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Improvement of Wellbore Cement by Addition of Graphene Nanoplatelets



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Outline

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Introduction

Wellbore cement provides:

- Holds the casing in place
- Mechanical stability
- Zonal isolation
- Chemical protection for steel casing

Optimum properties:

- Long-term sealing capability
- Strong and ductile behaviour
- Impermeability
- Geo-compatibility

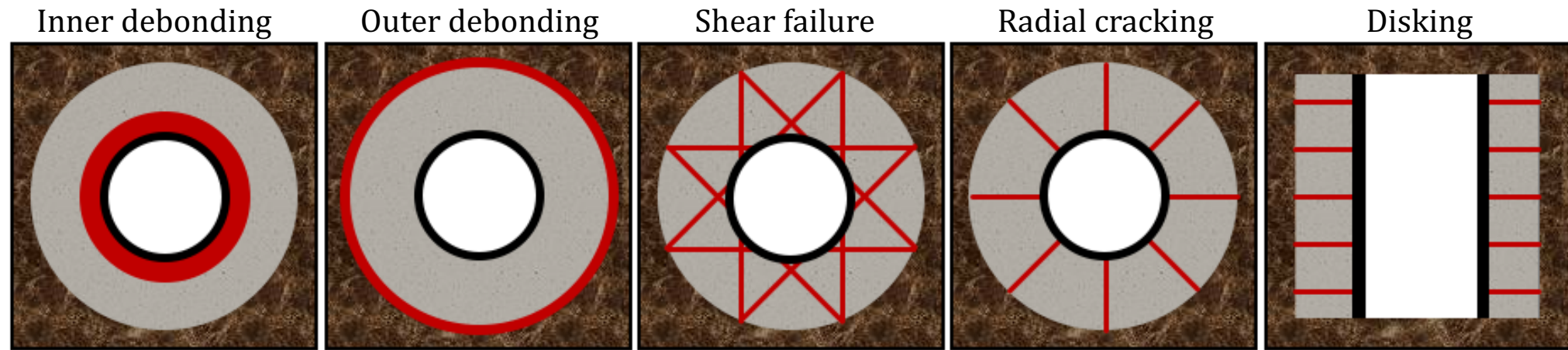


Figure 1: Common failure mechanisms of wellbore cement (red) creating leakage of subsurface fluids out of the well. Modified from Petty et al. (2003).

Scanning Electron Microscopy: *Morphology of Graphene*

Thinnest yet Strongest material currently known

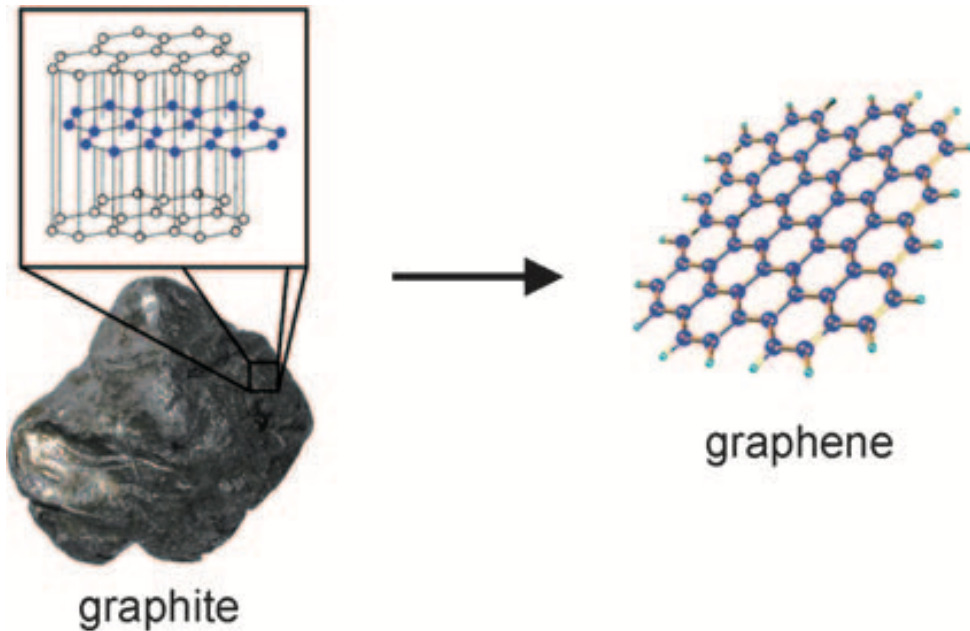


Figure 2: Graphic model of the transformation of graphene derived from graphite. Carbon atoms form hexagonal ring bonds that repeat to develop single graphene platelets with a thickness of one carbon atom. Dreyer et al. (2010).

