Wellbore Seal Repair Using Nanocomposite Materials

Project Number DE-FE0009562

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National Energy Technology Laboratory

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Presentation Outline

- Materials development
- Wellbore system testing
- Numerical model development

Benefit to the Program

- **BENEFITS STATEMENT: The project involves the development and testing of polymer nanocomposites for repairing flaws in annular wellbore seals. These materials will have superior characteristics compared to conventional materials, ensuring hydraulic isolation of the wellbore after closure. The technology contributes to the Program's effort of ensuring 99% CO_2 storage permanence.**

Project Overview: Goals and Objectives

- (1) Develop and test ***nanocomposite seal repair materials*** suitable for expected wellbore environments that have ***high bond strength*** to casing and cement, ***high fracture toughness,*** and ***low permeability***.
  - These materials will have superior properties compared to conventional materials to permit improved wellbore seal repair, contributing to the program's goal of 99% storage permanence.
  - Success criteria: Materials shall have superior properties and characteristics compared to conventional materials.

Project Overview:
Goals and Objectives (CONTINUED)

(2) Evaluate the effectiveness of developed materials to repair flaws in ***large lab-scale annular seal systems*** under conditions expected in wellbores.

- Evaluation and understanding of the expected performance of these materials to repair flaws within sealed wellbores will lead to more confidence in the ability to ensure 99% CO_2 storage permanence.
- Success criteria: The degree to which system permeability to CO_2 is reduced after repair, cost, material availability and ease of use compared to conventional materials.

Project summary

- **Polymer nanocomposites** (PNCs) have been developed as repair materials with **superior properties** suitable for expected wellbore environments.

Materials Development

We synthesized **26 candidate nanocomposites** using combinations of base polymers and nanoparticles.

Results were compared to reference microfine cement.

A comprehensive test program was used to down select to best repair material.

