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Impact of Graphene and the Testing Conditions on the Wellbore Cement Mechanical and Microstructural Properties

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Outline

1. Introduction
2. Relevance
3. Graphene Nanoplatelets
4. Methodology
5. Study Results
6. Discussion
7. Conclusion
8. Acknowledgements
9. Key References

Relevance

- 281 kilotons of methane released by 3.2 million abandoned wells in 2018

Groom (2020)

- Methane gas leakage of oil and gas wells are 60-100% > U.S. Environmental Protection Agency Greenhouse Gas Inventory (GHGI)

Alvarez et al. (2018) and Gorchov Negrón et al. (2020)

- Bipartisan senate bill: ~\$4.7 billion for P&A projects and clean-up

Gardner (2021)

- 2021 infrastructure plan: \$8 billion towards P&A

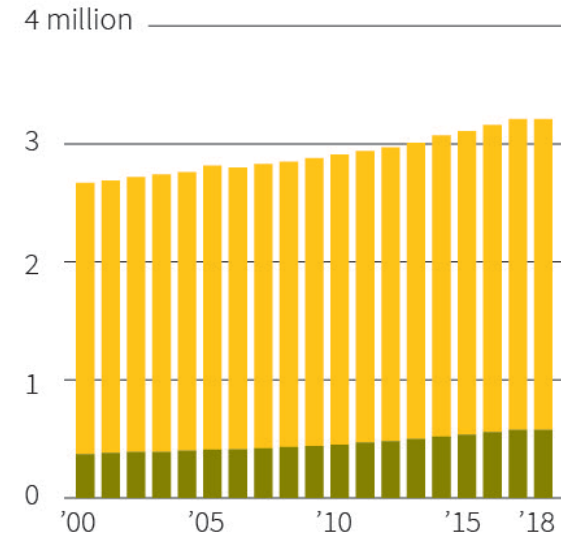
Gardner (2021)

Abandoned wells leaking methane

More than a century of oil and gas drilling has left behind millions of abandoned wells worldwide, many of which are leaching pollutants into the air and water.

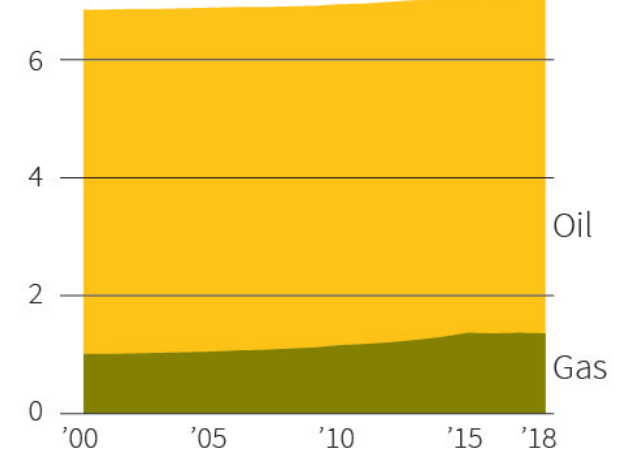
ABANDONED WELLS IN THE U.S.

Oil Gas



METHANE EMISSIONS FROM ABANDONED WELLS IN THE U.S.

8 million metric tons of CO₂ equivalents



Source: Environmental Protection Agency

Staff, 4/6/2020

REUTERS

<https://graphics.reuters.com/USA-DRILLING/WELLS/gjnpwylaapw/USA-DRILLING.jpg>

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

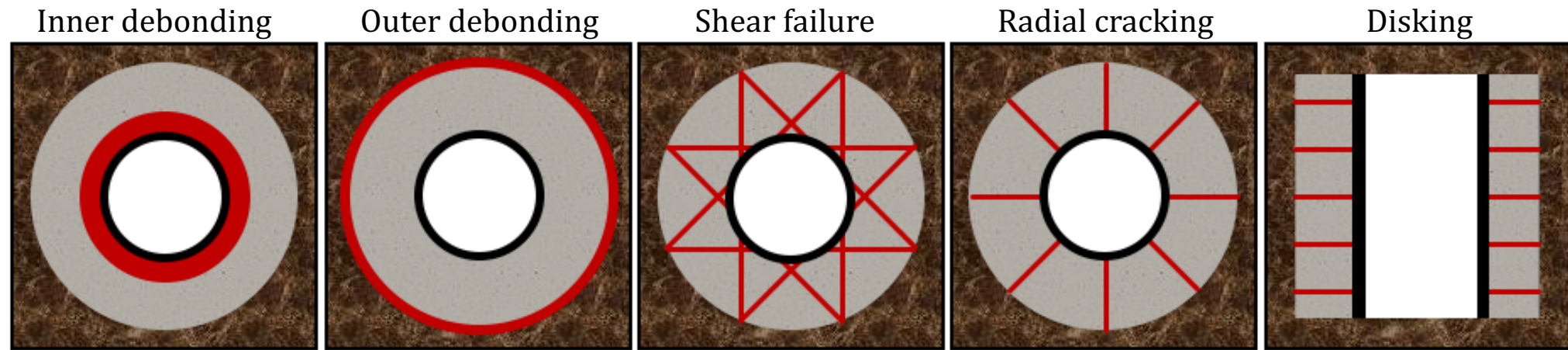


Figure 1: Common failure mechanisms of wellbore cement (red) creating leakage of subsurface fluids out of the well. Modified from Petty et al. (2003).