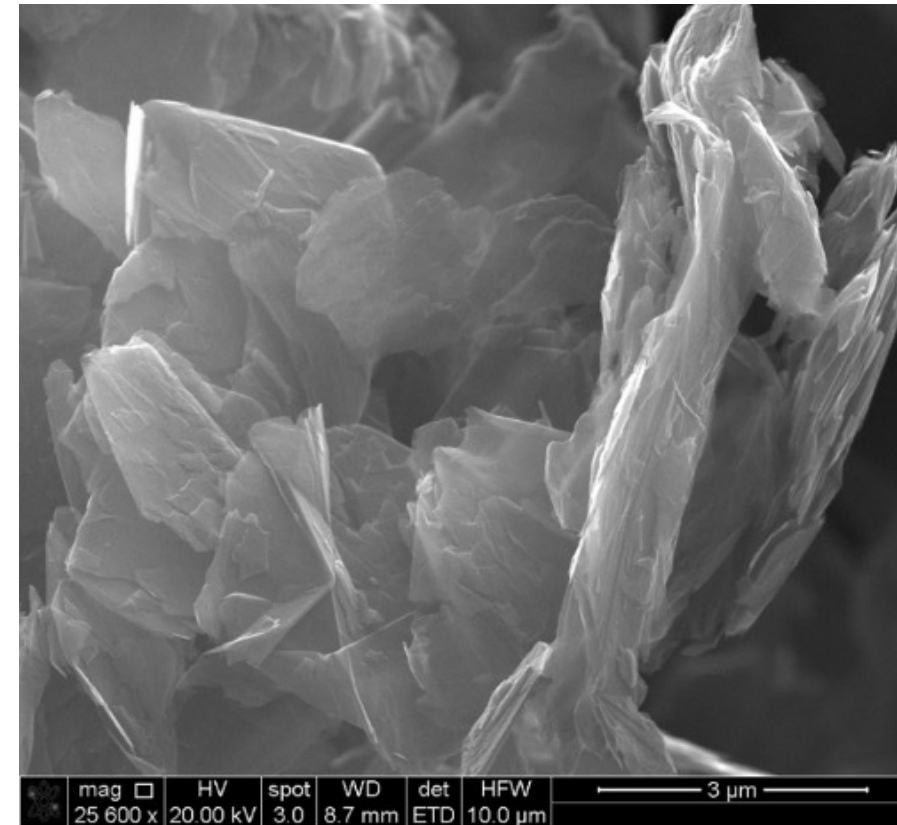


Figure 3: Graphene nanoplatelets at magnification of 25,600x depicts thin and nearly transparent individual platelets form layers.

Materials and Methodology

Sample making:

- Graphene nanoplatelets analysed using microscopy tools
- 16.4ppg (1.97 g/cm³) Class-H wellbore Additives of defoamer, friction reducer, and bentonite
- Graphene added in different percentages in **0, 0.008, 0.016, 0.05%** by weight of cement.
- API Standard RP-10B
- Cement was demolded after 24hrs and hydrated at 90°C and 95%RH for 28 days
- Cement microstructure and mechanical properties evaluated with varying graphene percentages

Sample testing:

- Scanning Electron Microscopy (SEM)
- Micro indentation
- Ultra-pore Porosimeter
- Mercury Intrusion Porosimetry
- Triaxial loading cell tests at simulated pressure and temperature
- Computed Tomography (CT) scanning

