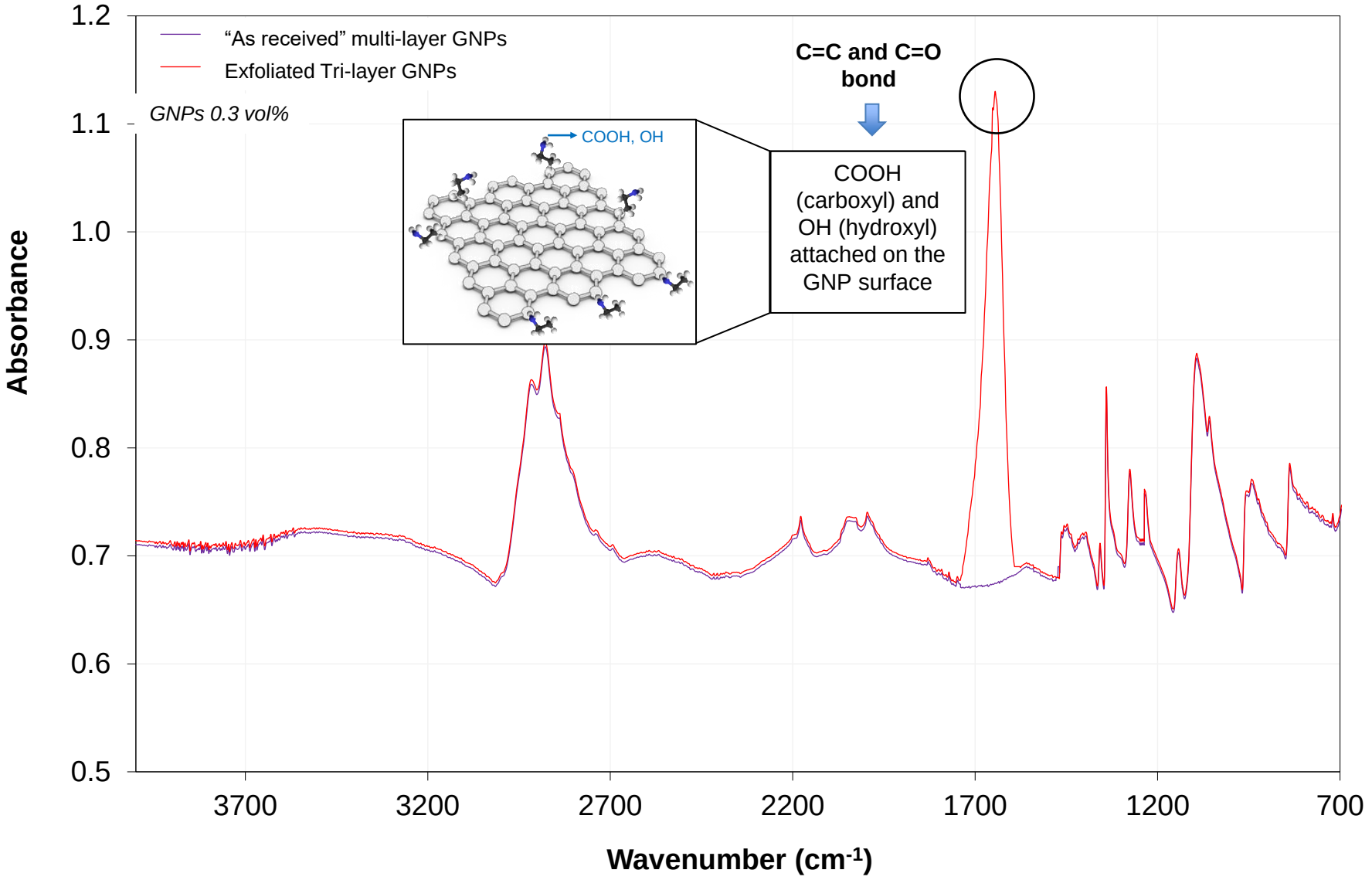
CO_2-cured Cement Paste

Functionalization of GNPs with carboxyl and hydroxyl groups