Flowability

↓

Bond strength

↓

Ductility

↓

Push-out tests

↓

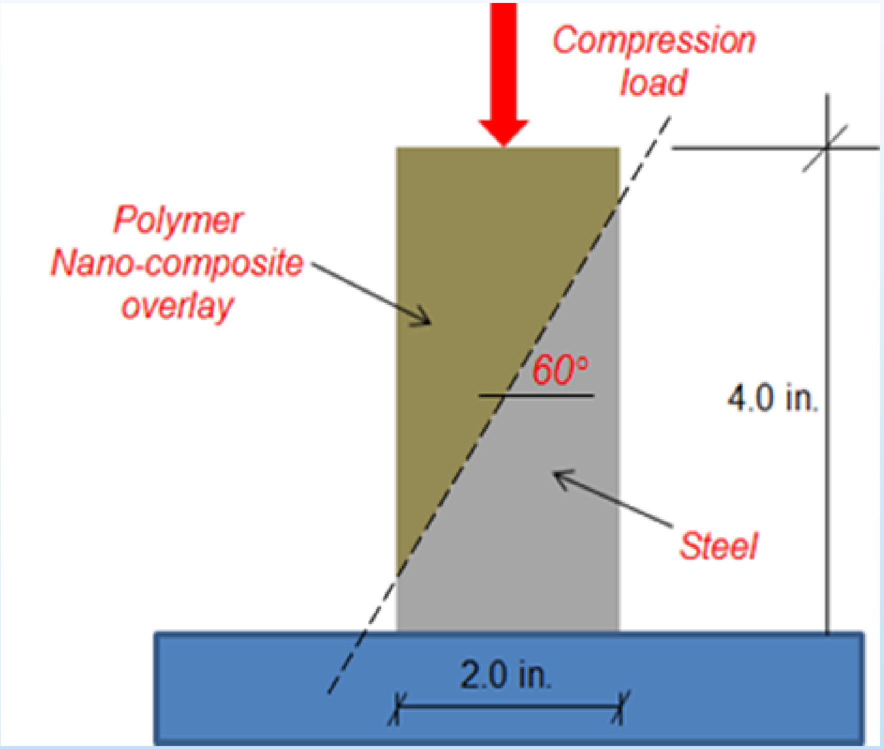
Penetrability

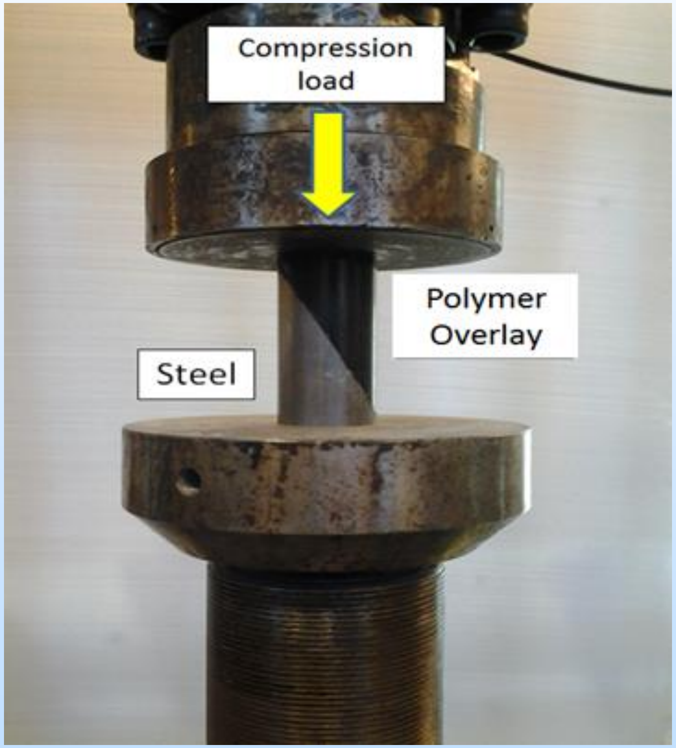
↓

<u>Best repair material</u>
Novolac epoxy with 2% nanoalumina

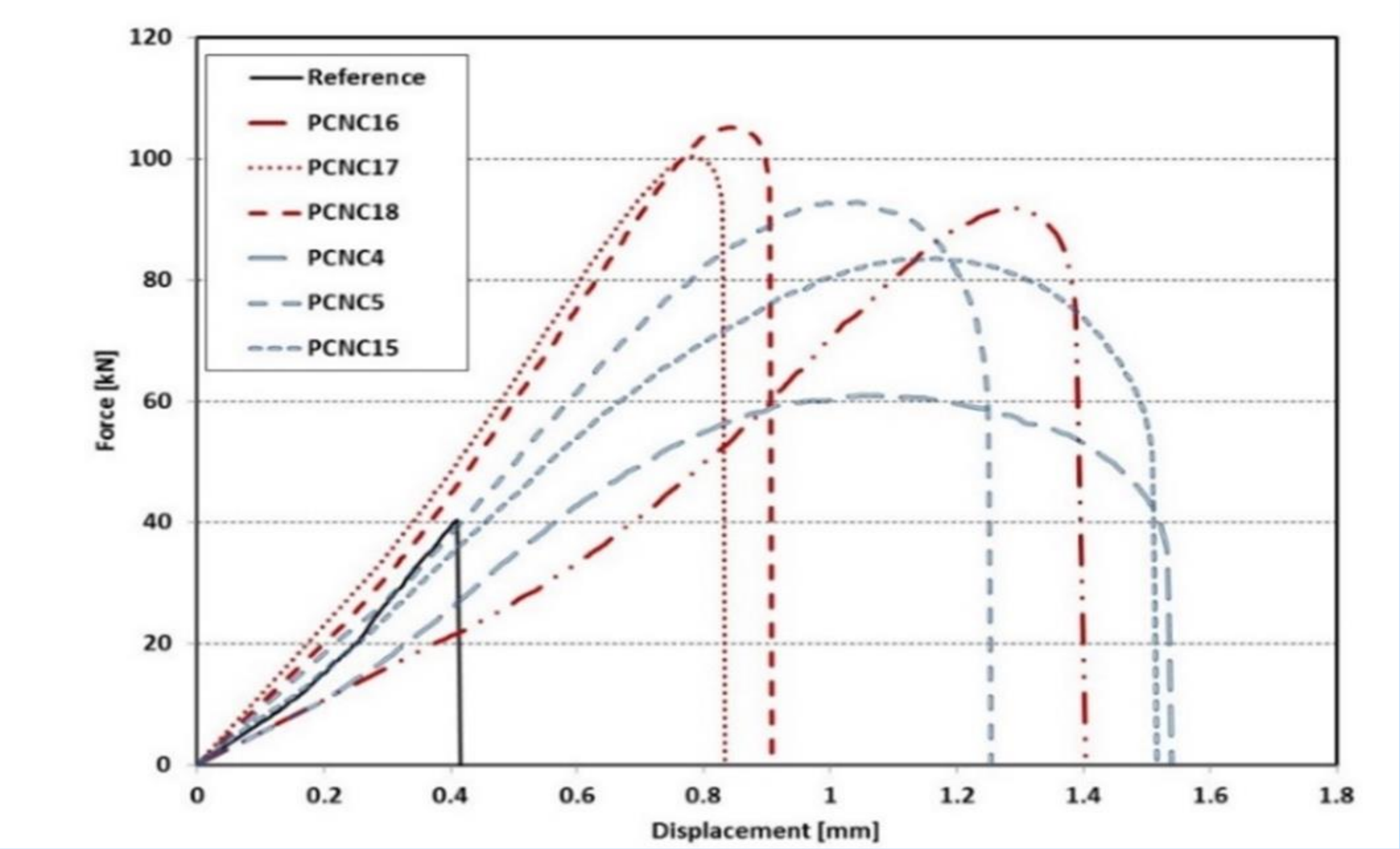
Bond strength characterization

- Slant shear test – a direct measure of PNC – steel bond strength



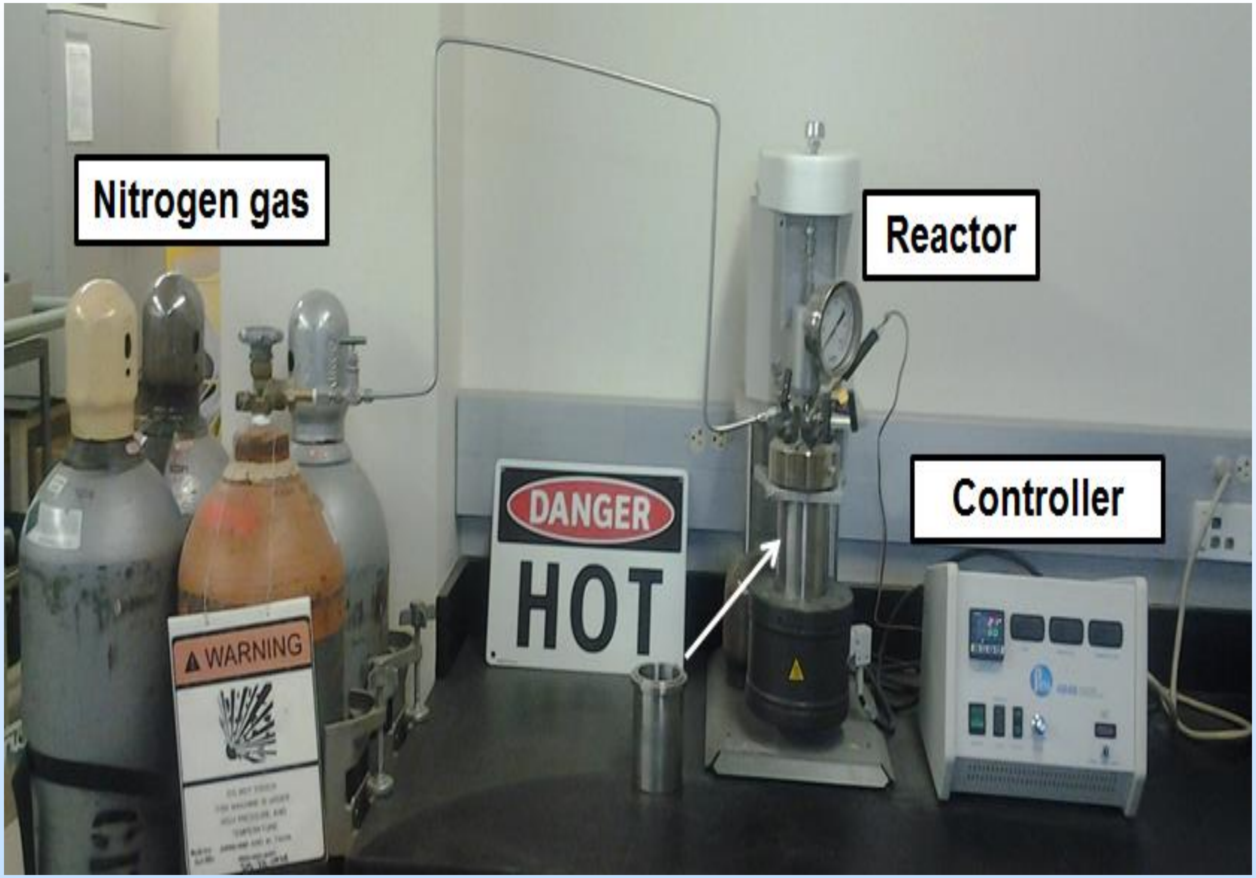


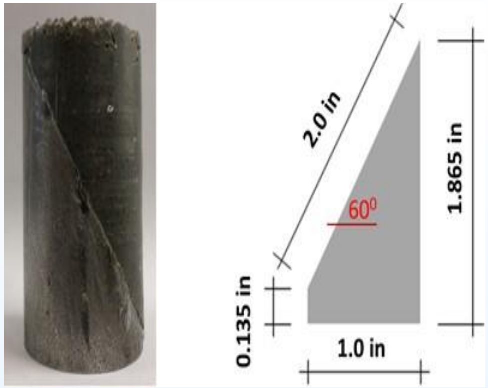
Slant shear test data reveal many PNCs has ***much greater bond strength to steel*** *and is* ***more ductile*** *than cements.*



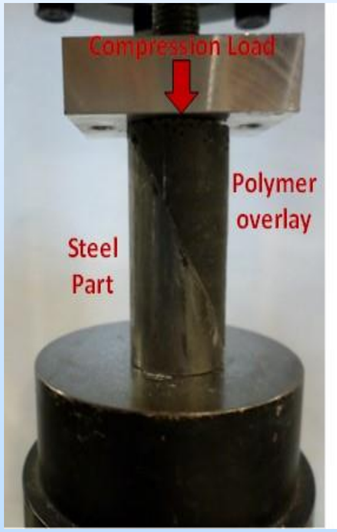
Douba, A. E., Genedy, M., Matteo, E., Stormont, J., Reda Taha, M. M., "Apparent vs. True Bond Strength of Steel and PC with NanoAlumina", Proceedings of International Congress on Polymers in Concrete (ICPIC), Singapore, Advanced Materials Research, Vol. 1129, pp. 307-314, October 2015.

