

GRC 2020 VIRTUAL ANNUAL MEETING & EXPO

October 18-23, 2020

grc2020.mygeoenergynow.org

—— #GRCAM2020 ——

Graphene-enhanced Wellbore Cement: Improving Cement Performance in the Construction of Geothermal Wellbores

Cody Massion

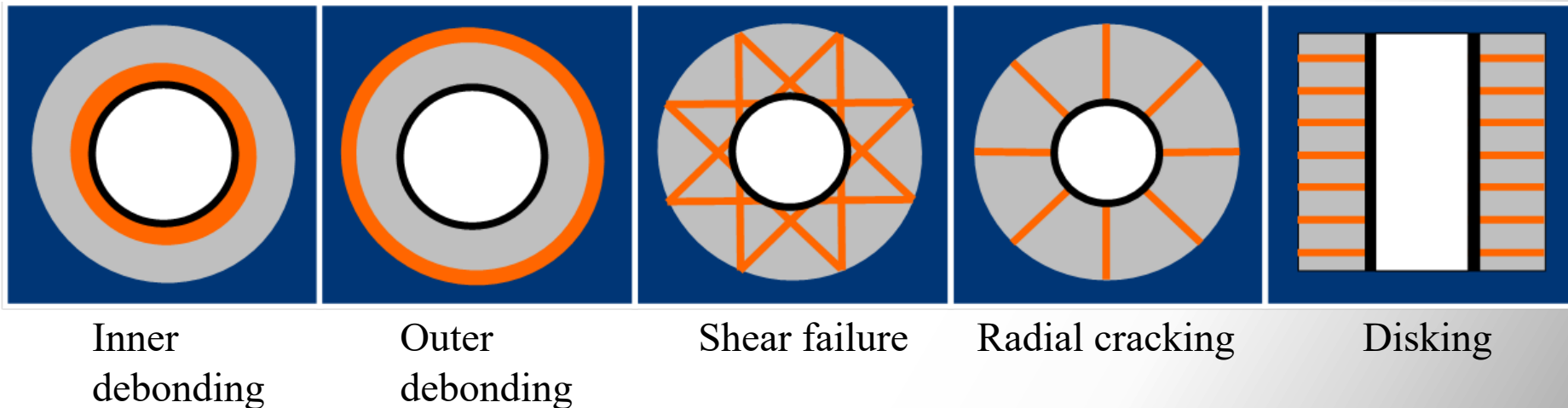
Daniel Bour

Mercy Achang

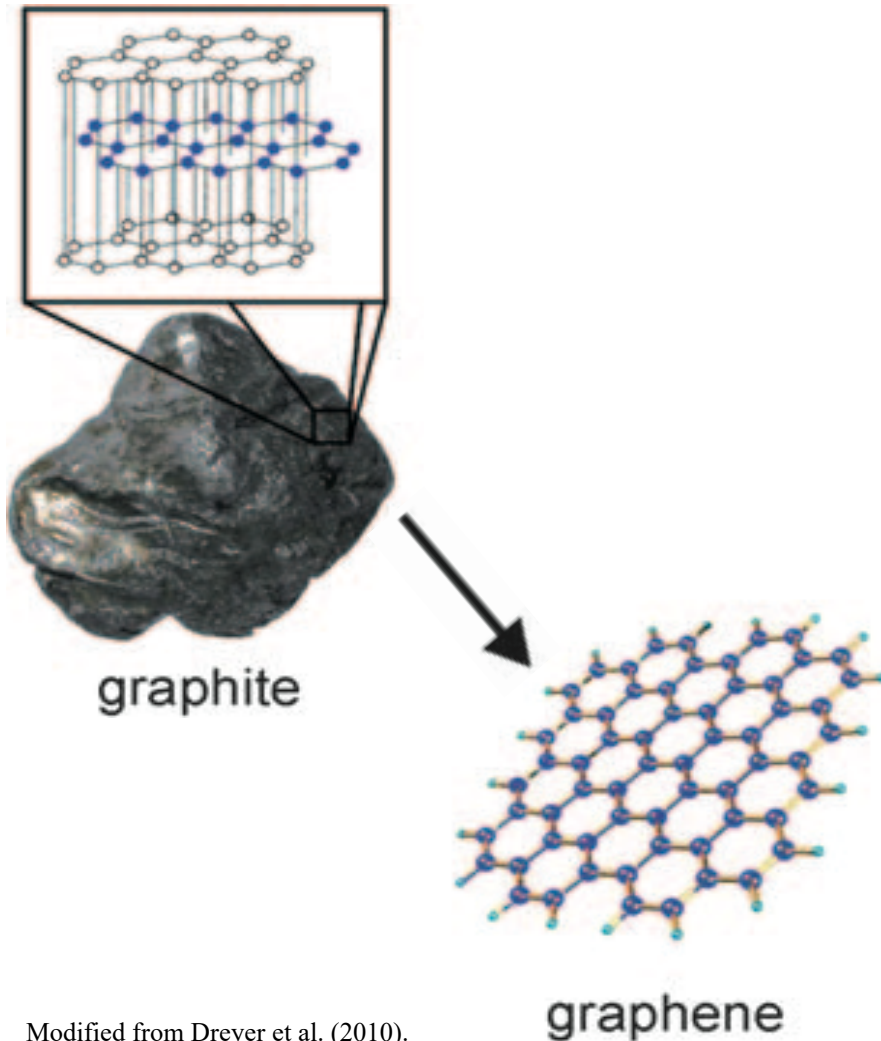
Mileva Radonjic

Introduction

- Importance of wellbore cement:
 - Provides chemical protection of casing
 - Holds casing in place
 - Provides mechanical stability
 - Provides zonal isolation



Introduction



- Characteristics and properties of graphene:
 - Single carbon atom layer made from graphite
 - Thinnest yet strongest material currently known.
 - Young's Modulus of 1TPa
 - High strength and high flexibility
 - Thermally and electrically conductive
 - Hydrophobic/chemical resistant

Materials and Methodology

- As received graphene was analyzed using microscopy tools
- Graphene added in different percentages to a 16.4ppg (1.97 g/cm³) Class-H wellbore cement slurry: 0, 0.05, and 0.1%woc
- API Standard 10B
- Cement was demolded after one day and hydrated at 90°C and 95%RH for 21 days.
- Cement mechanical, petrophysical, mineralogical properties were examined with the different graphene percentages.