SEM: *Identifying Mechanisms of Graphene in Cement*

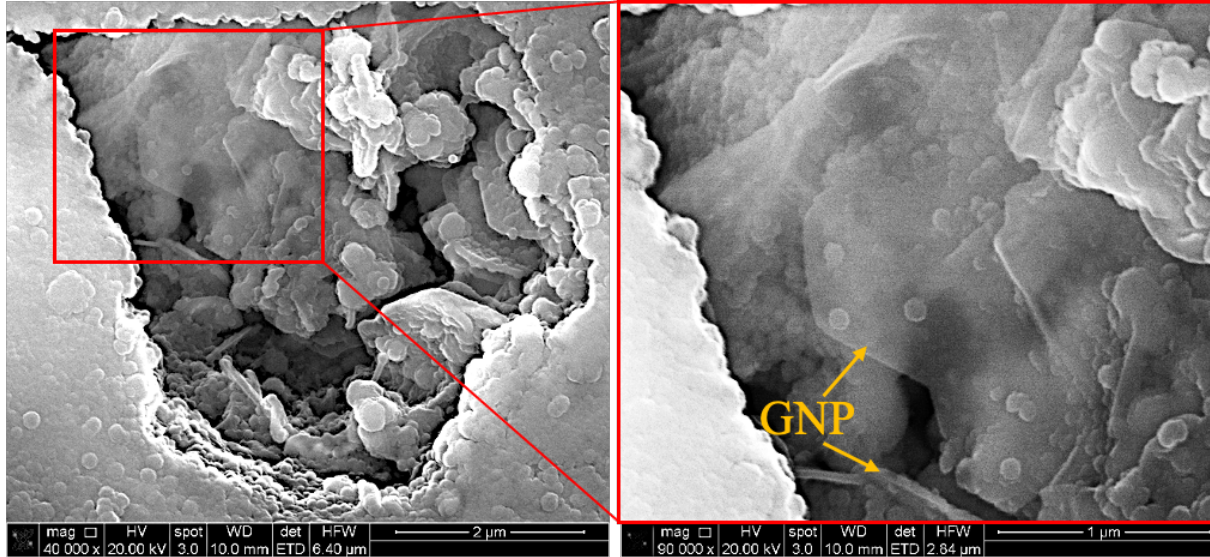


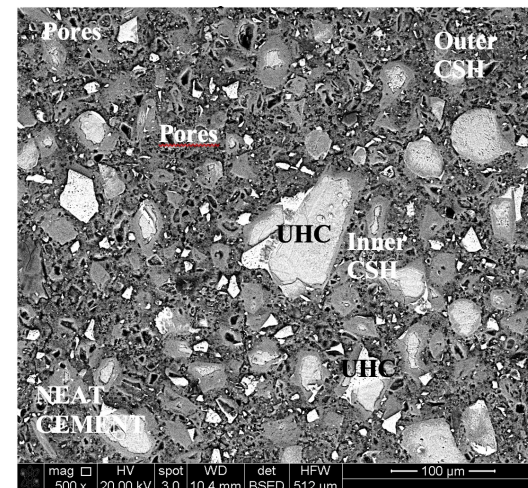
Figure 4: Graphene nanoplatelets imbedded into cement micropore space.

- Pore space is the weakest point in cement
- Graphene tends to accumulate within cement pore and reinforce the pore wall

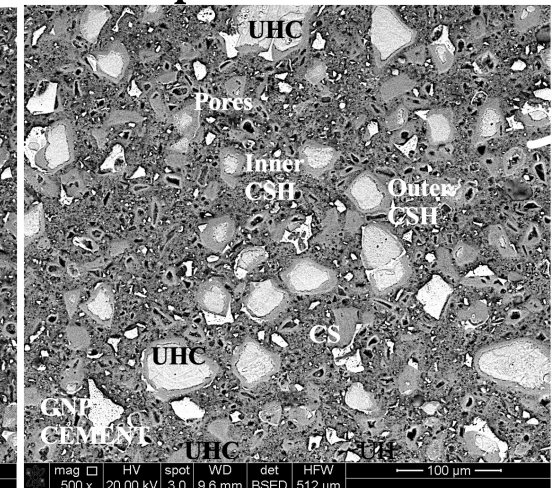
- Global microstructure of cement is unaltered when graphene is added.
- Large partially hydrated grains surrounded in CSH matrix

Figure 5: BSE micrographs with unhydrated cement clinker minerals (bright gray) with CSH hydration products outer rims (darker gray, within hydration matrix and porosity (black))