Examining the effect of high temperature and pressure



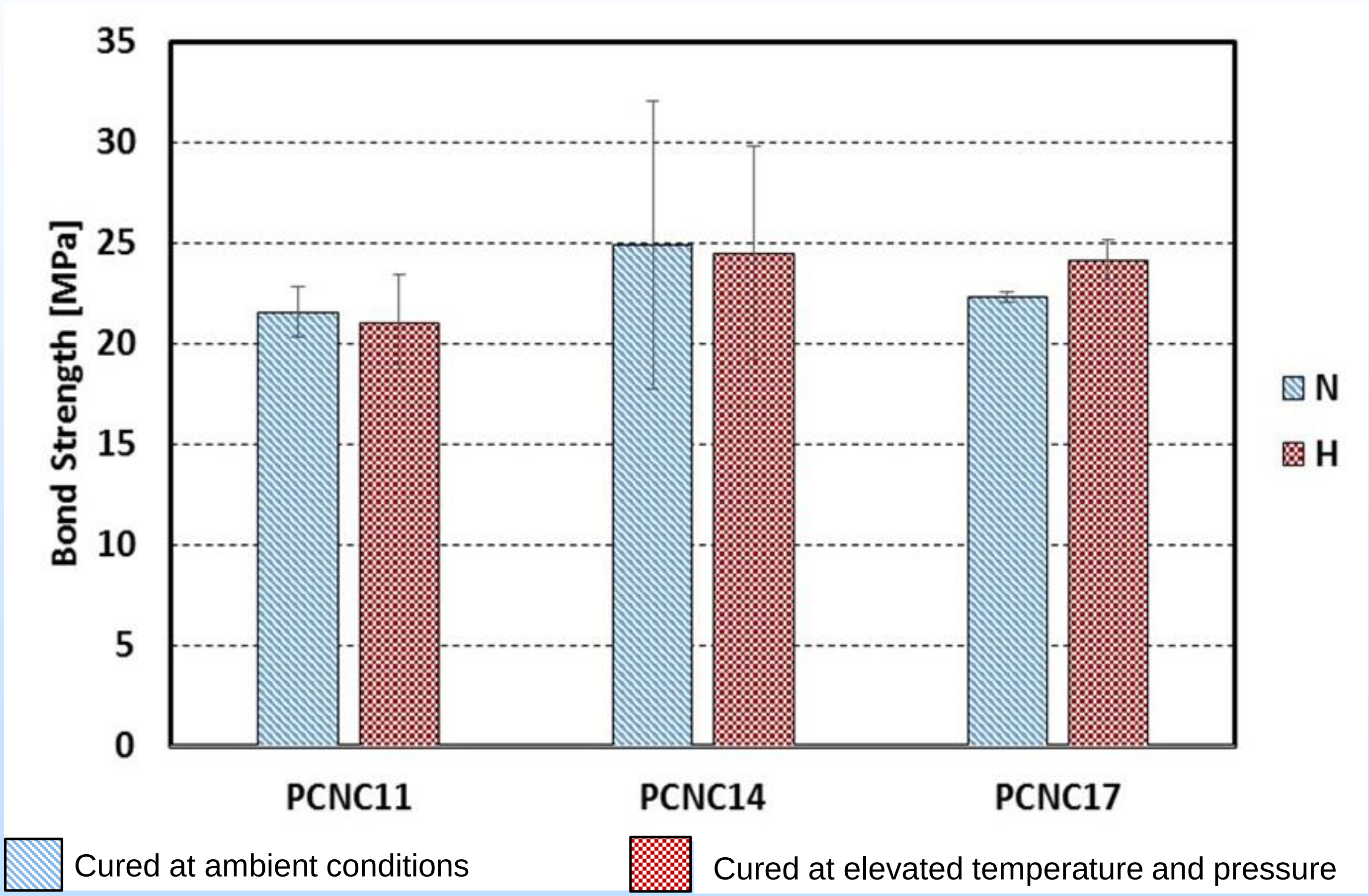


Scaled specimens

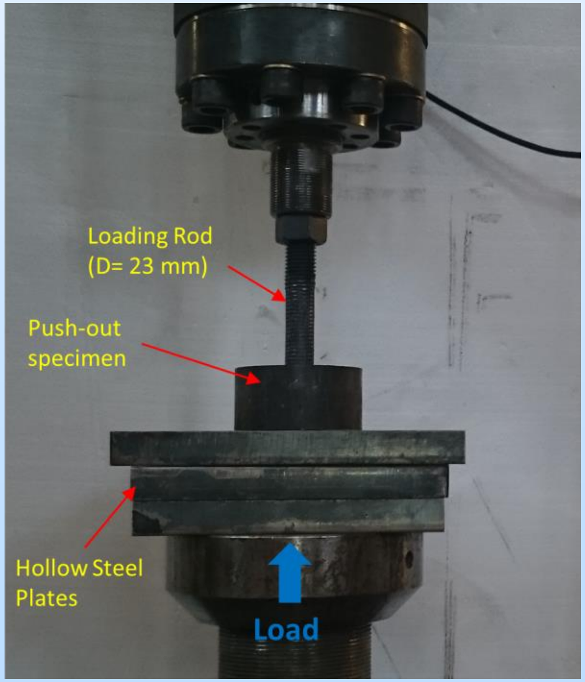


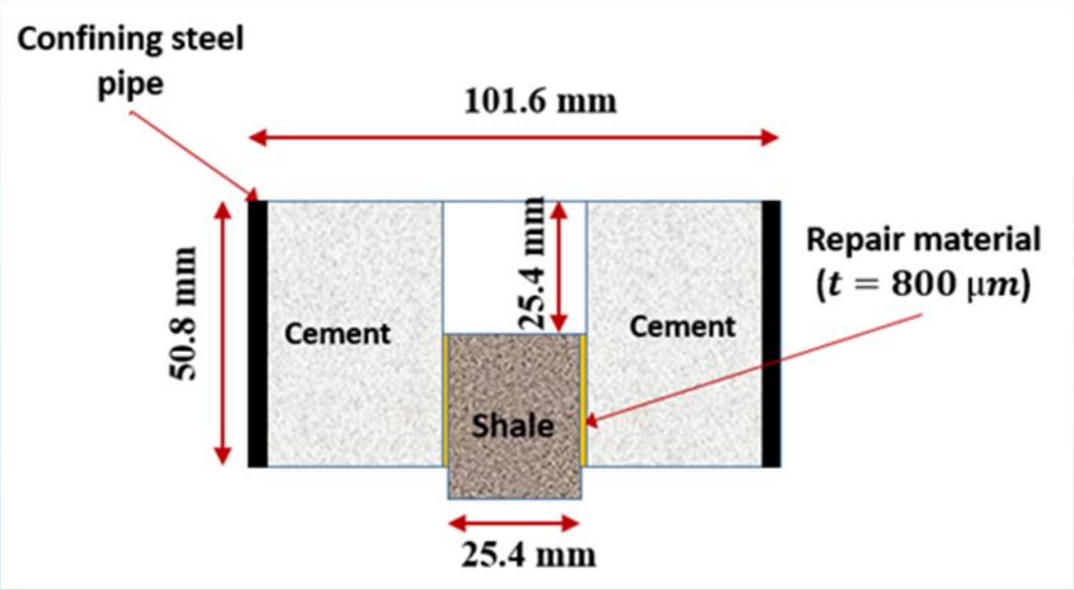
Temp: 80 °C, Pressure 10 MPa

No effect of elevated temperature and pressure on performance of PCNC

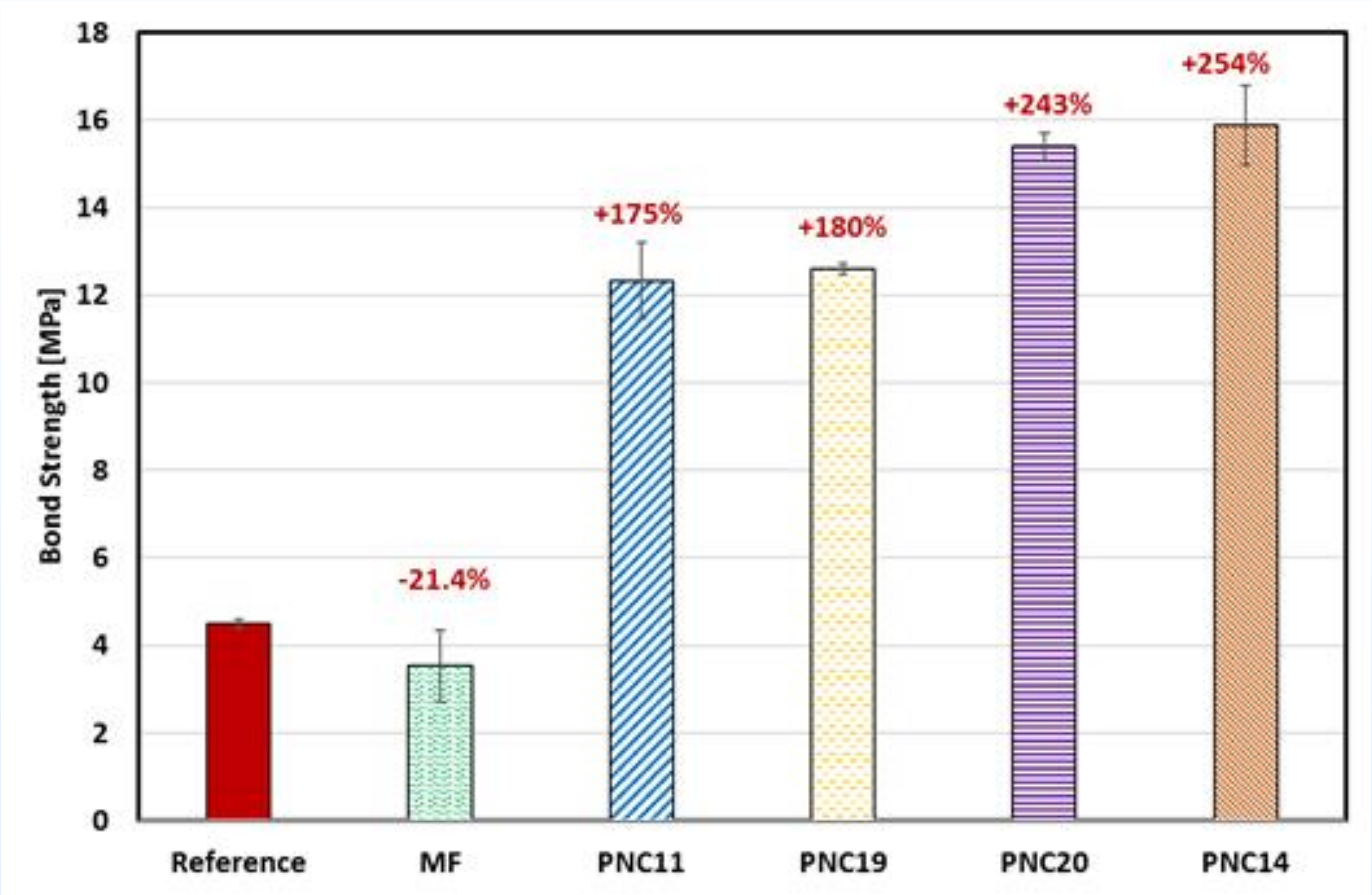


Push-out tests evaluated bond strength between shale and repaired shale-cement interfaces.