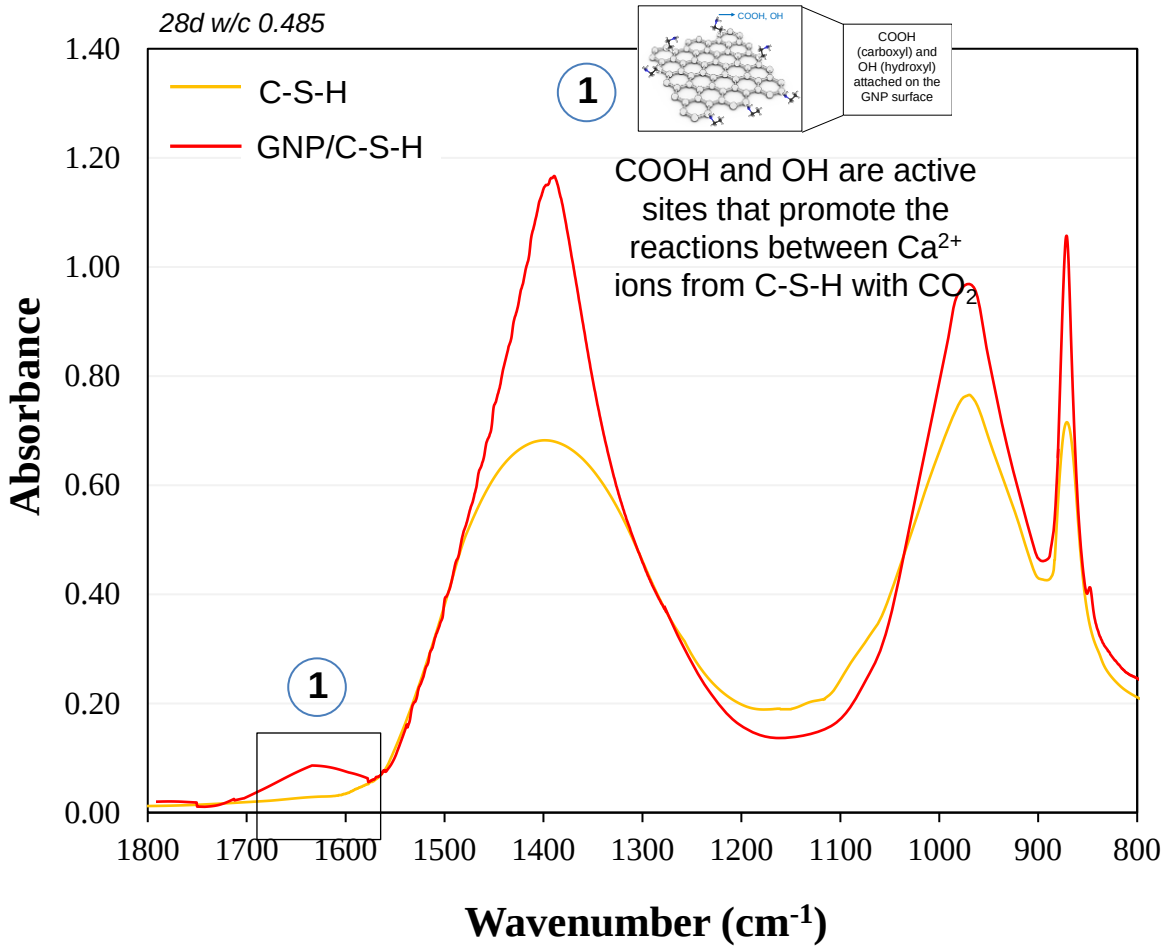
Functionalization of GNPs with carboxyl and hydroxyl groups