Scanning Electron Microscopy: *Morphology of Graphene*

Thinnest yet Strongest material currently known

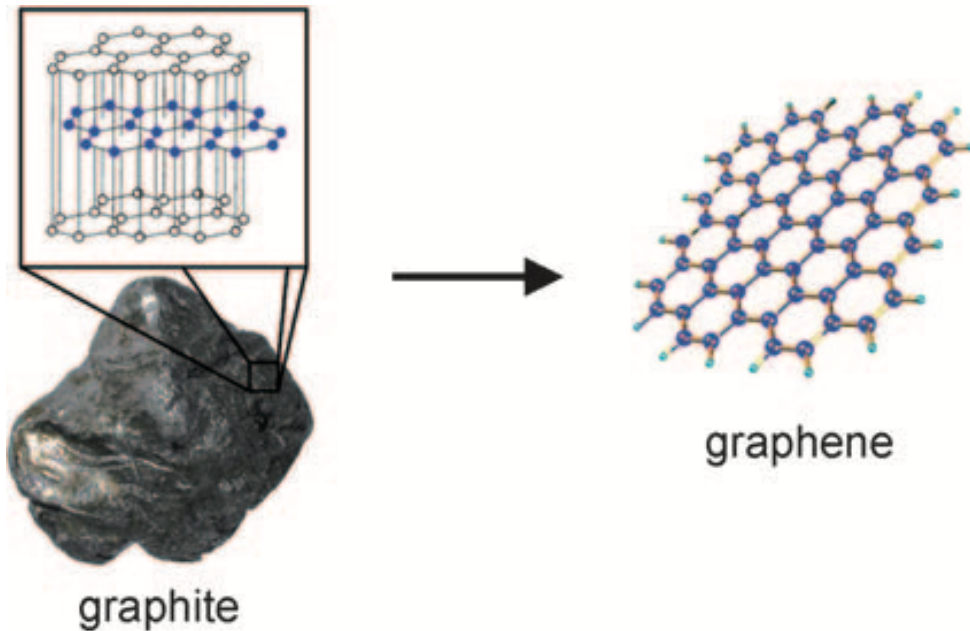


Figure 2: Graphic model of the transformation of graphene derived from graphite. Carbon atoms form hexagonal ring bonds that repeat to develop single graphene platelets with a thickness of one carbon atom. Dreyer et al. (2010).

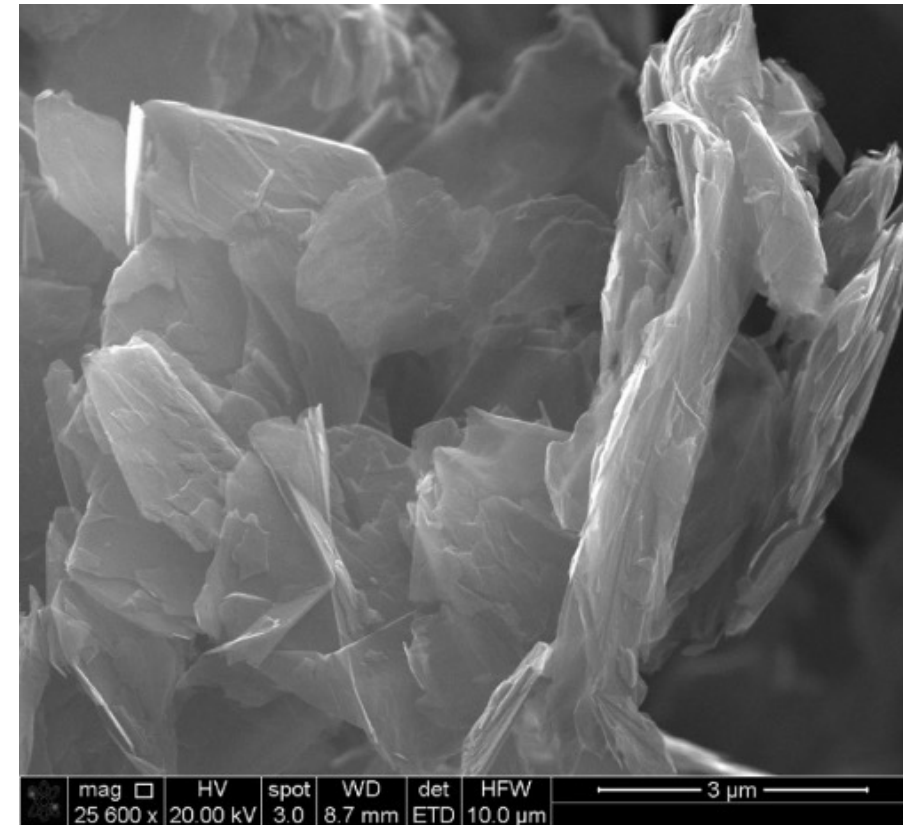


Figure 3: Graphene nanoplatelets at magnification of 25,600x depicts thin and nearly transparent individual platelets form layers.