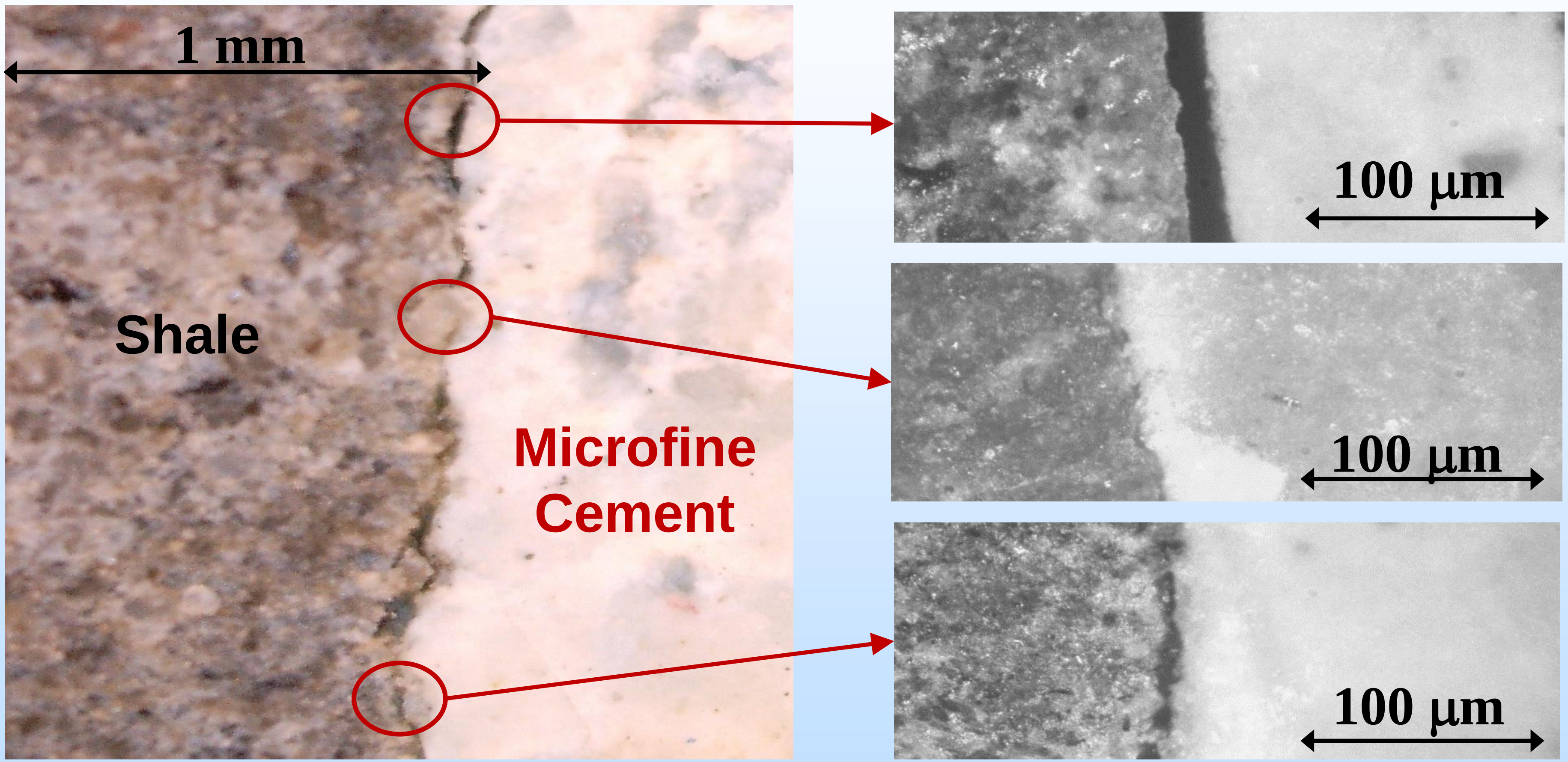


*PNCs had much **greater push-out strength** compared to microfine cement.*



Genedy, M., Kandil, U. F., Matteo, E., Stormont, J., Reda Taha, M. M., "A new polymer nanocomposite repair material for restoring wellbore seal integrity", International Journal of Greenhouse Gas, Accepted for publication, 2016.

Repair of shale-cement interface with microfine cement



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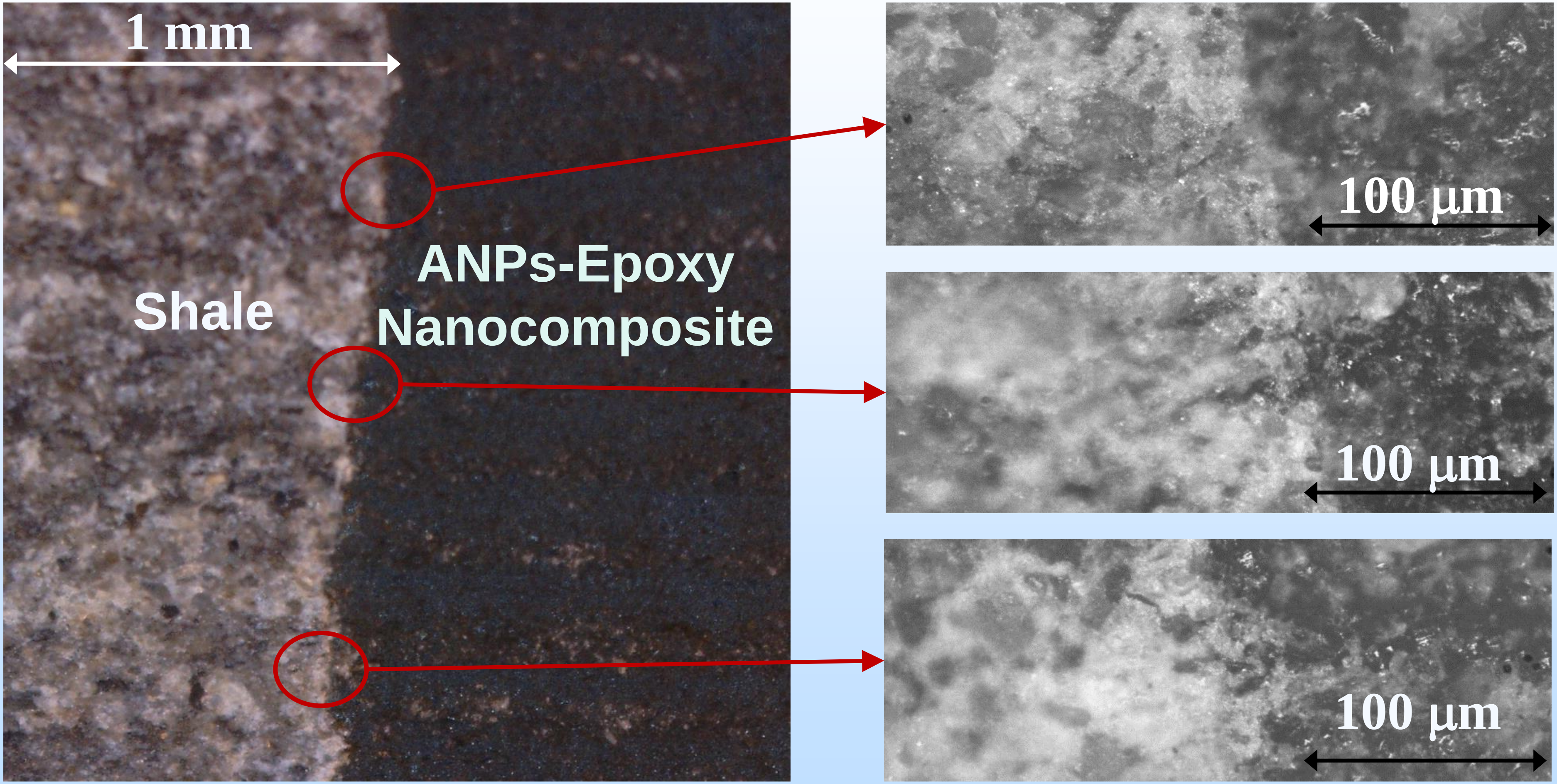
Repair of shale-cement interface with polymer nanocomposite



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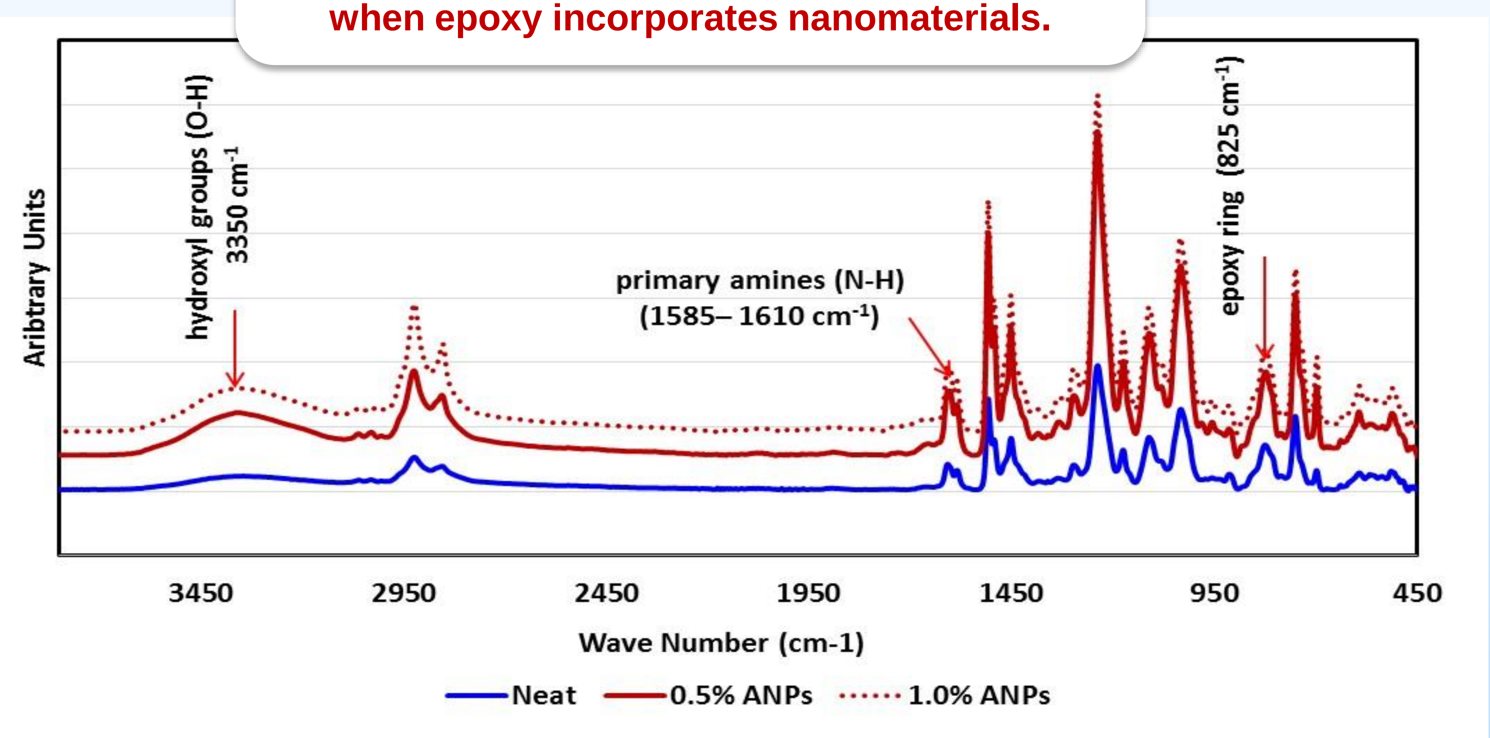
Nanomaterials enable synthesizing a polymer nanocomposite with improved characteristics

FTIR spectra of neat epoxy and epoxy incorporating nanomaterials showing significant changes in interface chemistry when epoxy incorporates nanomaterials.