Neat Cement



Graphene Cement



SEM: *Observations of Graphene within Micropore Walls*

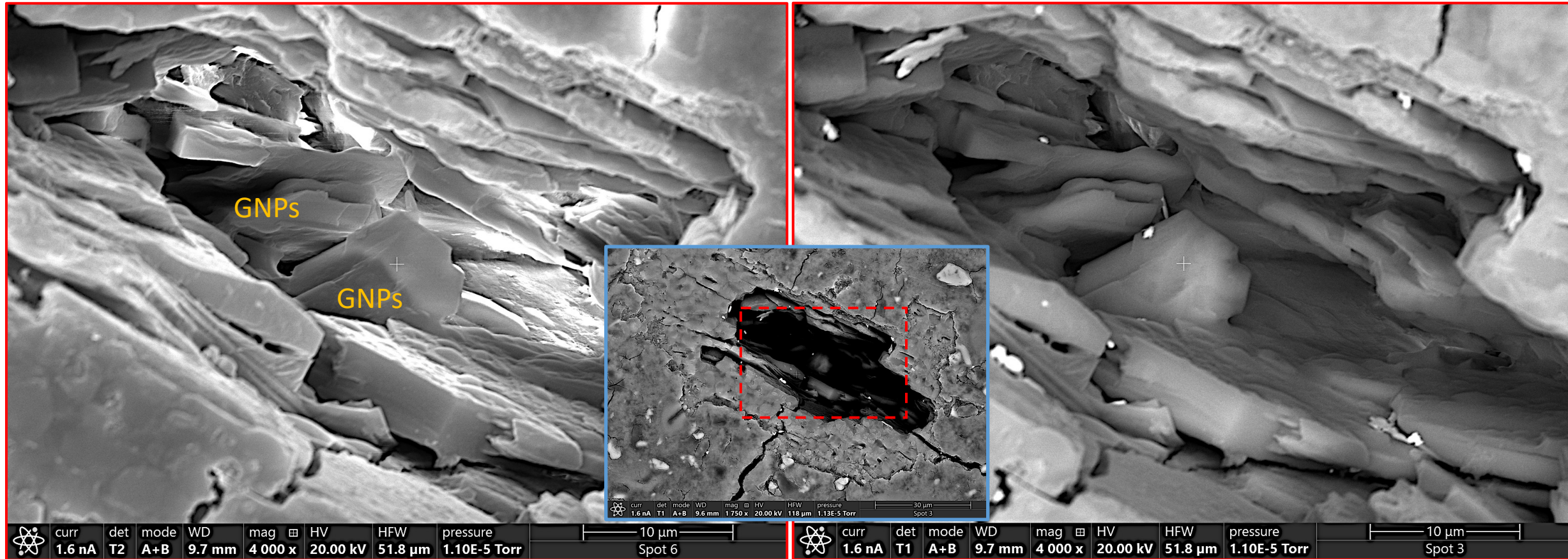
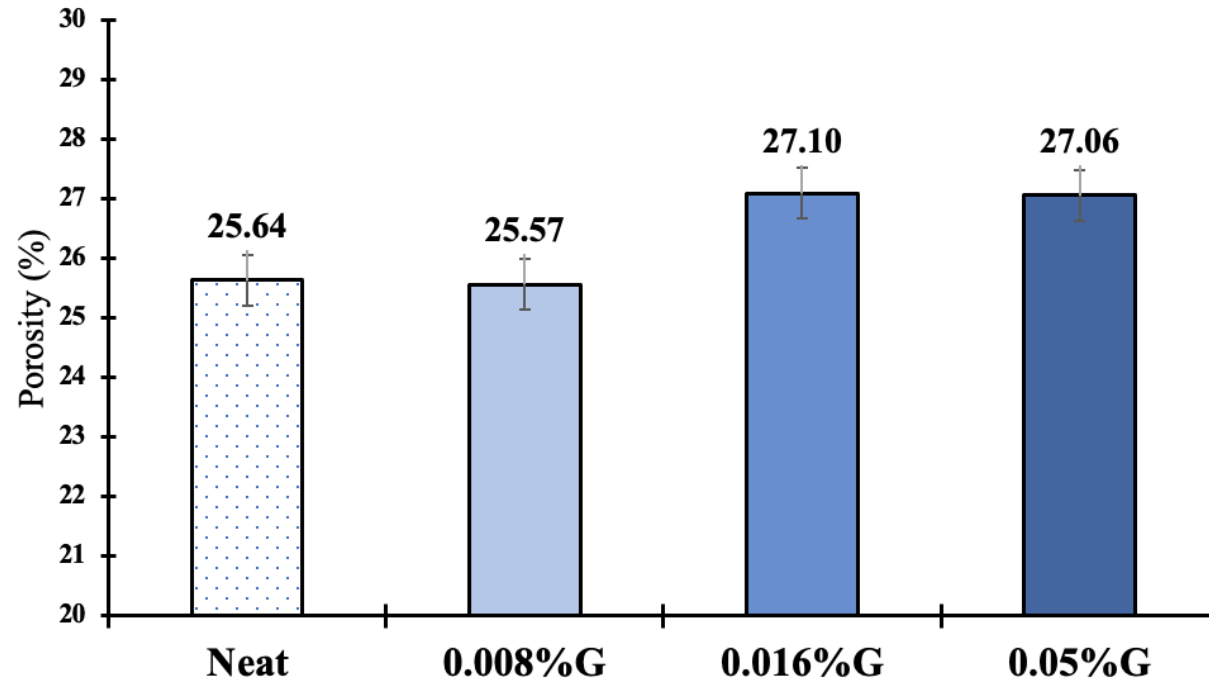


Figure 6: Graphene nanoplatelets reinforcing the micropore structure in secondary electron (left) and backscatter (right) imaging.