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, and 0.1%** 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

Sample testing:

- Scanning Electron Microscopy (SEM)
- Electron Dispersive Spectroscopy (EDS)
- Micro indentation
- Triaxial loading cell tests at simulated pressure and temperature
- Computed Tomography (CT) scanning

SEM: *Identifying Mechanisms of Graphene in Cement*

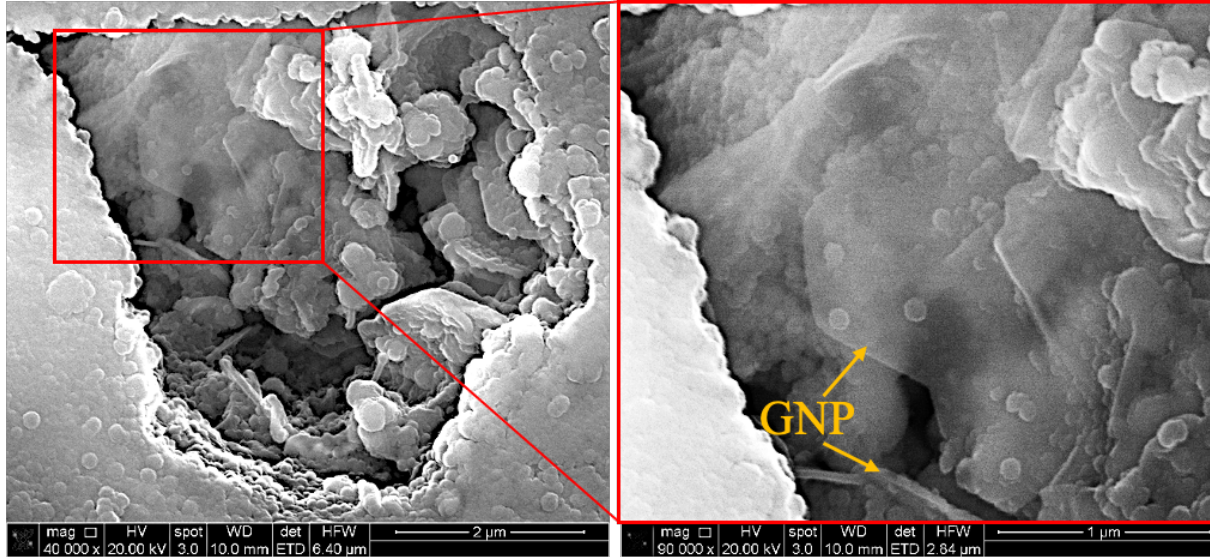
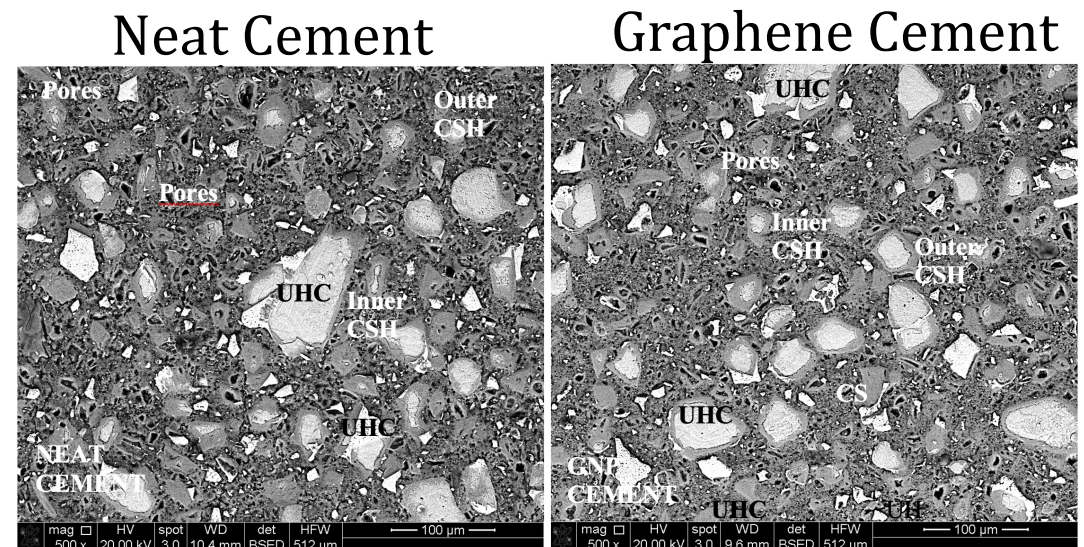


Figure 4: Graphene nanoplatelets imbedded into cement micropore space.