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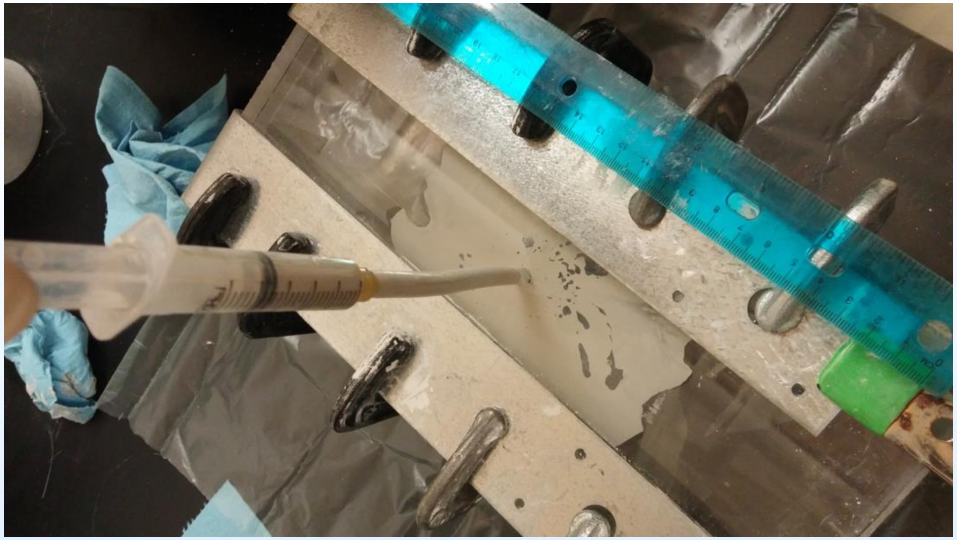
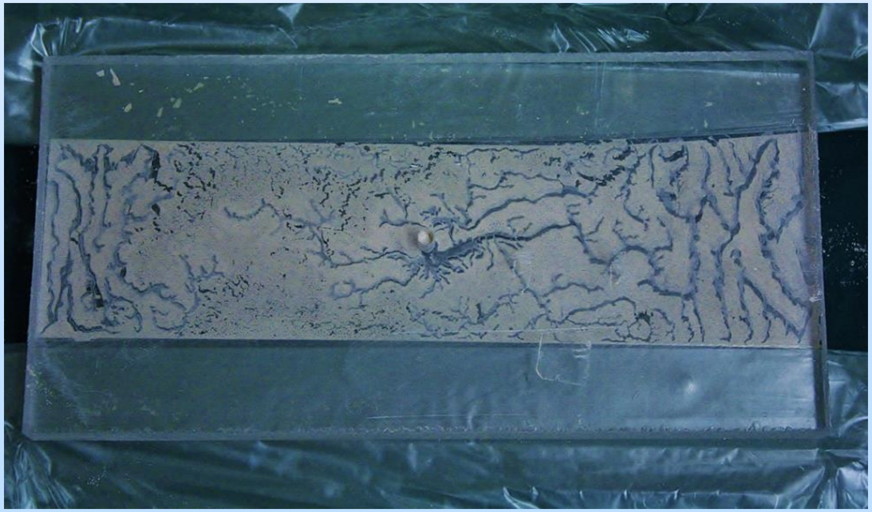
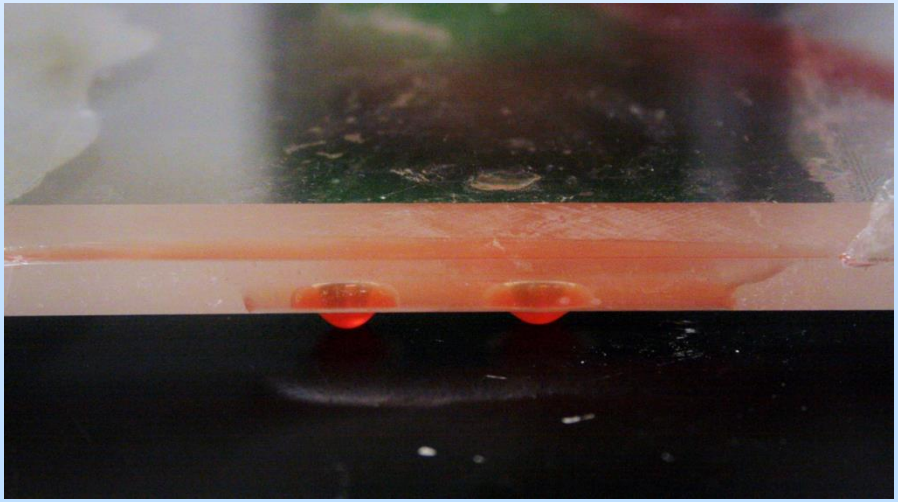
Penetrability