Materials and Methodology

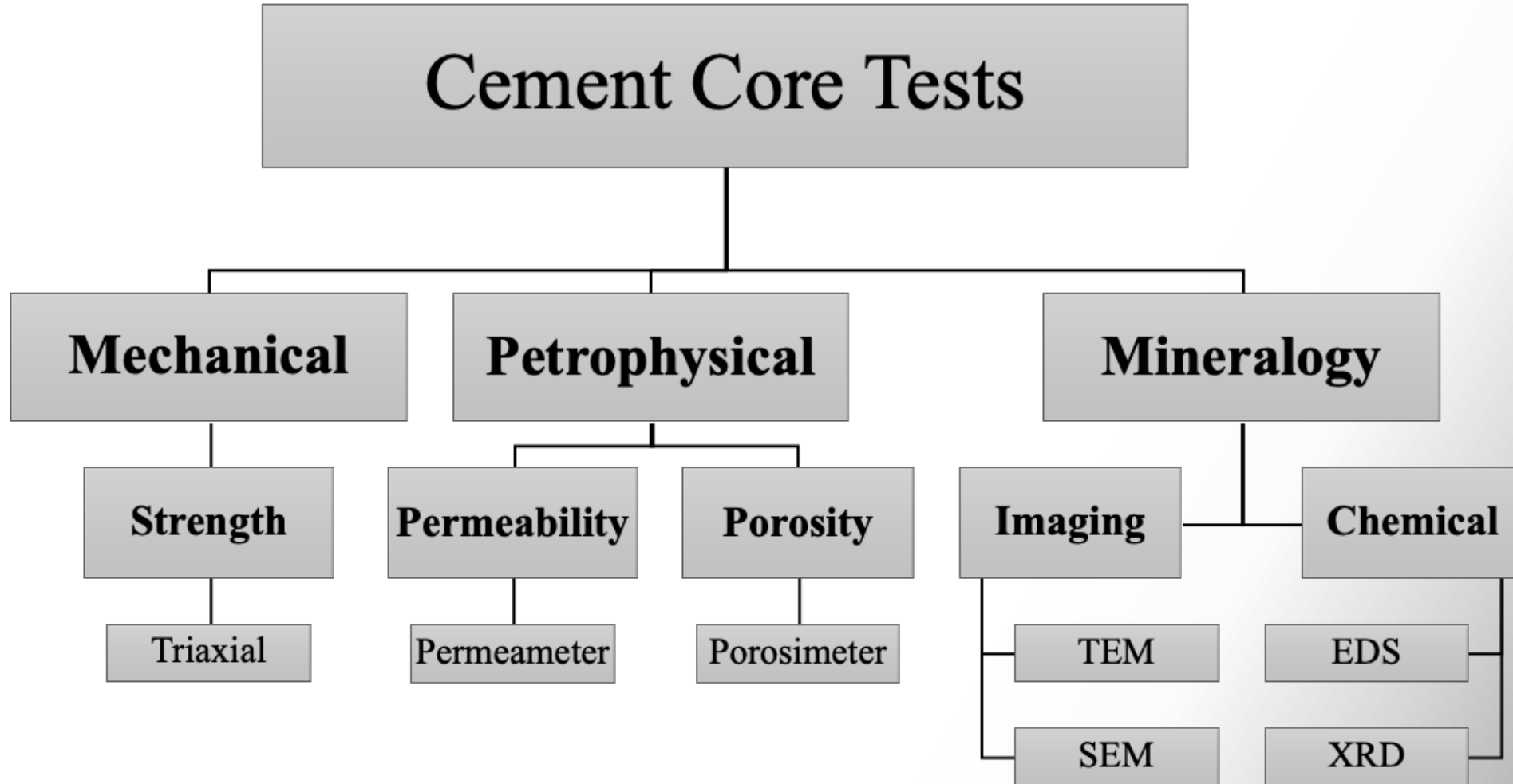


Figure 2: Testing protocol used in this study, categorized by the desired testing properties and followed by the equipment that will be utilized to obtain these properties.

Semi-transparent Graphene Nanoplatelets



Figure 3: A) Multiple layers of nanosheets are stacked on each other orderly. Defined lines are an indication of a platelet edge and darkening color indicating thicker sections. B) High magnification image at the edge of graphene cluster.