- 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))



SEM: *Observations of Graphene within Micropore Walls*

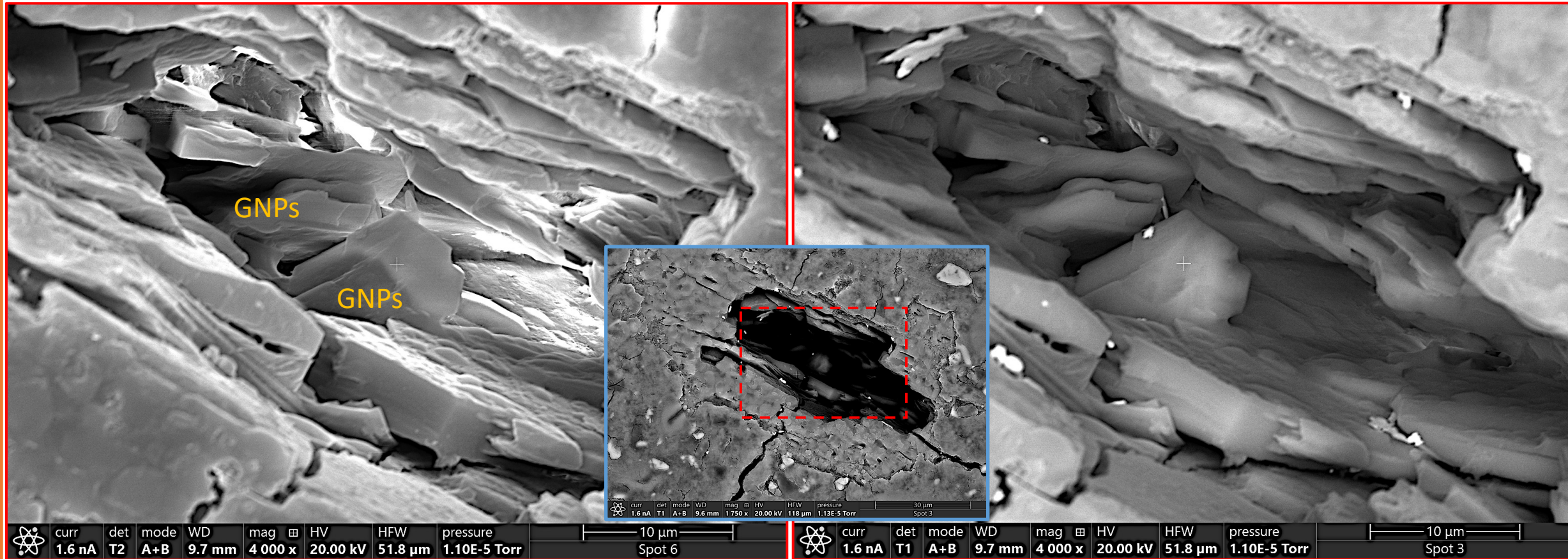


Figure 6: Graphene nanoplatelets reinforcing the micropore structure in secondary electron (left) and backscatter (right) imaging.