Porosimetry: *Porosity and Pore Throat Radius*

Helium Ultra-pore Porosimeter



Mercury Injection Petrophysical Properties

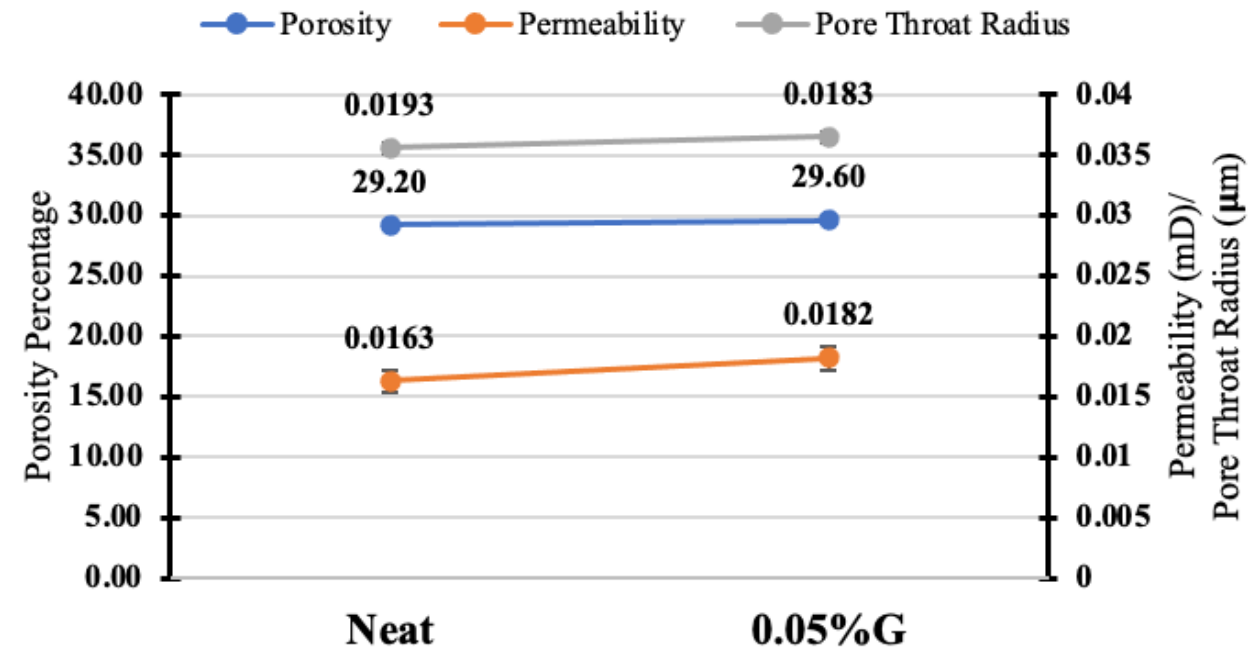


Figure 7: (Left) Ultra-pore porosimeter using helium gas. Measurements of 3 samples of each Neat Class-H, 0.008%, 0.016%, and 0.05%woc graphene in Class-H cement. (Right) Samples flooded with mercury at high pressure to measure the porosity, Swanson permeability, and pore throat size of both Neat Class-H and when 0.05%woc graphene added to the Class-H cement.