Graphene Nanoplatelet Conglomerates

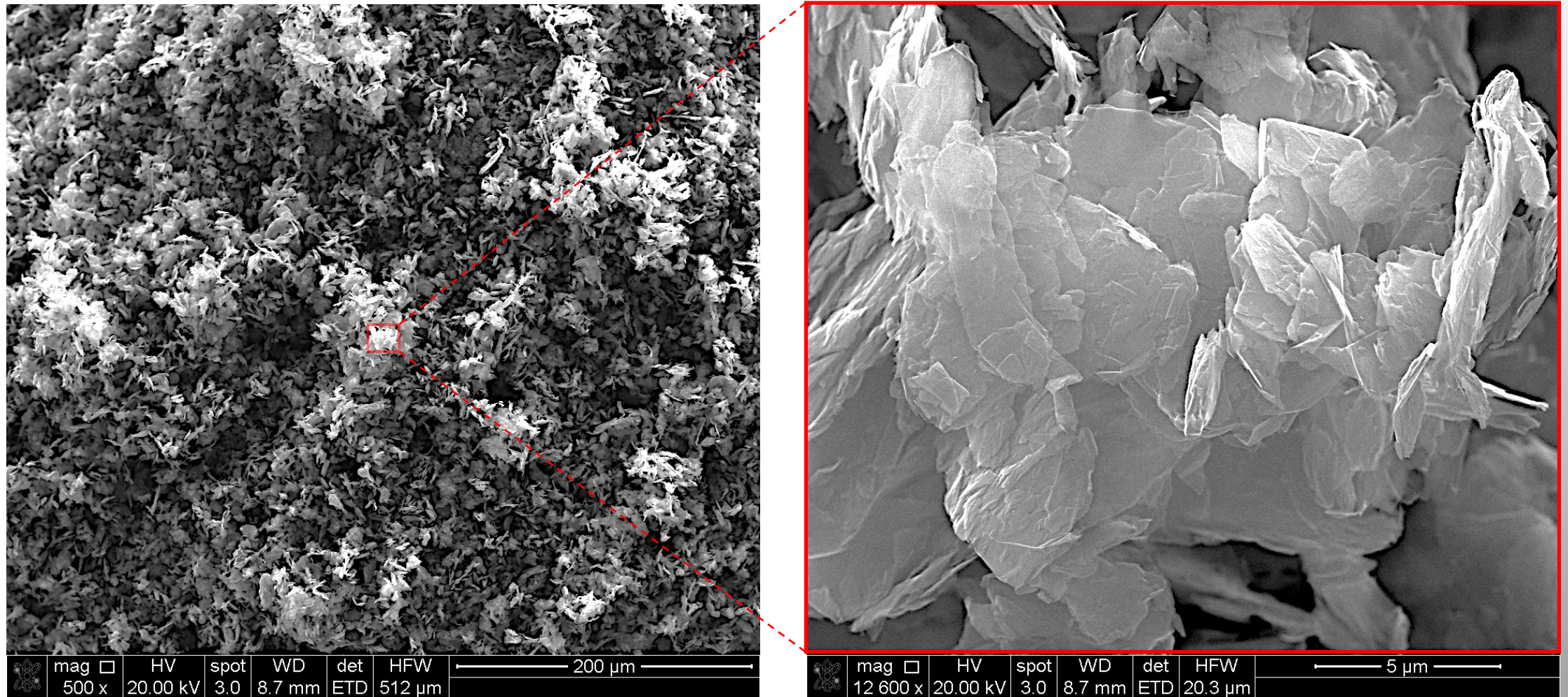


Figure 4: Secondary electron SEM images shows the as received graphene appears mostly as a powder until approximately the nanoscale when individual platelets are seen

Graphene Elemental Analysis

Element	Atomic	Mass
Carbon	92.83	90.48
Oxygen	7.03	9.13
Sodium	0.00	0.00
Magnesium	0.00	0.00
Aluminum	0.03	0.07
Silicon	0.03	0.07
Sulfur	0.02	0.06
Potassium	0.01	0.02
Calcium	0.02	0.06
Iron	0.02	0.10
Copper	0.00	0.02

Table 1: Energy-Dispersive x-ray Spectroscopy (EDS) of the as received graphene showing elemental composition.

Neat and Graphene Hydrated Cement

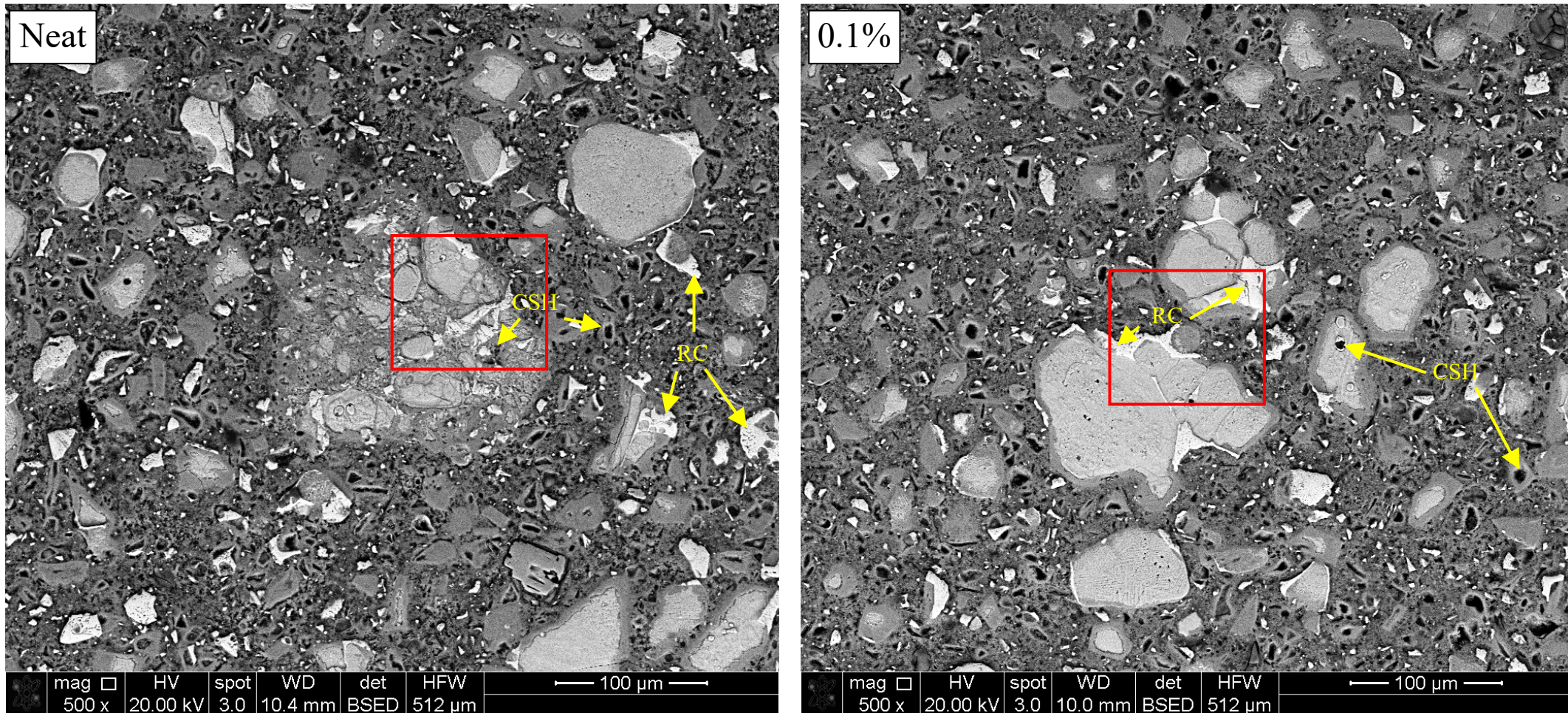


Figure 5: Backscatter image of A) neat Class-H cement and B) 0.1%woc graphene added to the same cement. Calcium-silicate-hydrate (CSH) and residual unhydrated cement (RC).