Correlative Microindentation: *Linking microstructure to micromechanics*

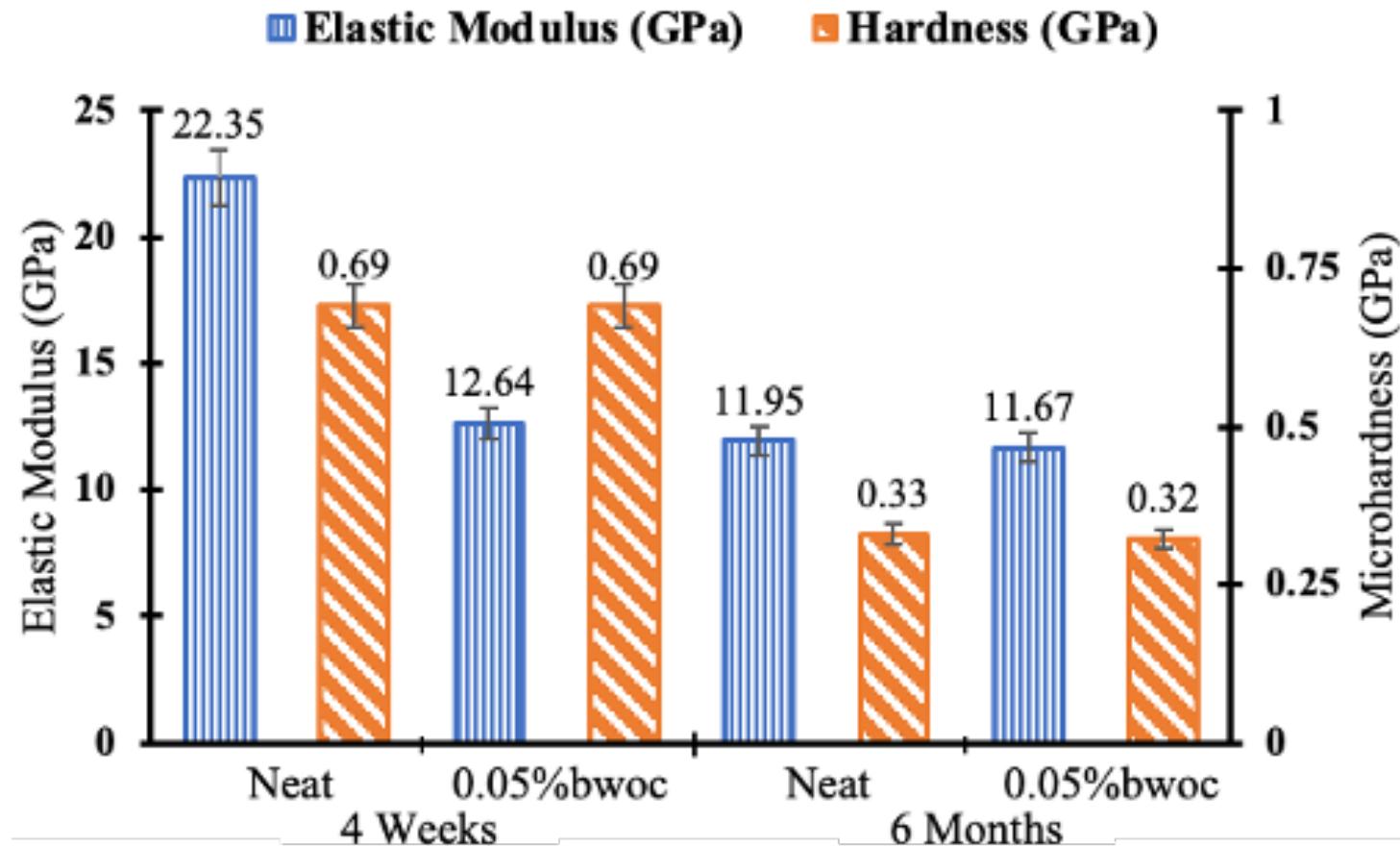


Figure 7: Micro-Vickers indentation conducted on a 5x5 matrix (25 indents) on neat cement and 0.05% graphene addition. Elastic modulus of graphene cement >40% that of neat.

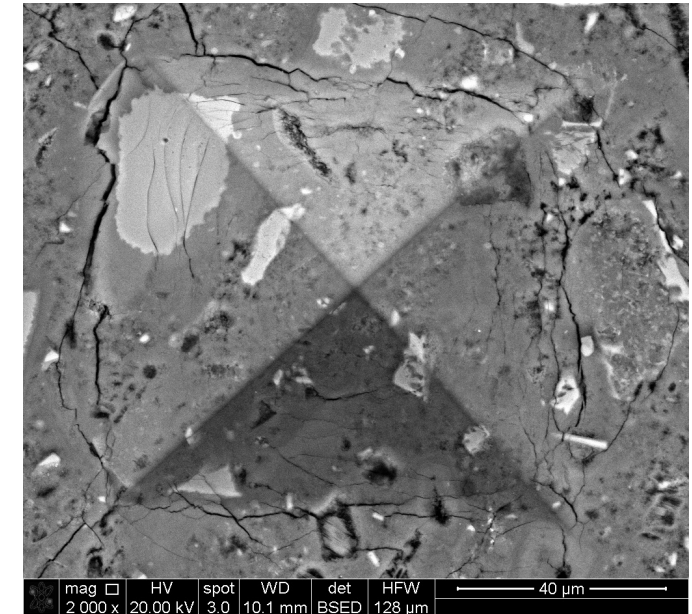


Figure 8: Backscatter electron image containing indentation by Vickers diamond indenter.