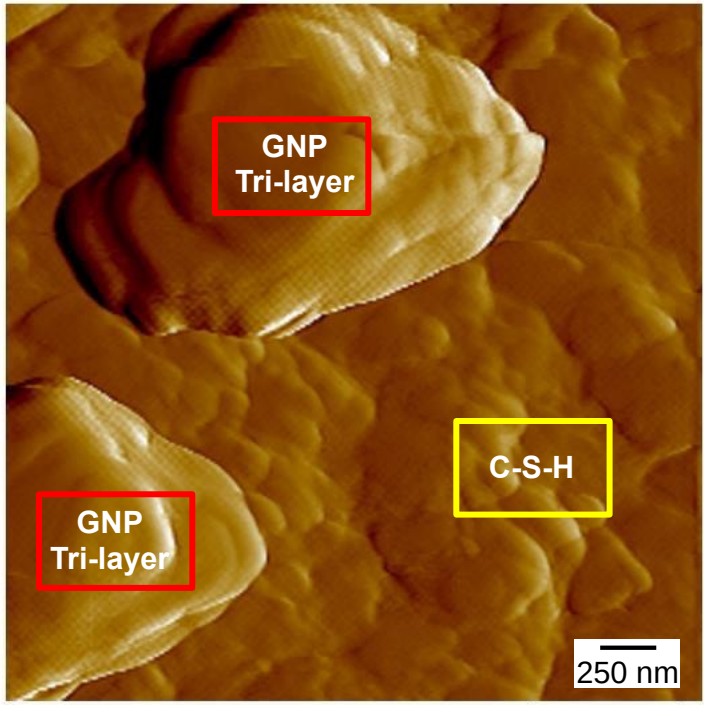
New Chemical Bond in FTIR



Sub-10nm IR Spectrum of GNP Reinforced Cement Paste

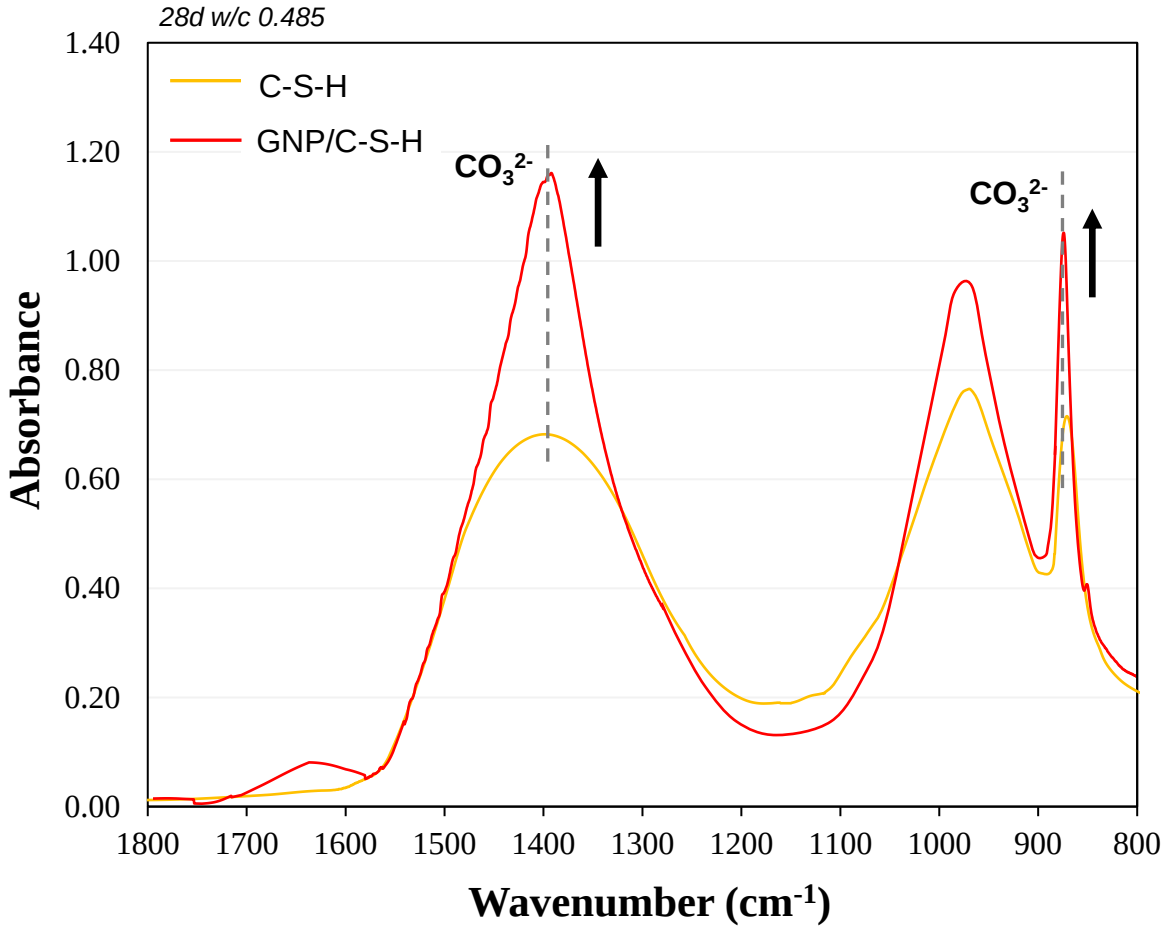
CO_2-cured specimens