Neat and Graphene Cement Microstructure

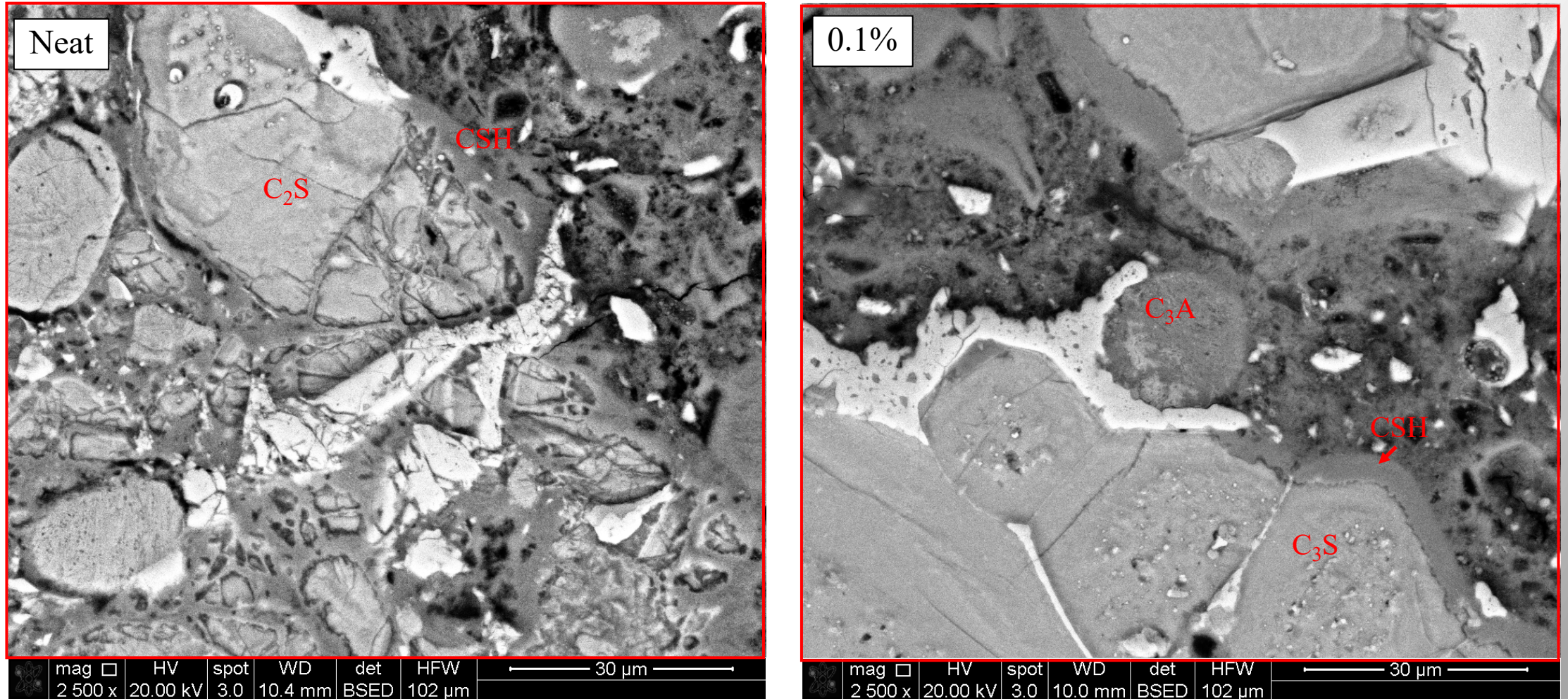


Figure 6: Higher magnification image of A) neat Class-H cement and B) 0.1%woc graphene added to the same cement. Various cement grains and hydration.