- Reduction of elastic modulus with addition of graphene compared to Neat cement

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

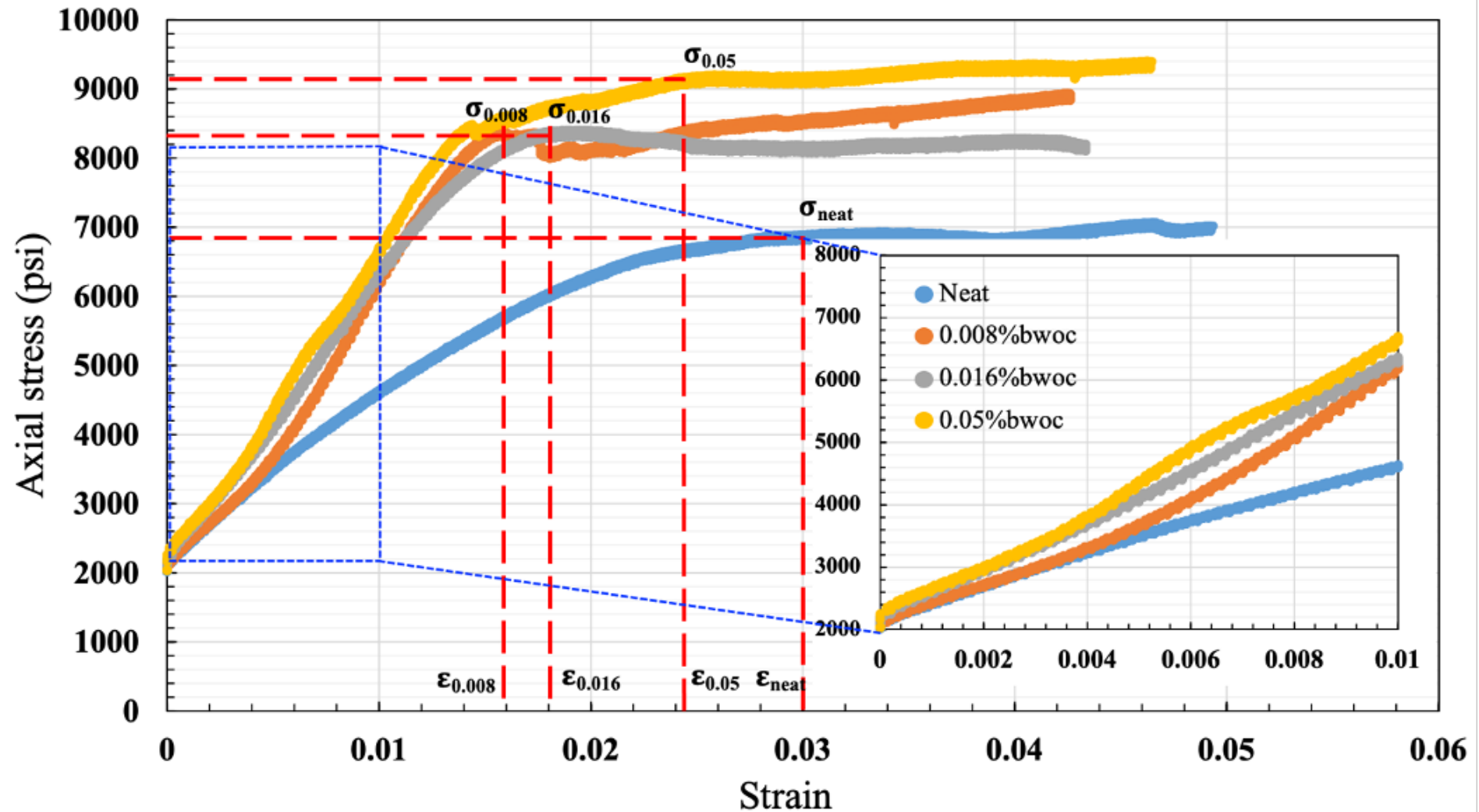


Figure 9: Triaxial compressive testing at simulated wellbore conditions of 90°C (194°F) and Confining pressure of 13.7Mpa (2,000psi).