Sub-10nm IR Spectrum of GNP Reinforced Cement Paste

CO_2-cured specimens

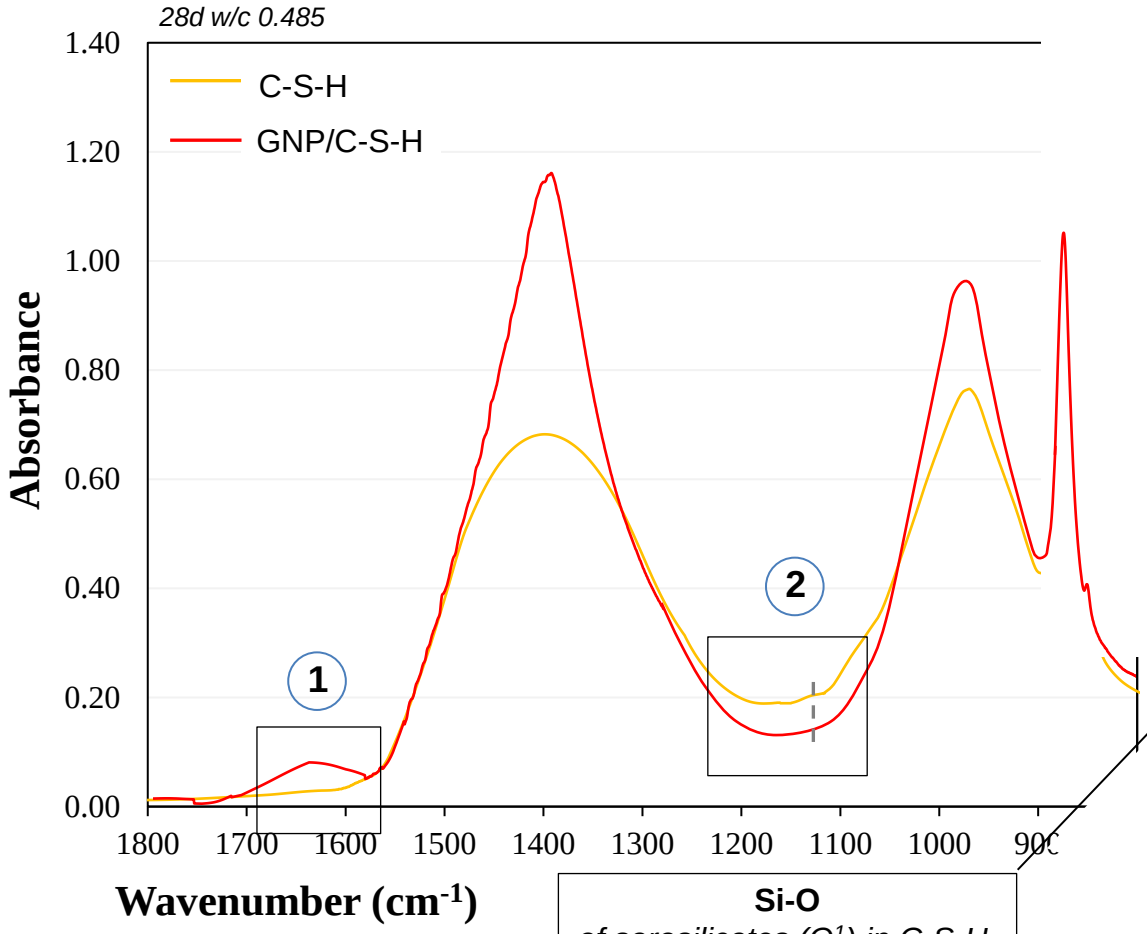


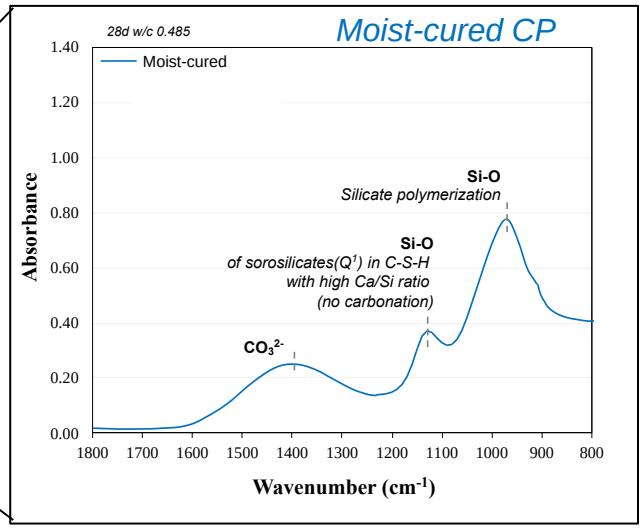
+60 – 75% higher absorbance intensity in CO_3^{2-} characteristics peaks