Hydrated Cement Elemental Analysis

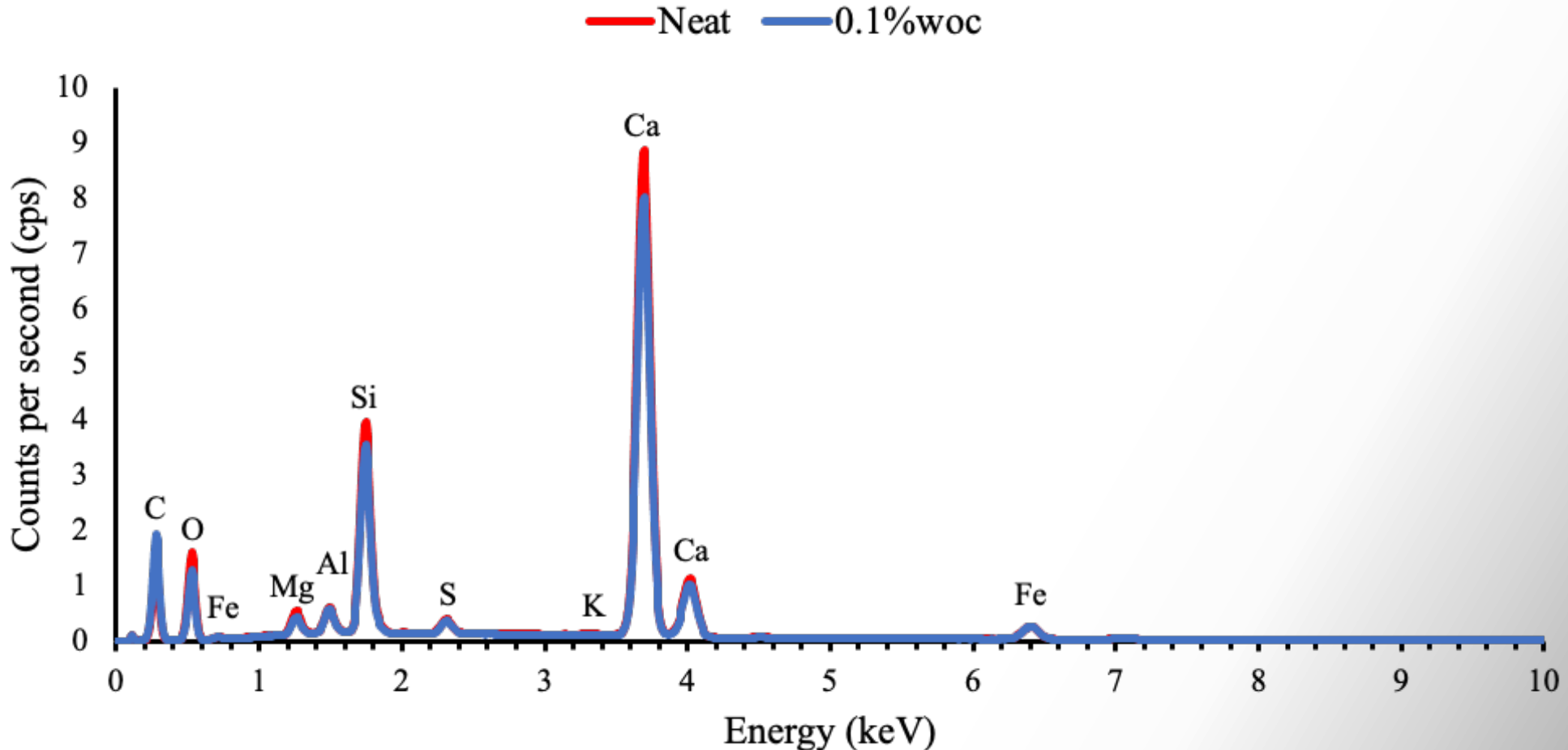


Figure 7: Energy dispersive x-ray spectroscopy (EDS) of graphene of 0.1%woc quantity as well as neat Class H to examine the elemental composition of each.

Hydrated Cement Phase Identification and Quantification

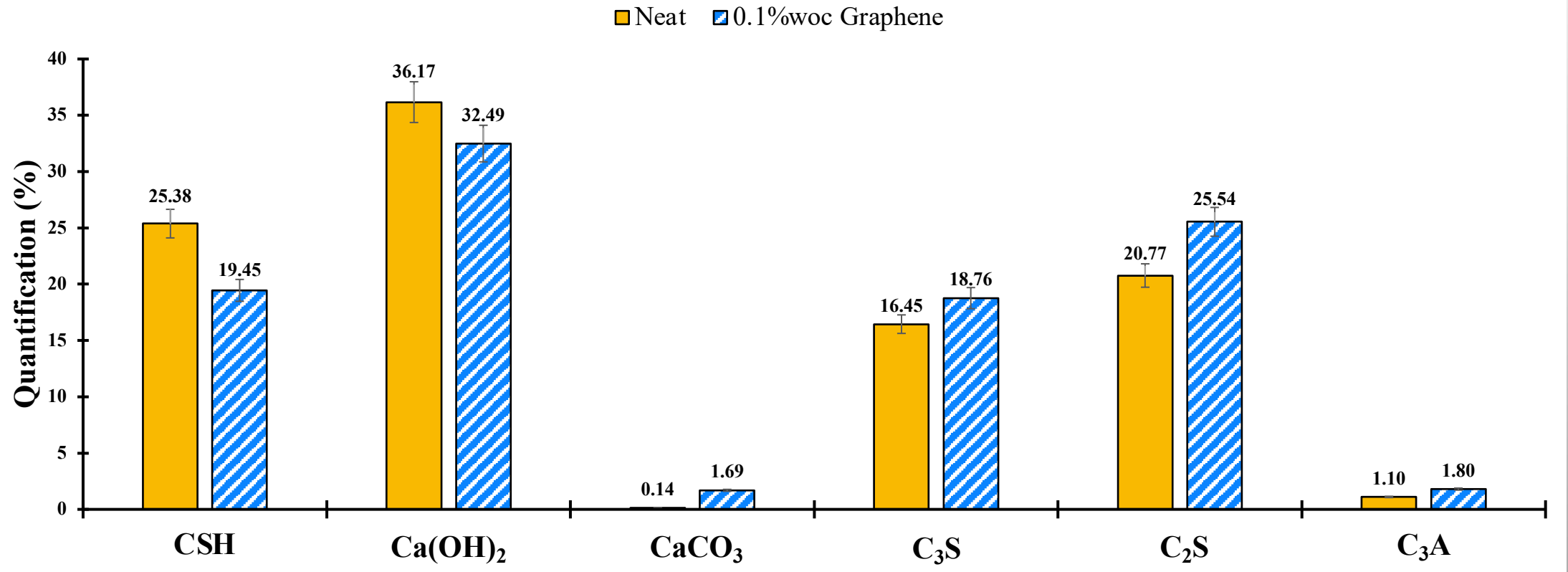


Figure 8: XRD analysis and identification of crystalline components show slower hydration [left-side of figure] and higher content of unhydrated cement clinker minerals [right-side of figure] with addition of 0.1%woc graphene in cement compared to neat Class-H.