Correlative Microindentation: *Linking microstructure to micromechanics*

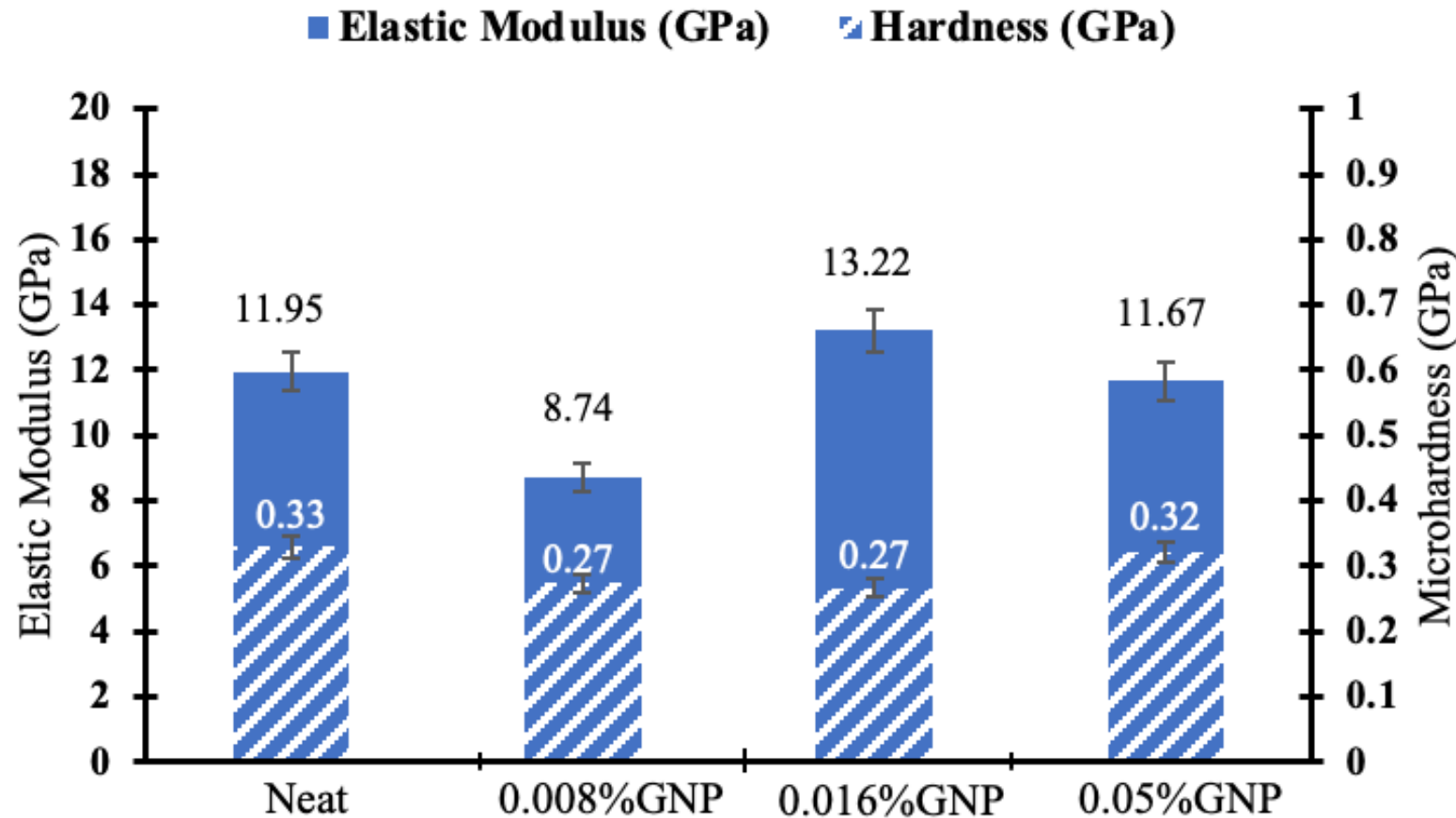


Figure 8: Micro-Vickers indentation conducted on a 5x5 matrix (25 indents) on neat, 0.008%, 0.016%, and 0.05% graphene addition.

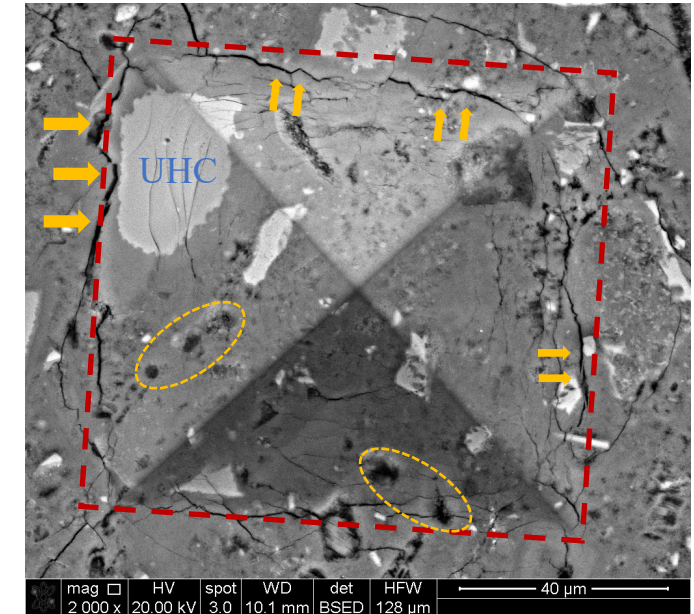
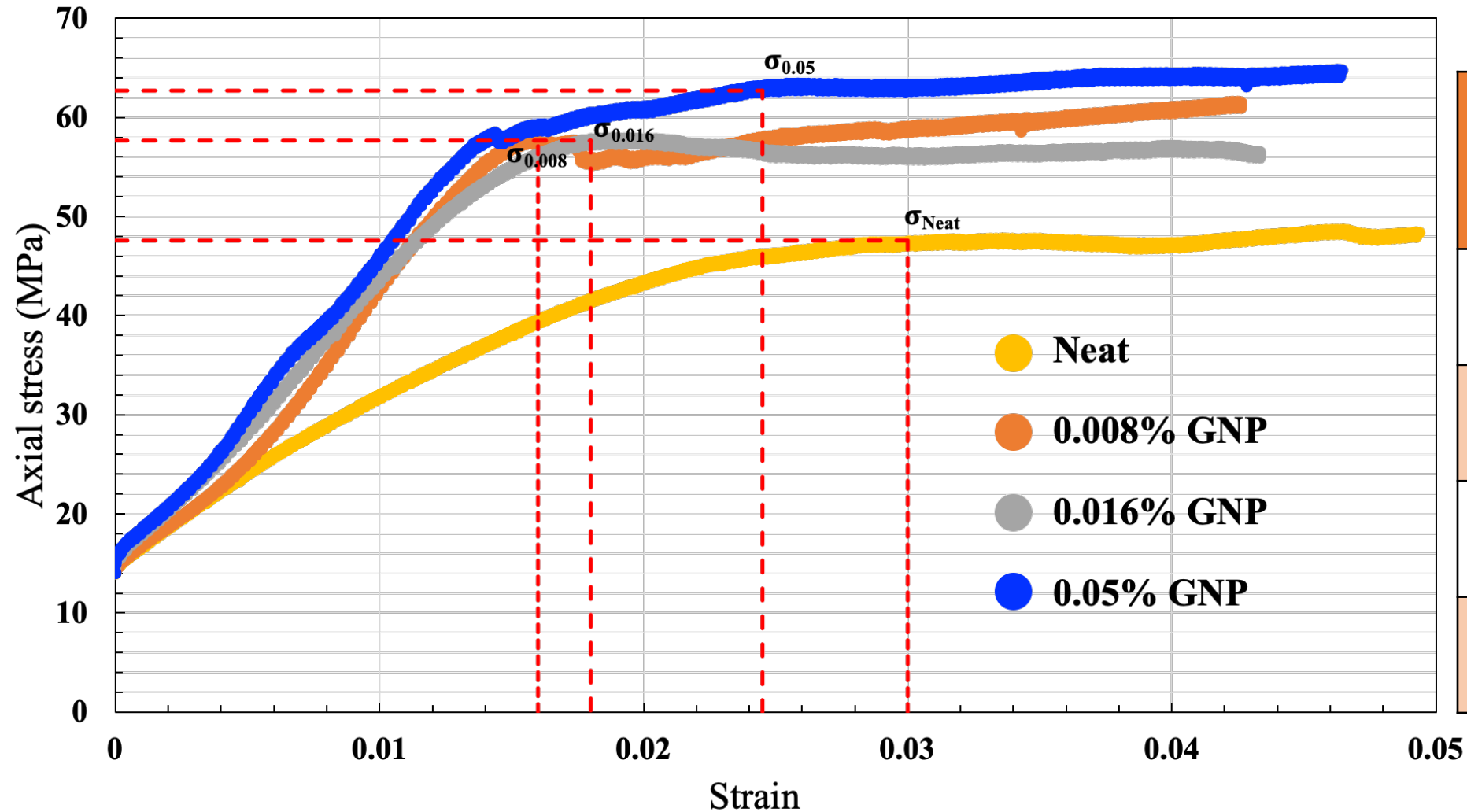