Higher amounts of $CaCO_3$ (CO_2 mineralization)

Sub-10nm IR Spectrum of GNP Reinforced Cement Paste

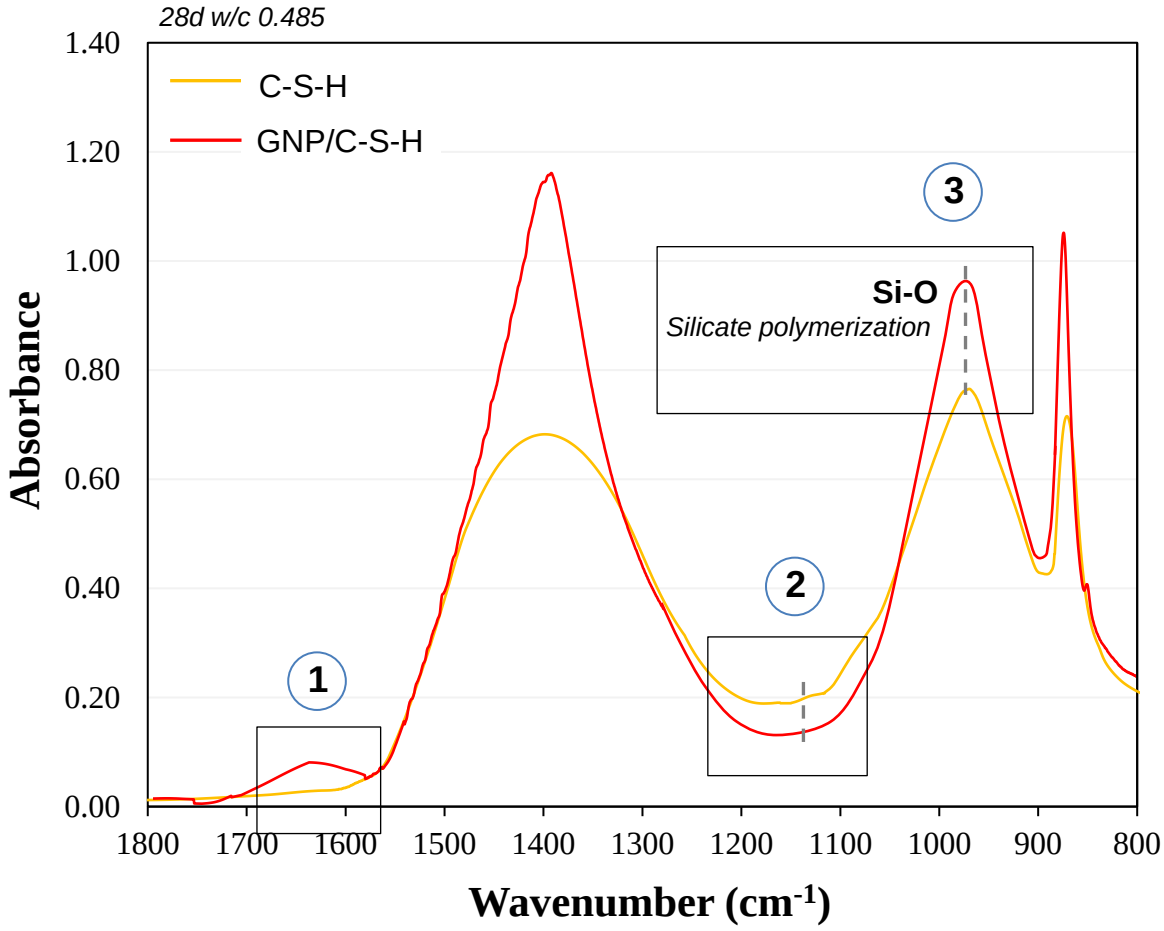
CO_2-cured specimens





Sub-10nm IR Spectrum of GNP Reinforced Cement Paste

CO_2-cured specimens