Graphene within Cement Micropores

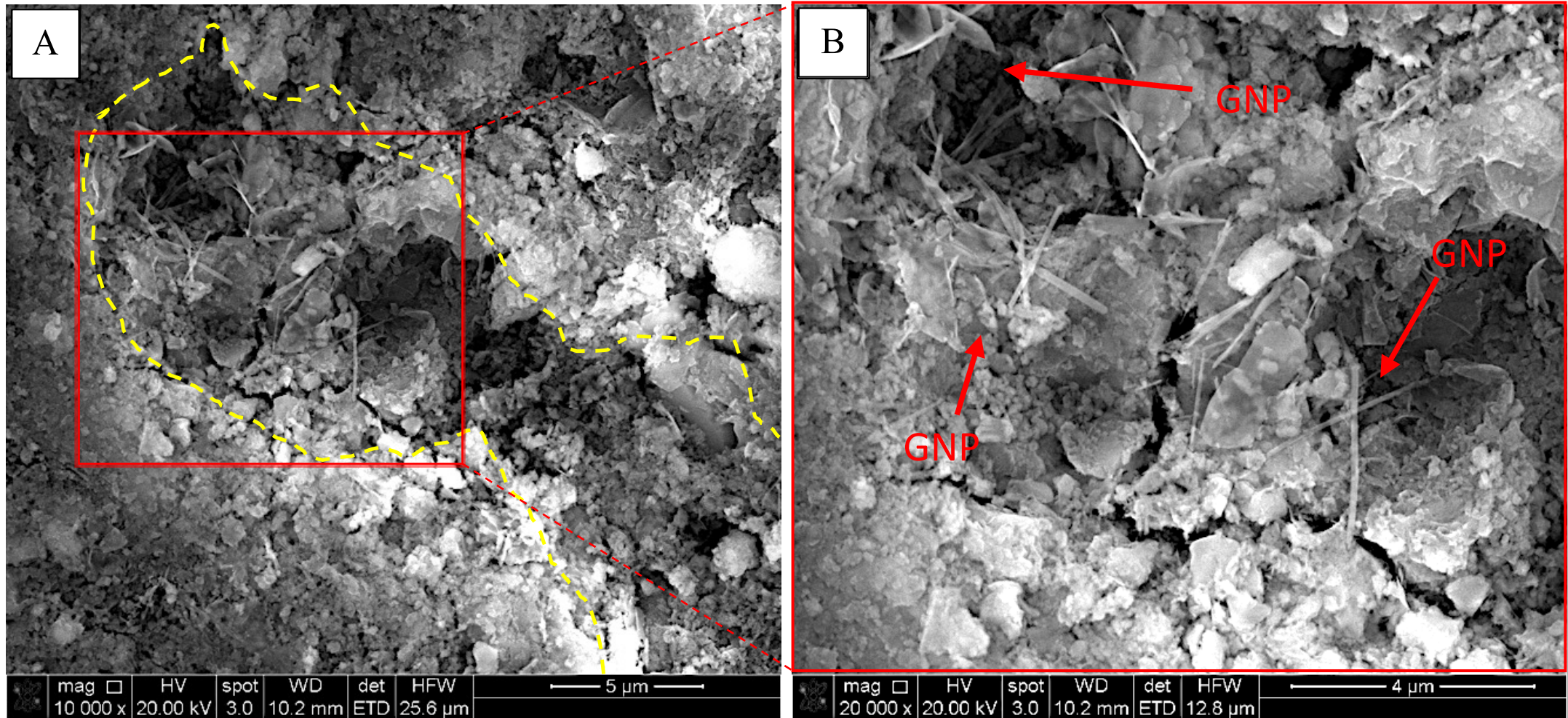


Figure 9: Graphene added to Class H cement at 0.05%woc. Secondary electron (SE) imaging was used to image graphene nanoplatelet inclusions into the cement.

Hydrated Cement Petrophysical Properties with Graphene

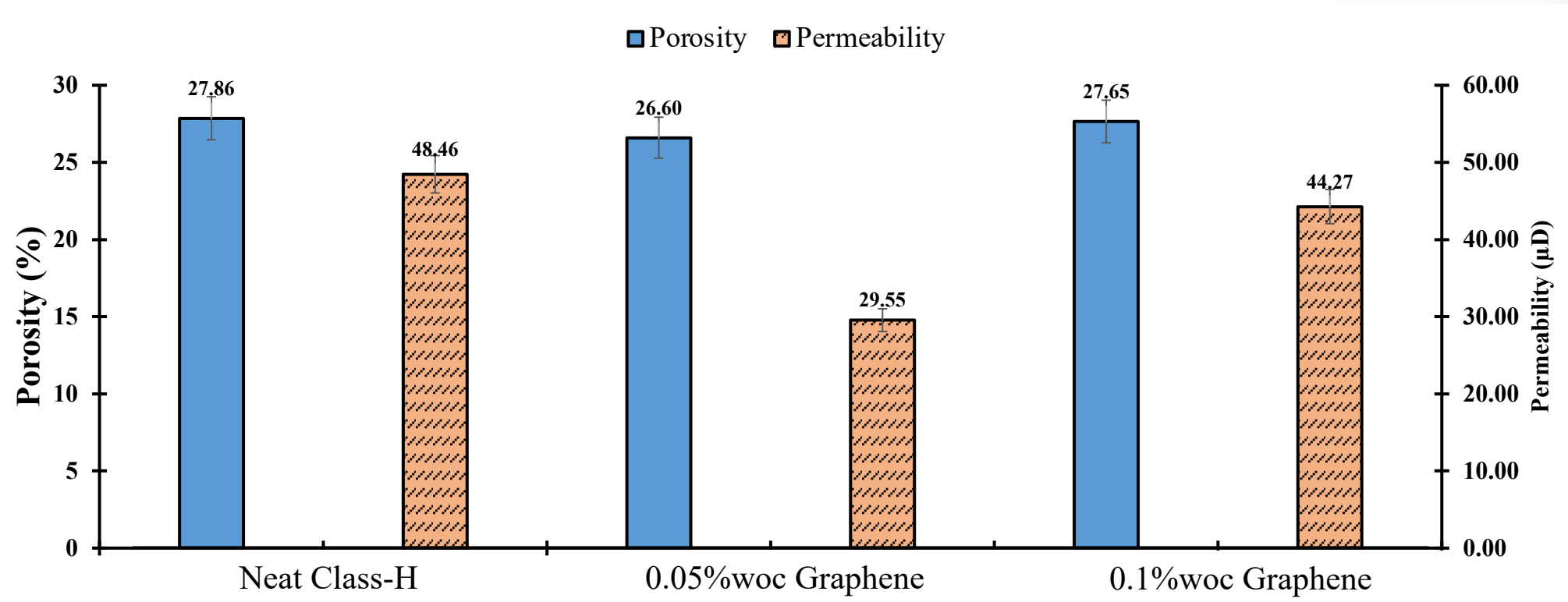


Figure 10: Ultra-pore porosimeter and nano-perm permeameter measurements of 3 samples of each Neat Class-H, 0.05%, and 0.1%woc graphene in Class H cement.