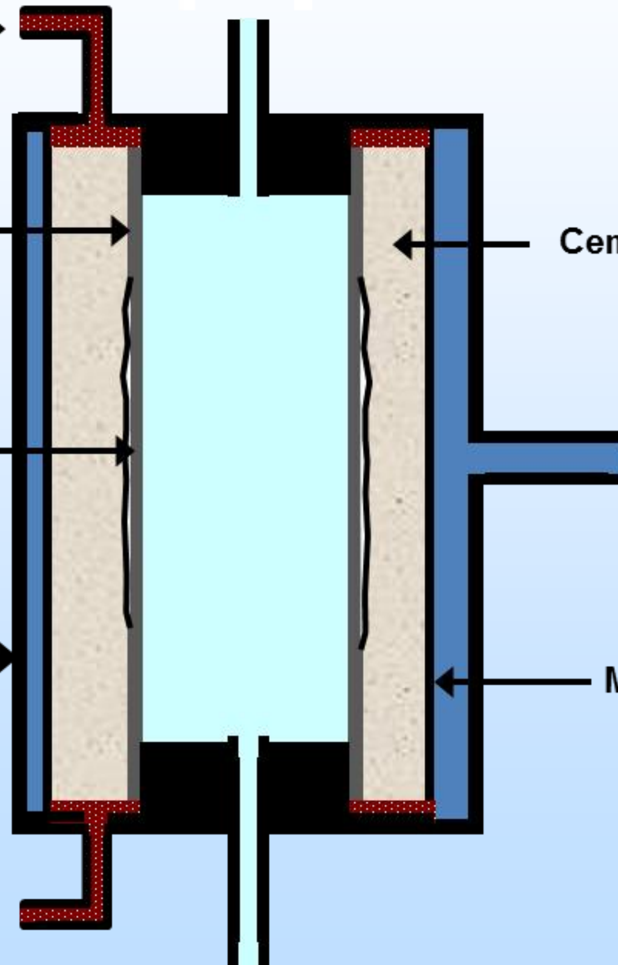
Microfine penetrated 75 μm gap



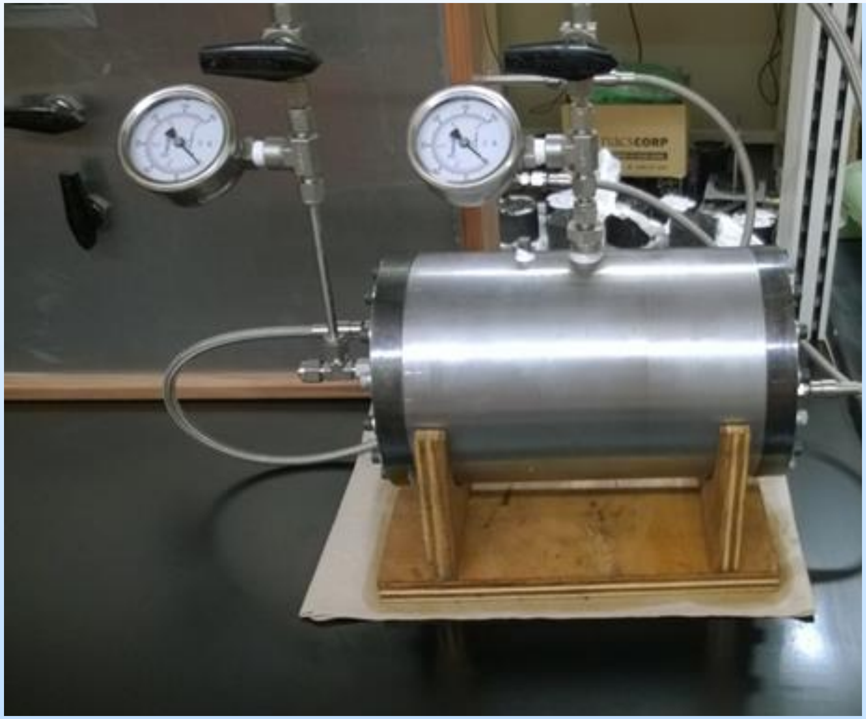
Nanocomposite penetrated 13 μm gap

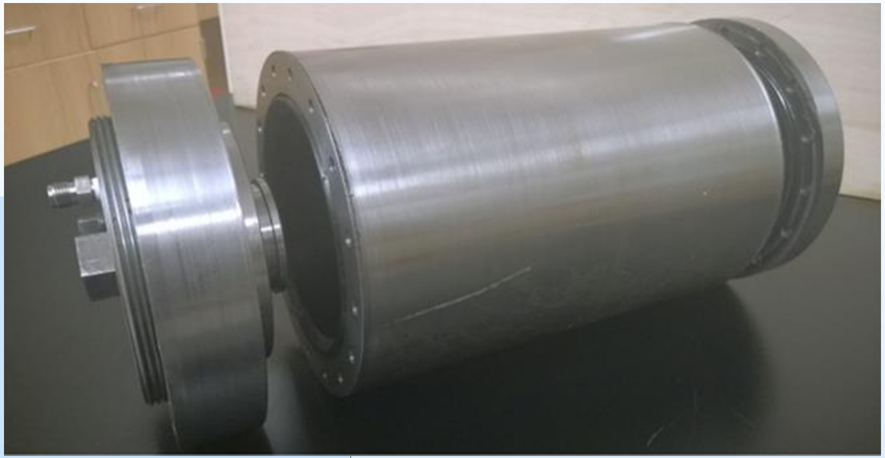


Testing damaged and repaired wellbore systems



Pressure vessel



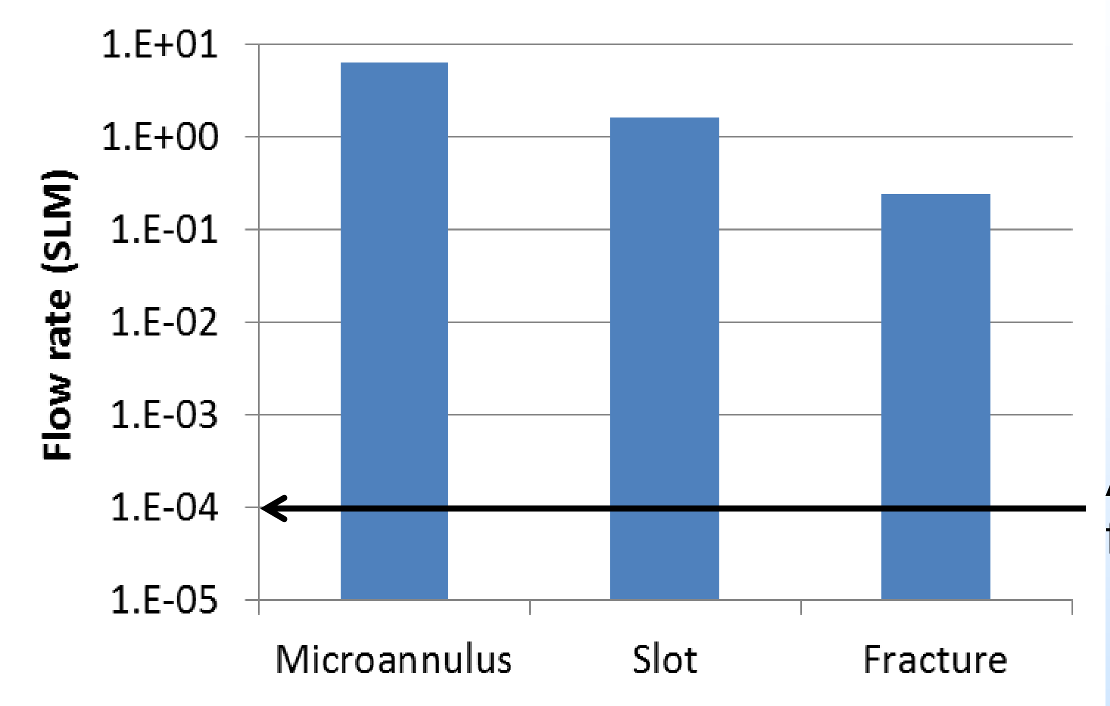


Independent control of confining pressure to 30 MPa and casing pressure to 20 MPa.