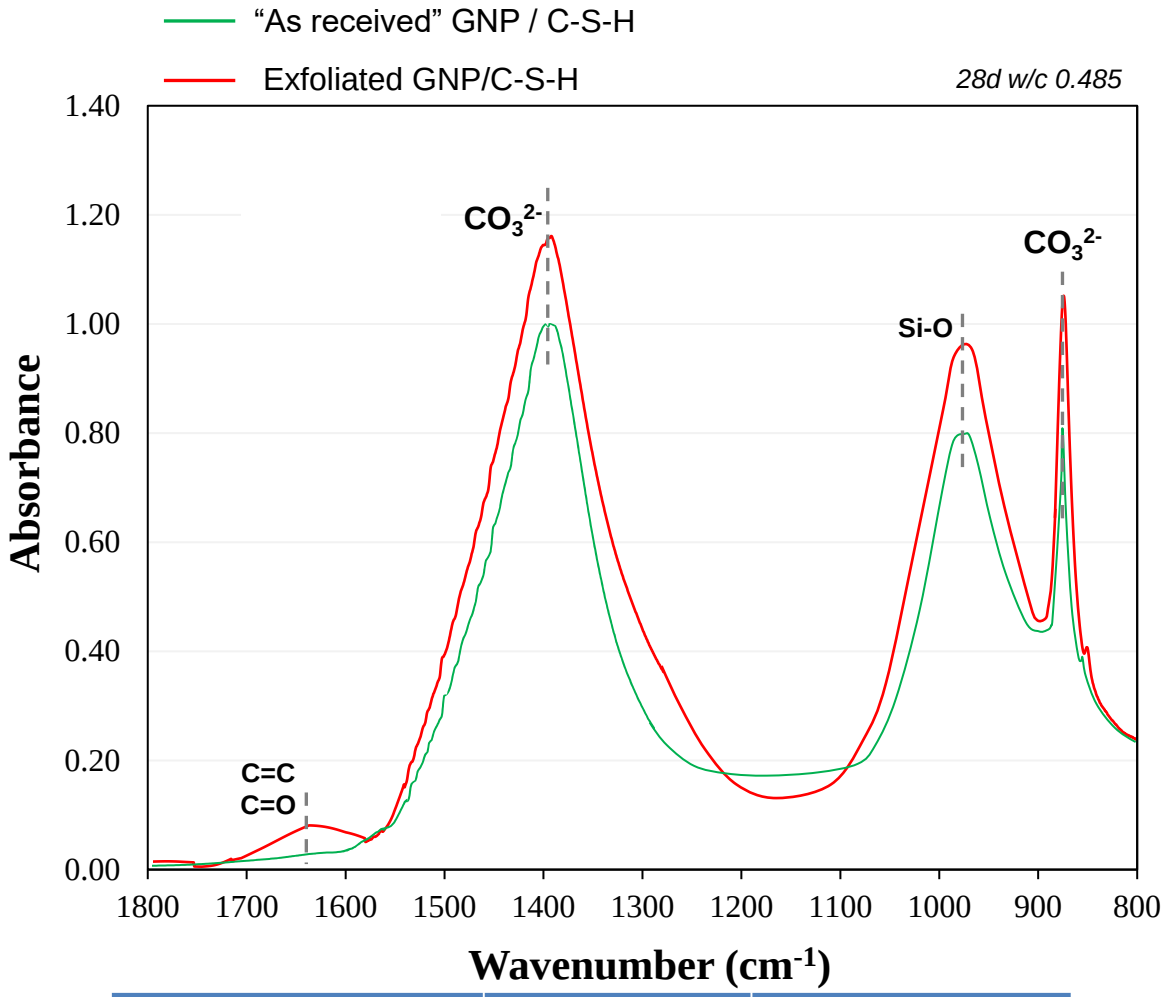
3

Higher polymerization degree of silicates in GNP/C-S-H

Formation of longer silicate chains in GNP/C-S-H

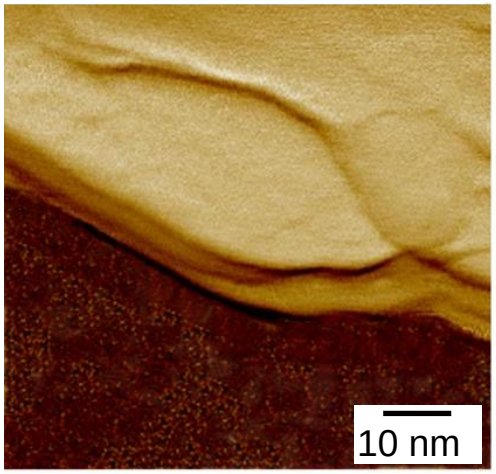
Sub-10nm IR Spectrum of GNP Reinforced Cement Paste