Wellbore Simulated Graphene Cement Strength

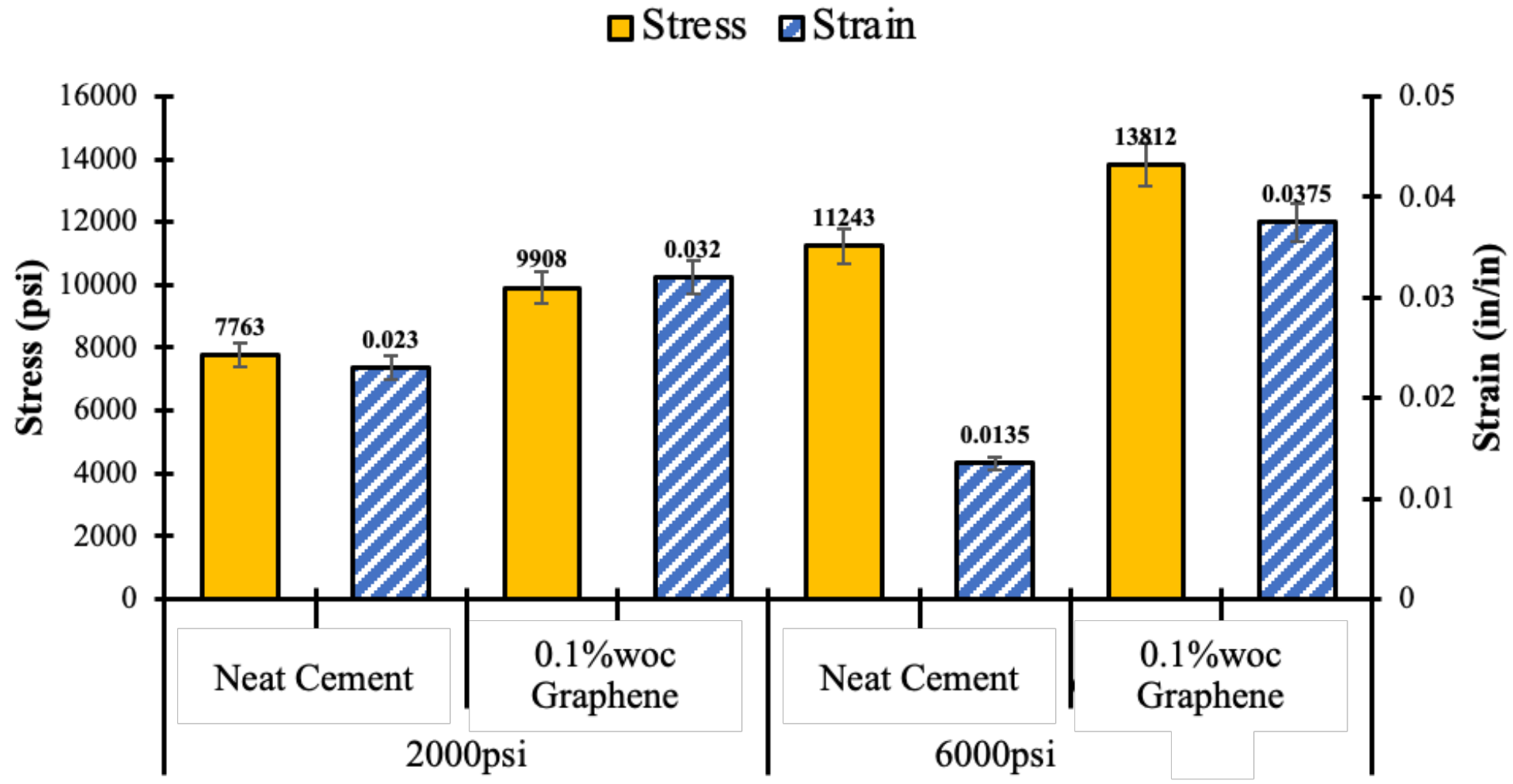


Figure 11: Neat and 0.01%woc graphene cement samples were tested under undrained triaxial loading at the same temperature but with different confining pressures. Test results courtesy of Yunxing Lu and Dr Andrew Bunger at the University of Pittsburgh.

Discussion

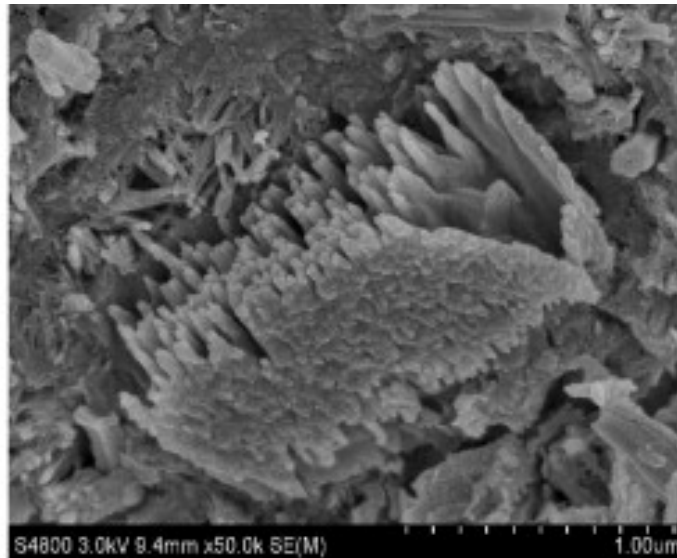
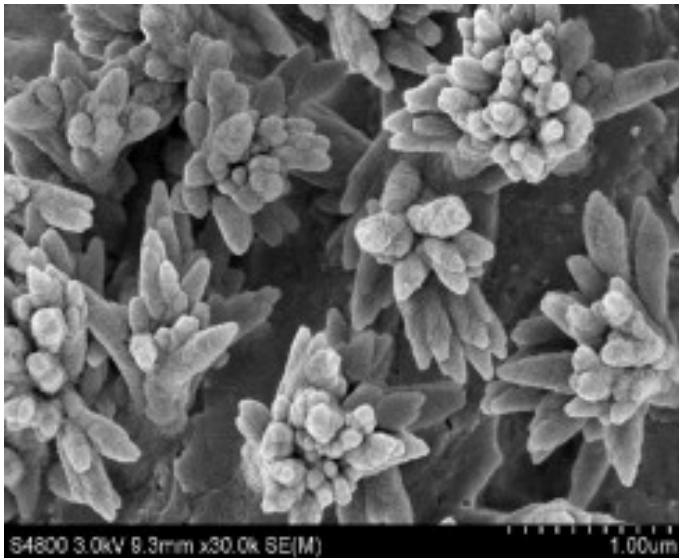
- Graphene has different material and chemical properties than the graphene oxide and reduced graphene oxide.
- Suggested that graphene-like materials improve mechanical properties of cement-based materials
- Proposed mechanisms:
 - the strongest material, graphene, migrates to empty pore areas.
 - Graphene provides a nonreactive template for hydration to begin
 - Graphene attracts calcium ions within the cement.