Figure 9: Backscatter electron image containing indentation by Vickers diamond indenter. Unhydrated cement (UHC) grain with pores (circles) and fractures (arrows) highlighted.

Triaxial Load Cell: *Mechanical Testing at Simulated Reservoir Conditions*

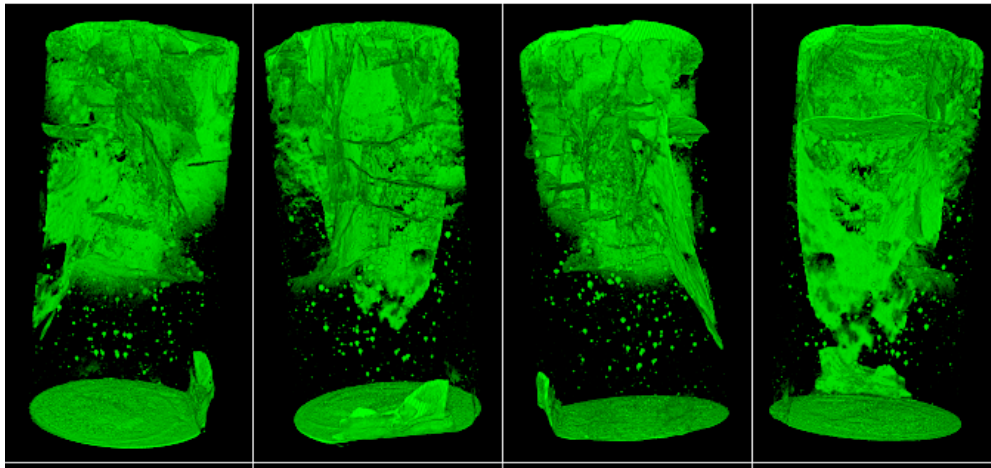


Graphene Percentage	Ultimate Stress (MPa)
Neat	47.57
0.008%	57.57
0.016%	57.64
0.05%	62.69

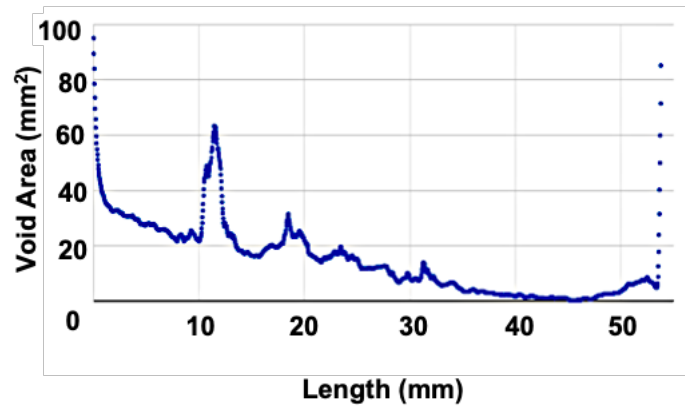
Figure 10: Graphene cement samples were tested in undrained triaxial compressive testing at simulated wellbore conditions and confining pressure of 13.7 MPa (2,000psi) and temperature 90°C (194°F). The graphene cement exhibited improvements in strength when compared with the neat cement. Failure stress and strength denoted by dotted line on the respective axes.