As Received GNPs

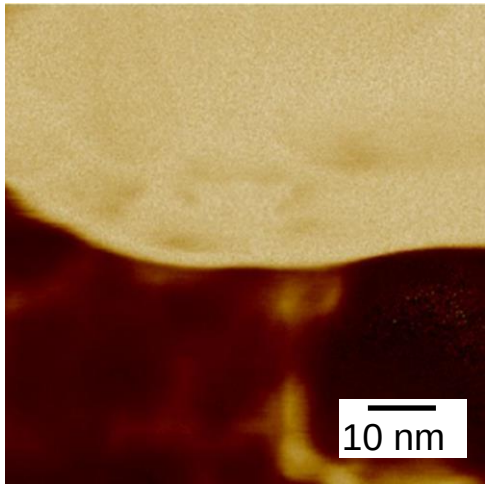


	"As received" GNP/C-S-H in CP	Exfoliated GNP/C-S-H in CP
C=C, C=O (1640 cm^{-1}) *COOH (carboxyl) and OH (hydroxyl) attached on the GNP surface*	✗	✓
Si-O (980 cm^{-1}) Silicate polymerization	0.8	0.98 (↑ 23%)
CO_3^{2-} (870 cm^{-1}, 1370 cm^{-1}) $CaCO_3$ (CO_2 mineralization)	0.8 – 1.0	1.05 – 1.15 (↑ 23%)