Discussion

- Our hypothesis of graphene's mechanism for improving cement strength based on literature:
 1. Cement hydration crystal morphology can impact the overall cement Young's Modulus (Dunant et al., 2020).
 - Higher aspect ratios of crystal length to width, such as needle-shaped crystals, result in larger Young's Modulus
 - Shorter and wider crystals result in a lower Young's Modulus

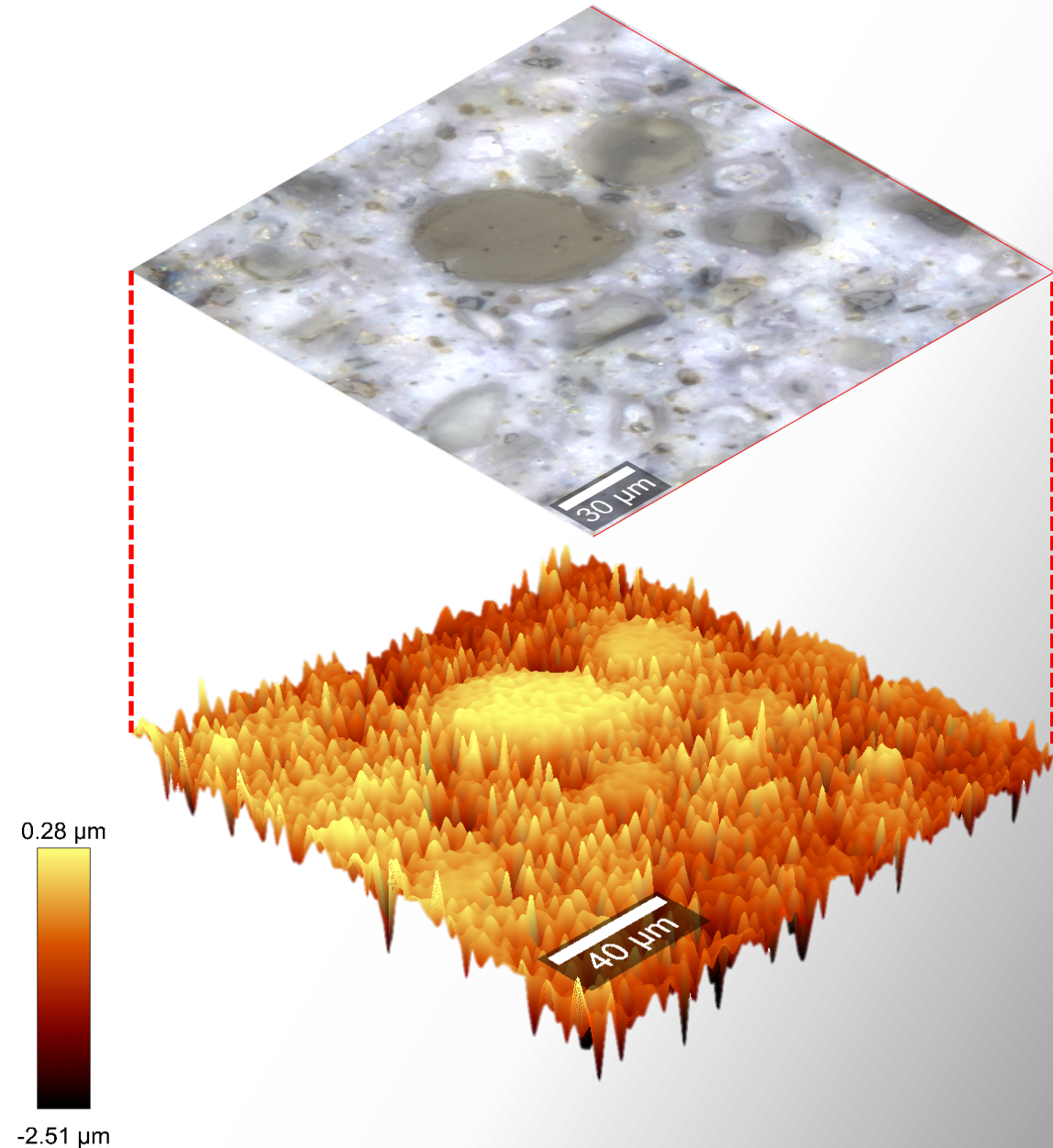
Discussion

- Our hypothesis of graphene's mechanism for improving cement strength based on literature:
 2. Graphene-like materials have been shown to result in cement hydration products shaped such like a lotus-flower and not typical CSH-needles (Lv et al., 2014).



Ongoing Work

- Polished 0.1%woc graphene Raman scan with depth profile.
- Dark and nearly black areas - pore space
- Light areas – cement grains and products
- Approximate polished surface roughness - 0.25 to 0.28 μm



Conclusion

Preliminary results indicate that the addition of graphene nanoplatelets in cement:

- Shear strength had increased with by approximately 20% with 0.1%woc graphene compared to neat Class-H.
- 0.1%woc caused some phase or phase quantity change during the cement hydration process with reduced the quantity of hydration phases such as calcium-silicate-hydrate and calcium hydroxide.
- Reduced pore volume of cement by about 1% pore volume, 4.5% decrease, with 0.05%woc.
- Reduced permeability of hydrated 16.4ppg (1.97 g/cm^3) cement, at 21 days curing in 95% RH and 90C by 35% decrease, with 0.05%woc.

Acknowledgements

- National Academy of Science Engineering and Medicine Gulf of Mexico Program (NASEM-GRP) grant #10002358
- Brent Johnson and Lisa Whitworth at Oklahoma State University Microscopy Laboratory
- Tatiana Pyatina at Brookhaven National Laboratory
- Yunxing Lu and Andrew Bunger at the University of Pittsburgh
- Paul Beasant and NovaGraphene™
- Halliburton for supplying of cement and materials
- Oklahoma State hydraulic barrier materials team: Sai Vamsi Krishna Vissa, Lashell Williams, Guofan Luo, and Allan Katende