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

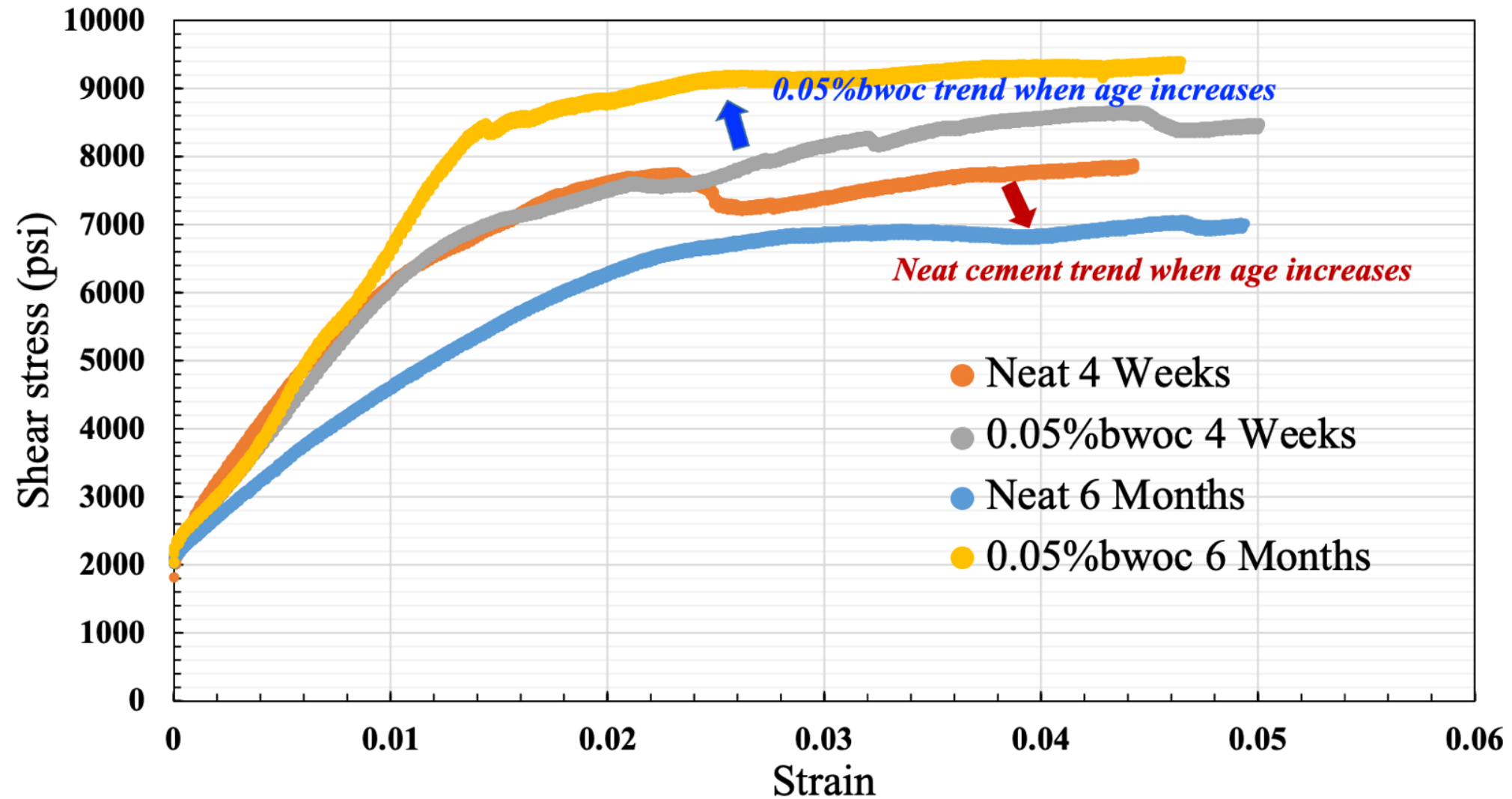
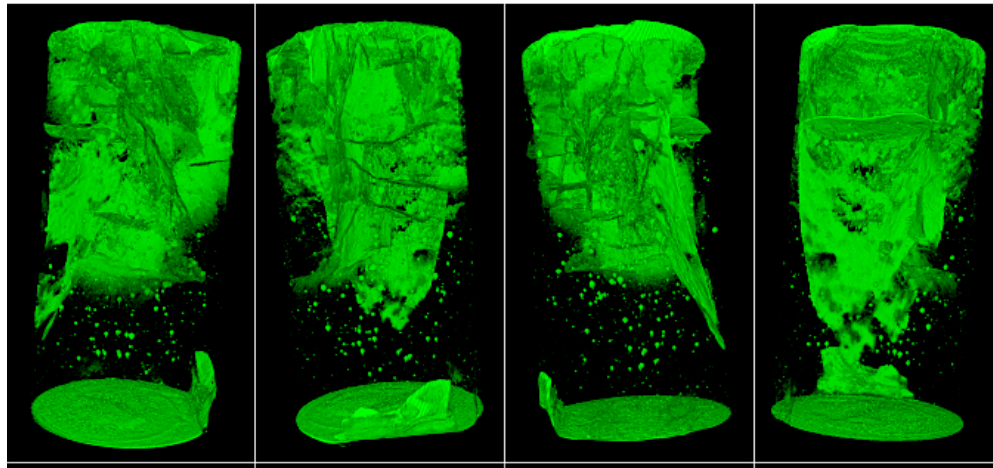


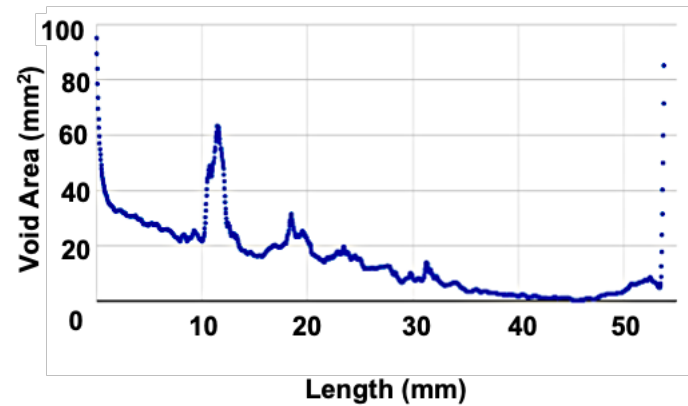
Figure 10: Strain-stress curve comparison between different ages of neat cement and 0.05%bwoc cement (4 weeks and 6 months).