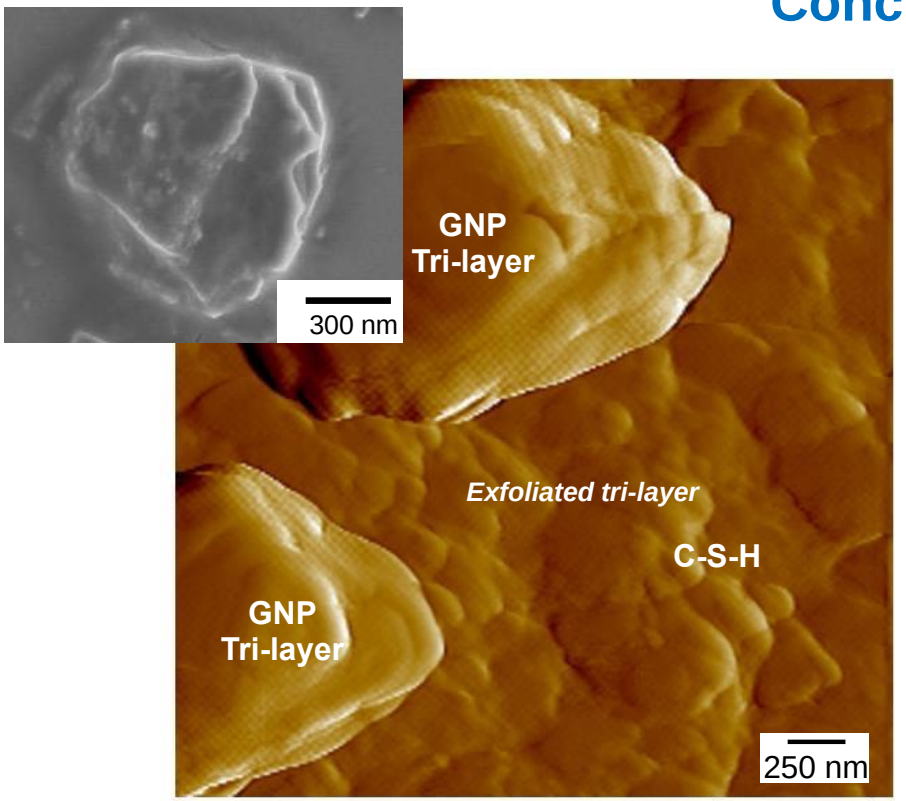
Exfoliated GNP/C-S-H in CP

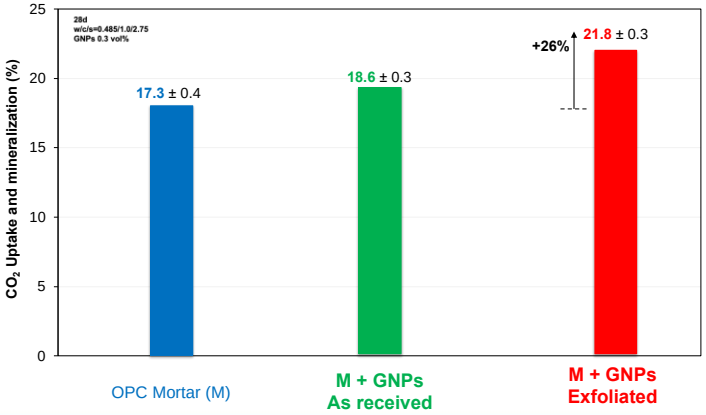


"As received" GNP/C-S-H in CP



Conclusions





- While both multilayer and tri-layer GNPs increase concrete's capacity for CO2 uptake and mineralization, highly exfoliated/few-layered functionalized GNPs are able to better enhance CO_2 uptake and mineralization.

Formation of higher amounts of $CaCO_3$

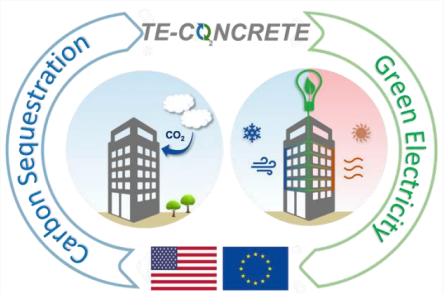
- 28-day CO_2 cured mortars reinforced with exfoliated tri-layer GNPs exhibit:
  - ✓ 26% higher CO_2 uptake and mineralization than OPC mortar
  - ✓ 8% higher CO_2 uptake and mineralization than mortar reinforced with "as received" GNPs

- The use of exfoliated/few-layered functionalized GNPs is crucial to provide active sites that promote the chemical reaction between CO_2 and cement hydration products and facilitate the production of $CaCO_3$ (mineralization)

Acknowledgements

UTA Center for Advanced Construction Materials

The authors would like to acknowledge the financial support of the National Science Foundation – Partnerships for International Research and Education (PIRE) Research Funding Program "Advancing International Partnerships in Research for Decoupling Concrete Manufacturing and Global Greenhouse Gas Emissions" (NSF – PIRE – 2230747).

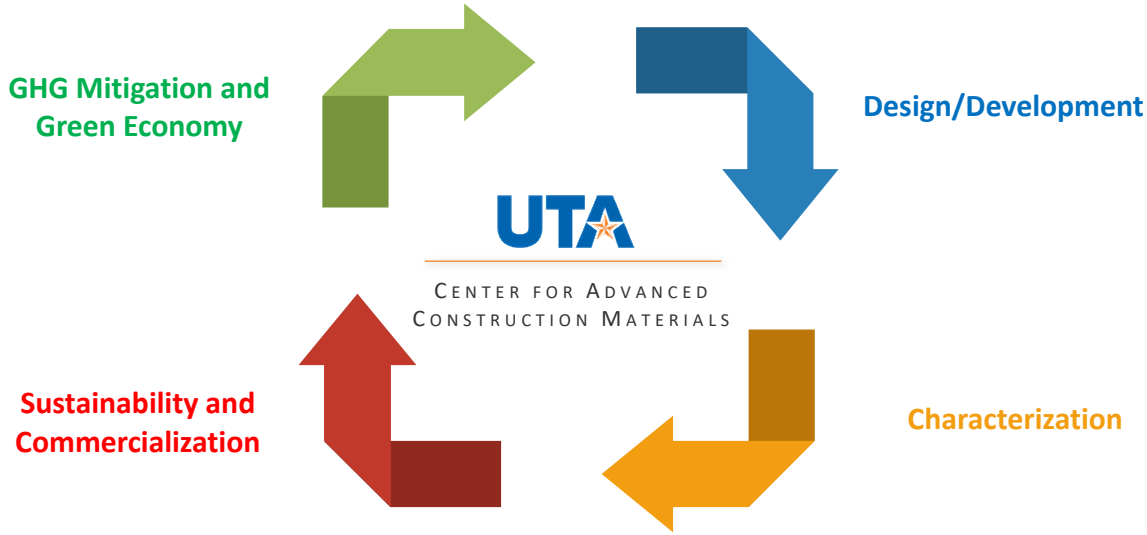


Advancing International Partnerships in Research for Decoupling Concrete Manufacturing and Global Greenhouse Gas Emissions

National Science Foundation

Partnerships for International Research and Education (PIRE)

Thank you!



Maria S. Konsta-Gdoutos
Professor of Civil Engineering
Associate Director, Center for ACM
maria.konsta@uta.edu

https://cacm.uta.edu/