Computed Tomography: *Calculated Fracture Density of Post Triaxial test*

Neat Cement



1.18in x 2.4in
cement samples



Reduction in fracture:

- Density
- Conductivity
- Propagations

Graphene Cement

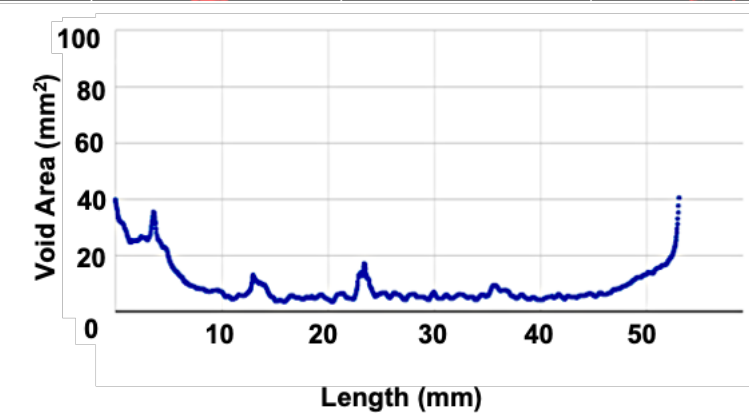
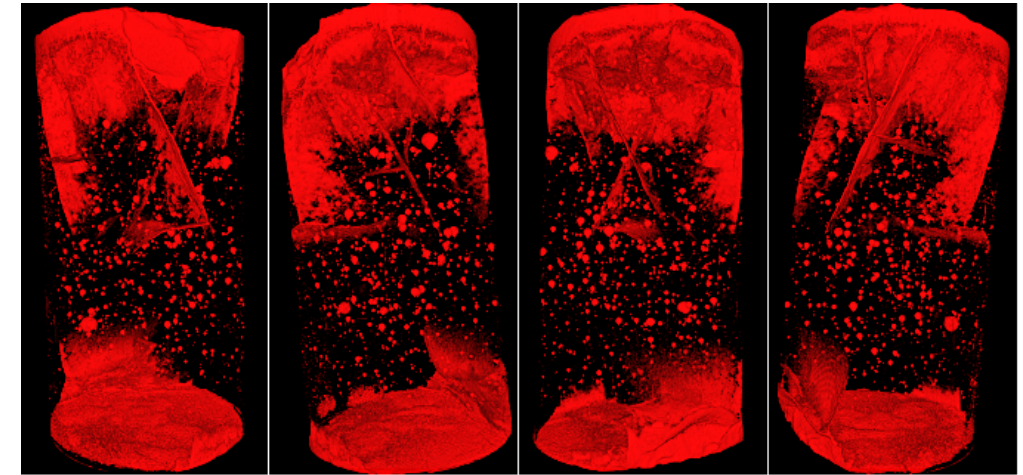


Figure 11: Calculated void space using CT scanning conducted after triaxial fracturing

Discussion

Literature comparisons:

- Suggested that graphene-like materials improve the mechanical properties of cement-based materials
- Literature 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 (cont.)

This study's hypothesis on how graphene nanoplatelets enhance cement properties 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 smaller Young's Modulus
 - Shorter and wider crystals result in a higher Young's Modulus
2. Stacking graphene platelets slide against one another under load due to weak Van der Waal forces between, acting as nano springs within the matrix Berman et al. (2014).

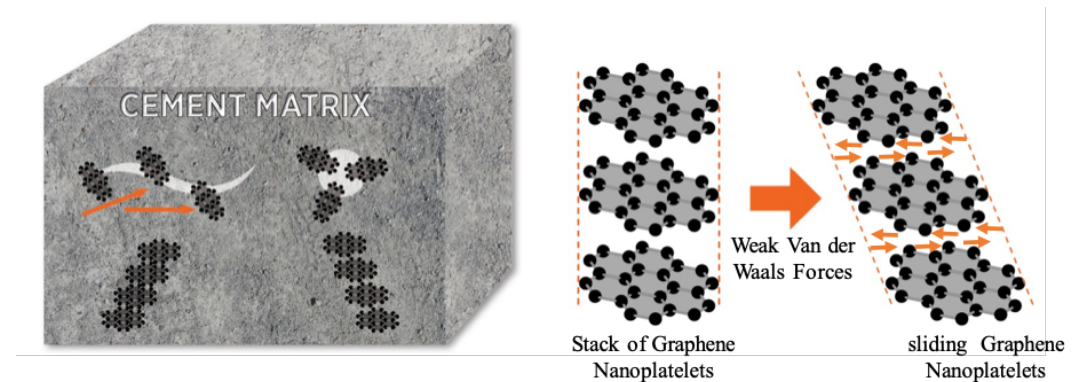


Figure 12: Proposed mechanisms of graphene nanoplatelets within the cement matrix by bridging fracture propagations, reinforcing pore structures, and stack and sliding due to Van der Waals forces between the platelets.

Conclusion

Preliminary results for the addition of graphene nanoplatelets in wellbore cement indicate:

1. Graphene reinforces cement pore walls and matrix
2. No significant alterations observed to the cement microstructure or petrophysical properties
3. An increase in ultimate axial stress over 20% observed for all graphene percentages at simulated reservoir conditions
4. Addition of graphene reduced the cement brittleness and Young's modulus in the microstructure at 0.008%GNP.

FIB/SEM Short Video



Acknowledgements

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Key References

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Thank You For Listening!



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