Specimen preparation

- Microannulus
  - Large
  - Small
- Cement fracture

Flow dominated by flaws



Approximate flow rate for intact specimen

Cubic law for hydraulic aperture

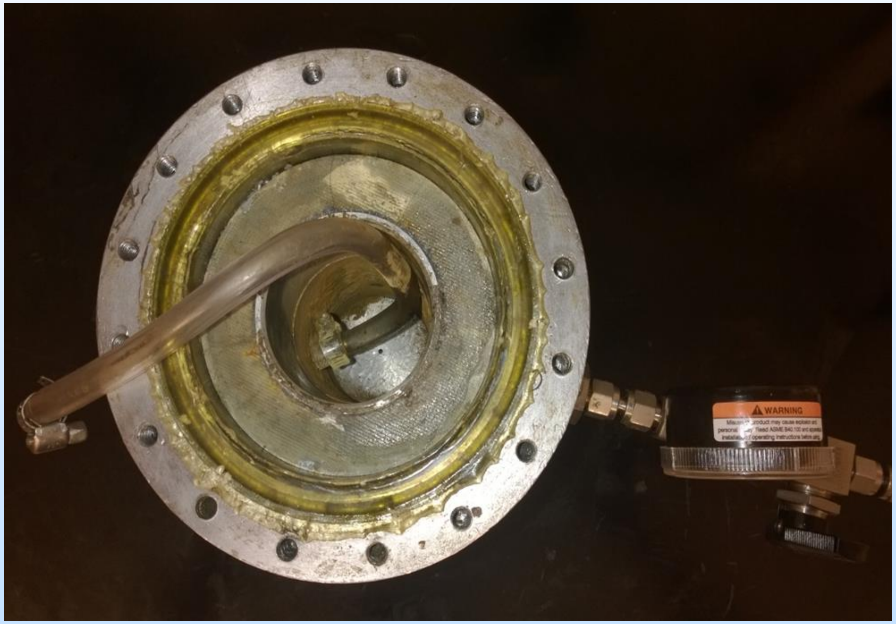
$$h^3 = \frac{12\,k\,A}{w}$$

Repair of damaged wellbores

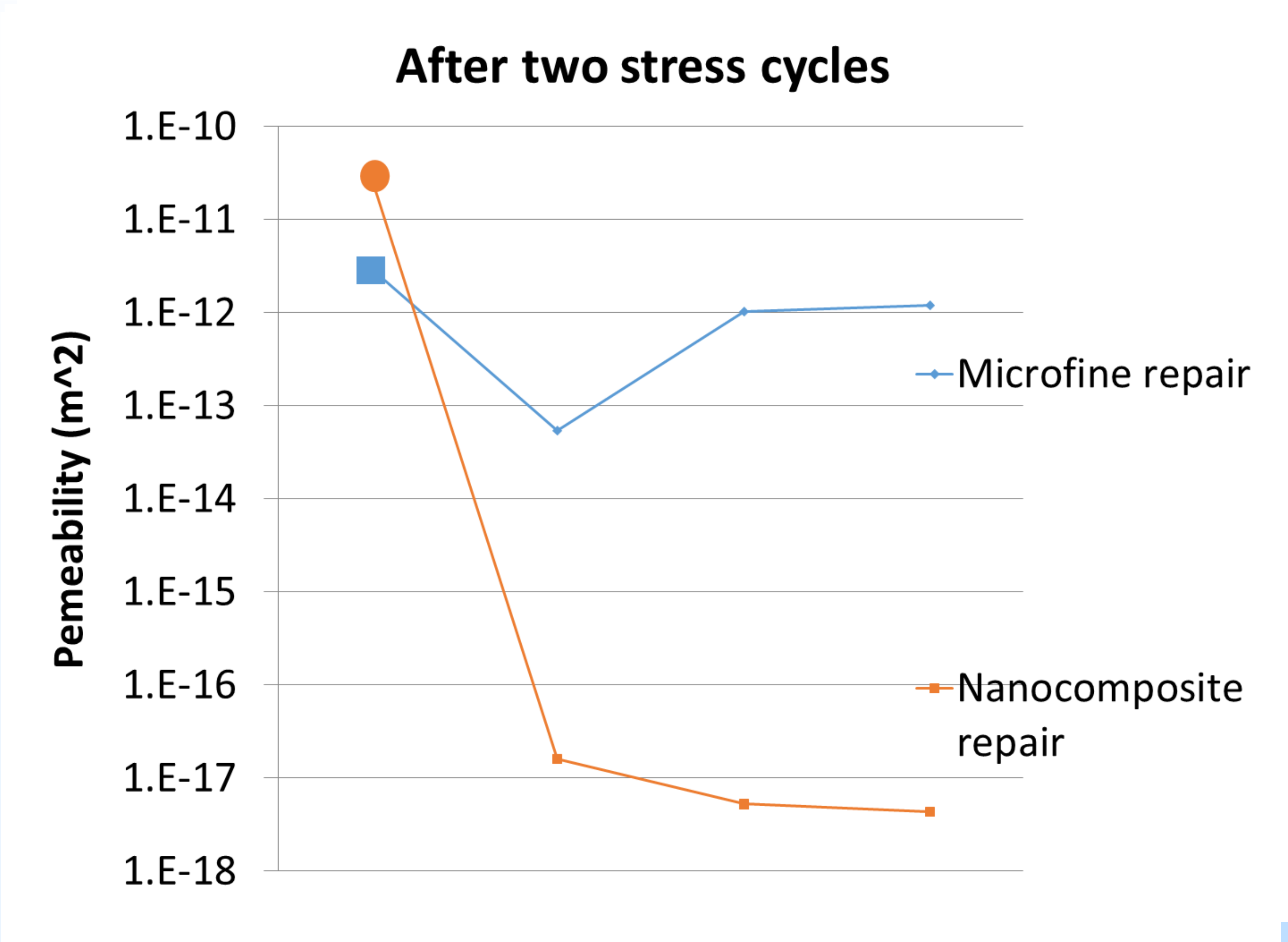
1. No pressure

2. Separate pressurized system

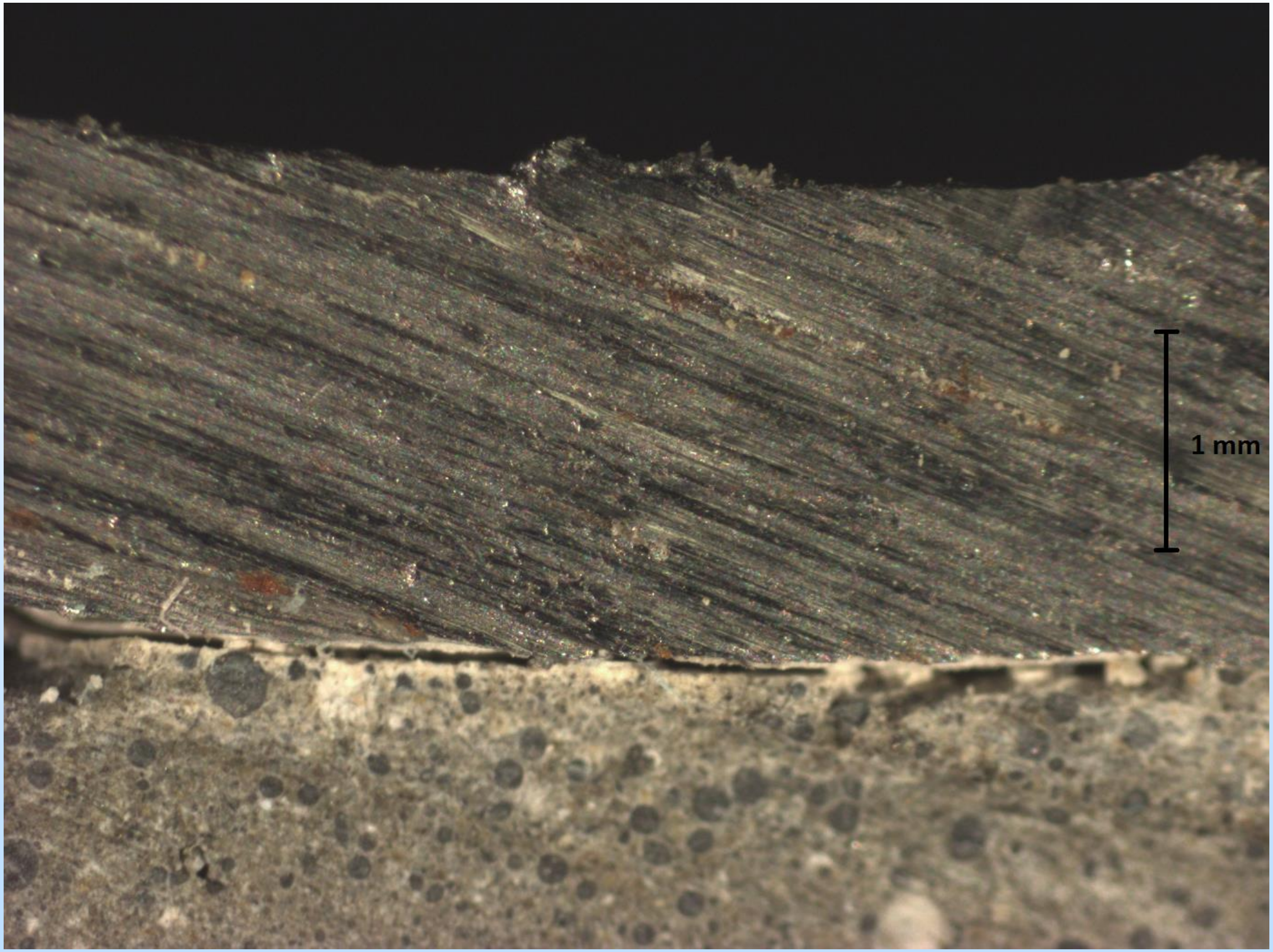
3. In pressure vessel



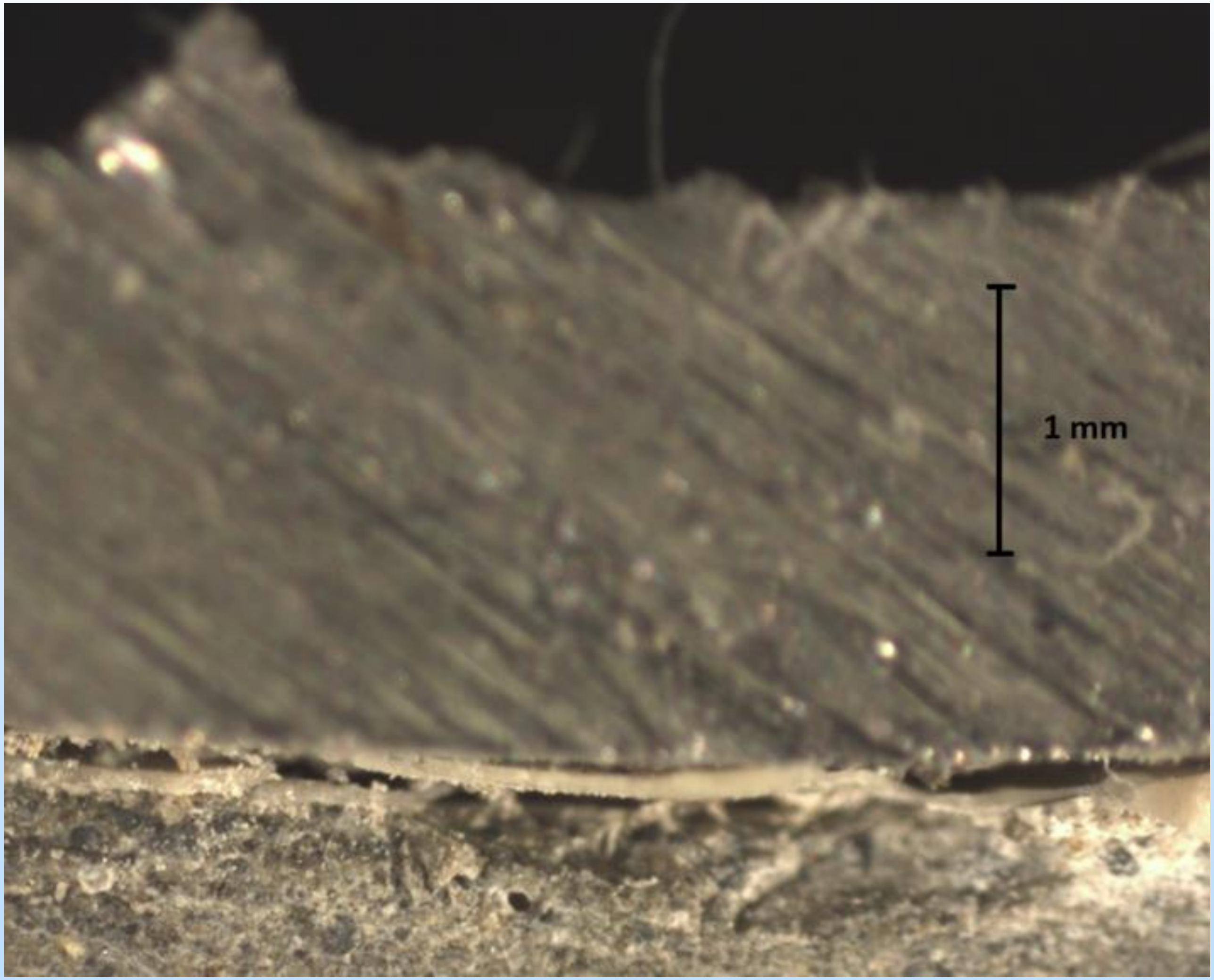