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

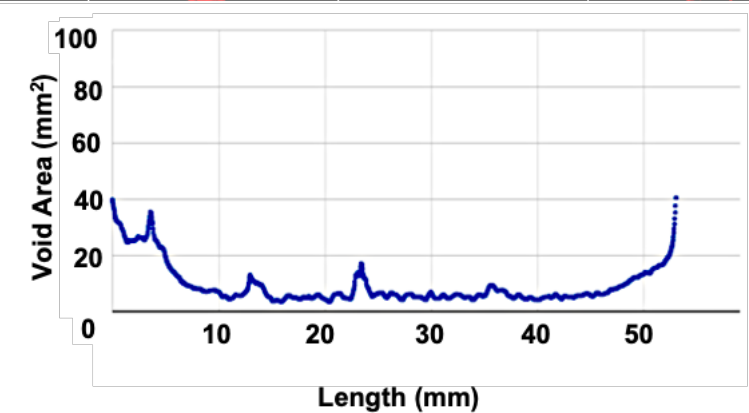
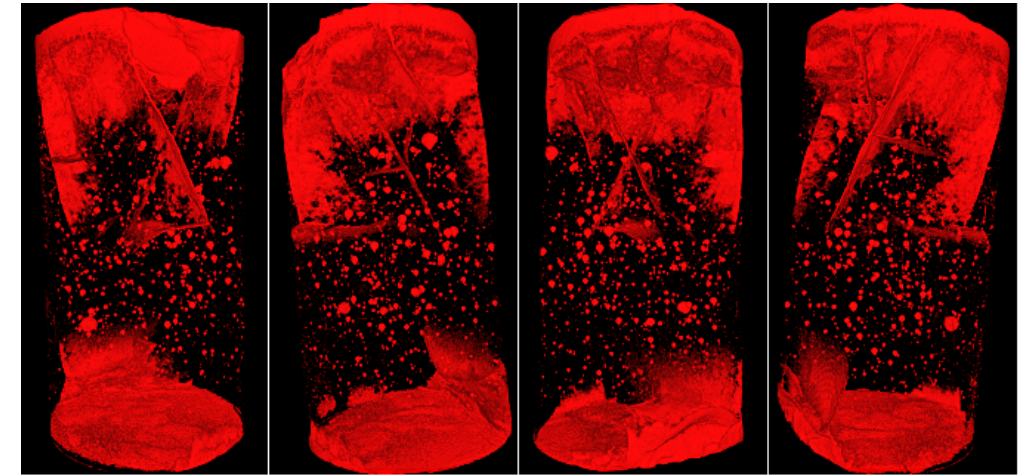


Figure 11: Calculated void space using CT scanning conducted after triaxial fracturing

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).

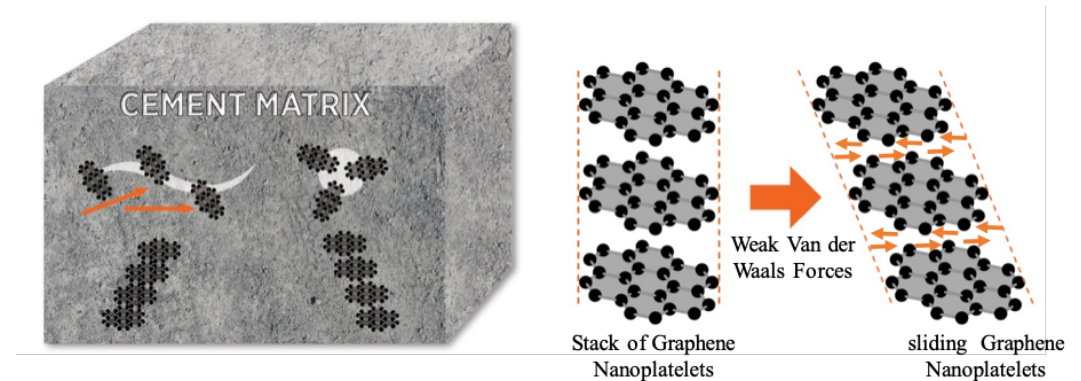


Figure 12: Proposed mechanisms of graphene nanoplatelets within the cement matrix by bridging fracture propagations, reinforcing pore structures, and stack and sliding due to Van der Waals forces between the platelets.

Conclusion

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

1. Graphene reinforces cement pore walls and matrix
2. An increase in ultimate axial stress over 20% observed for all graphene percentages at simulated reservoir conditions
3. Addition of graphene significantly reduced the cement brittleness 4 weeks
4. Preparation, aging, and testing wellbore cement at simulated conditions is imperative when testing materials to be used for wellbore construction

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