Repair response to stress cycles



Repaired with microfine cement



Repaired with microfine cement



Repaired with polymer nanocomposite

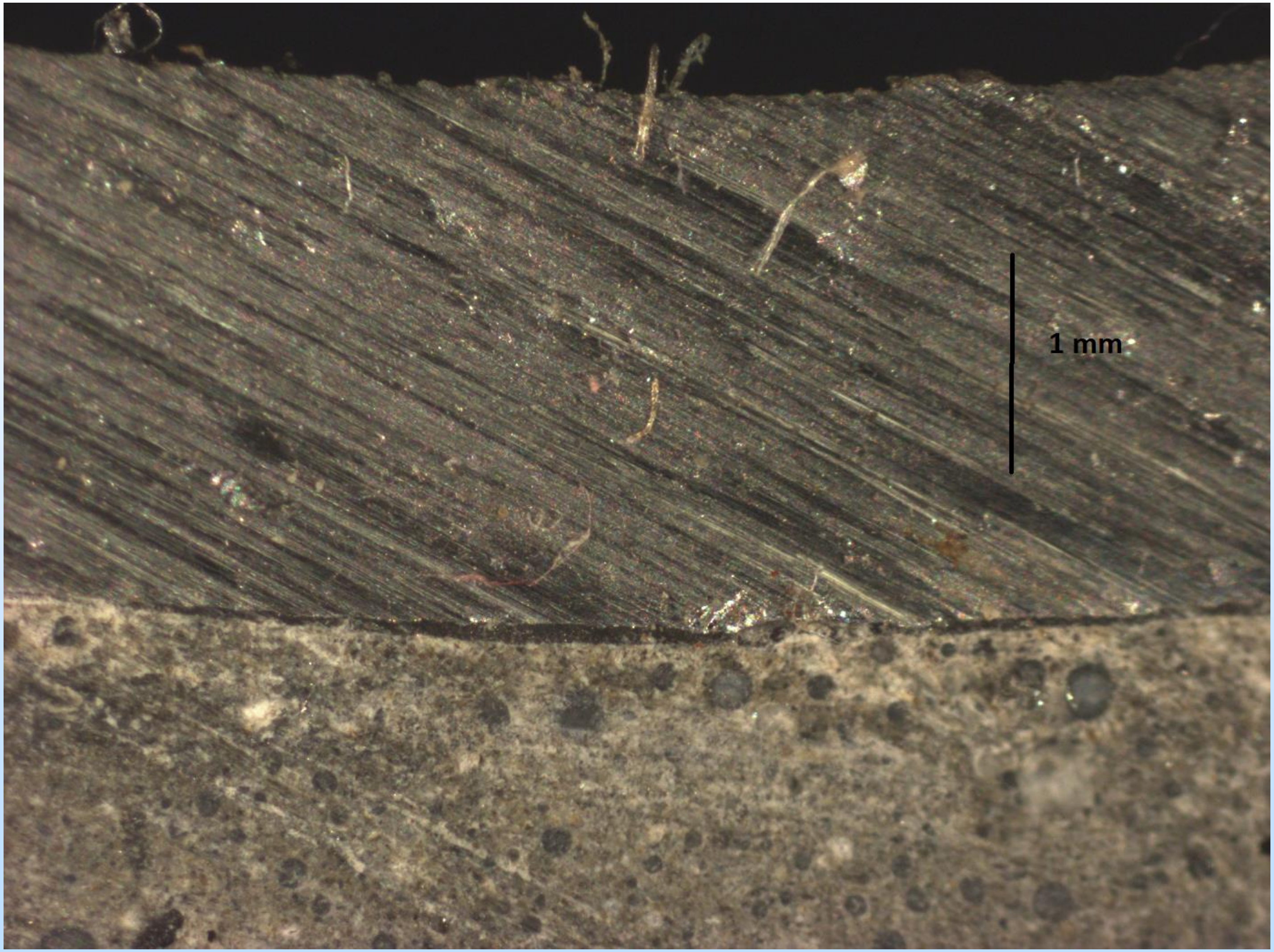
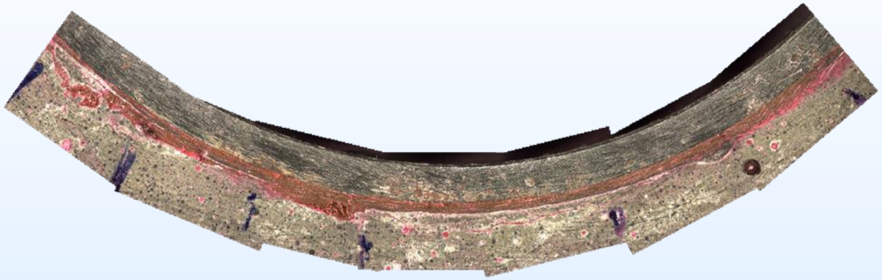
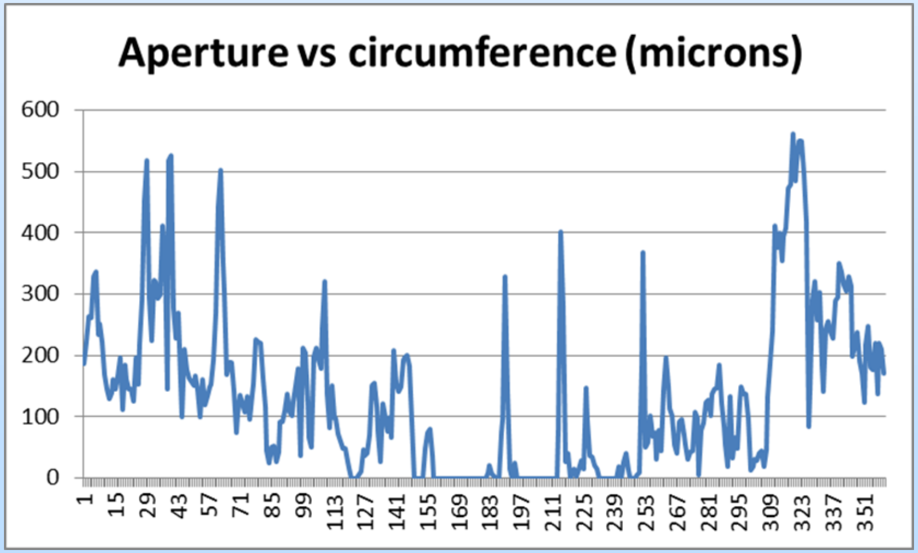
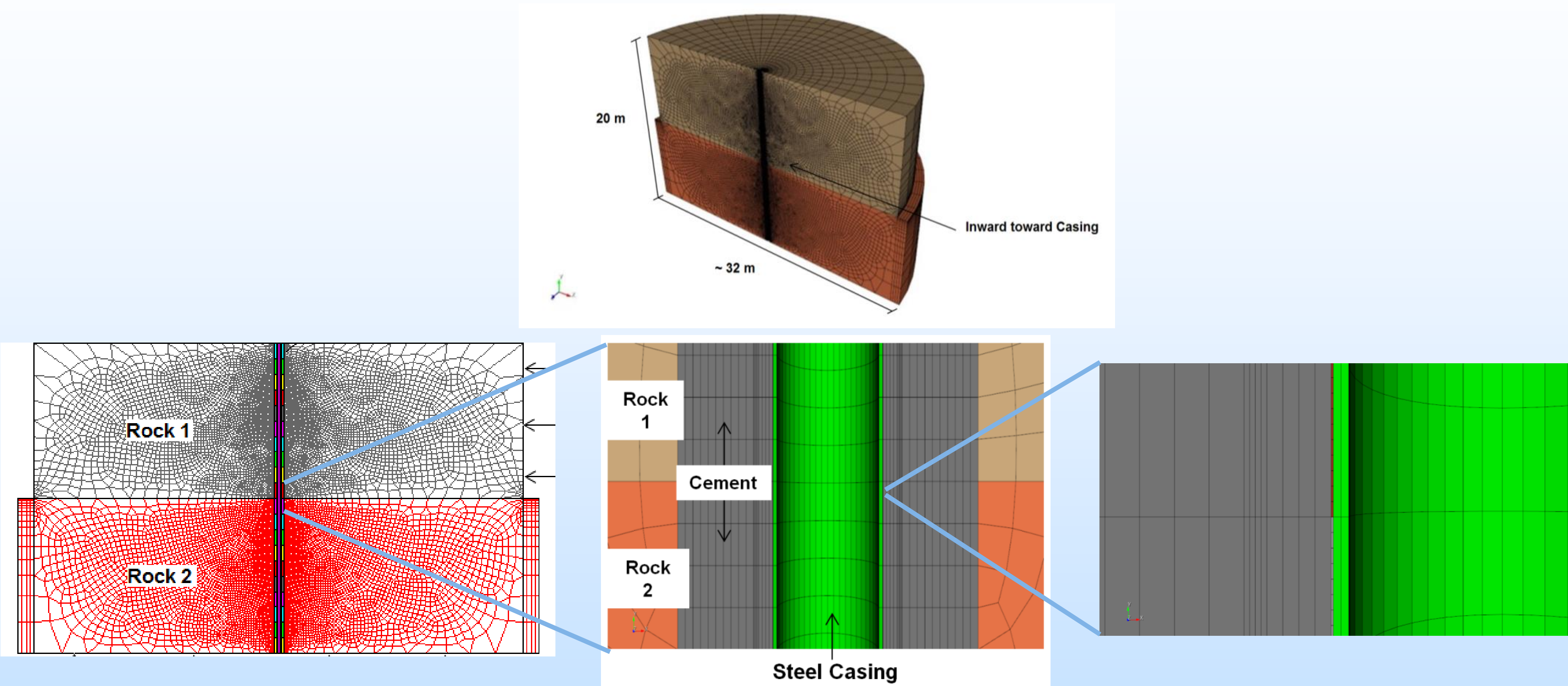


Image analysis of microphotographs to obtain microannulus aperture distribution.



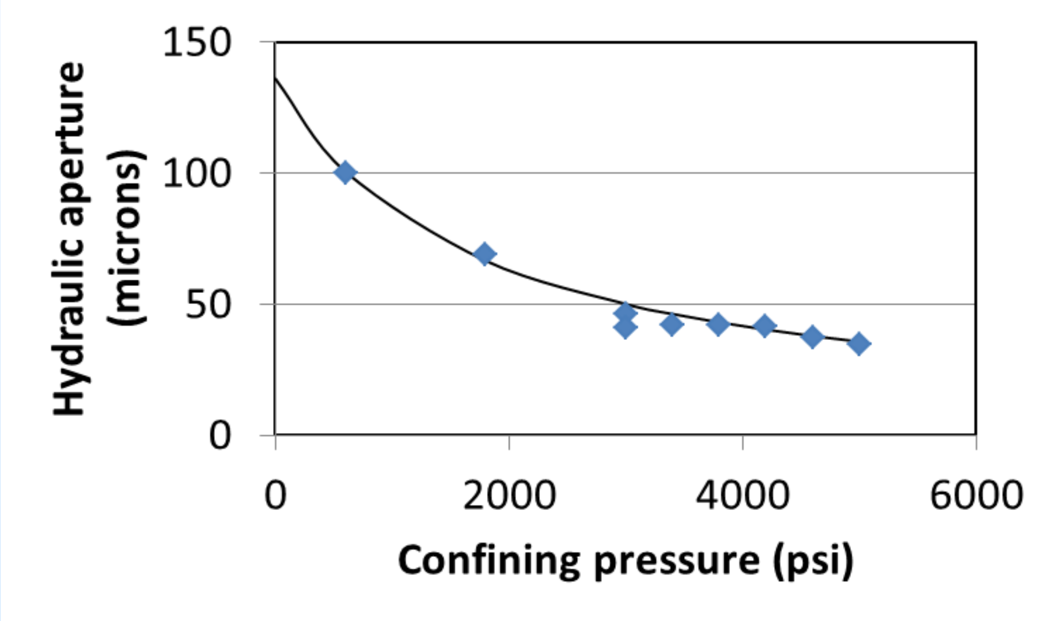


Wellbore Model



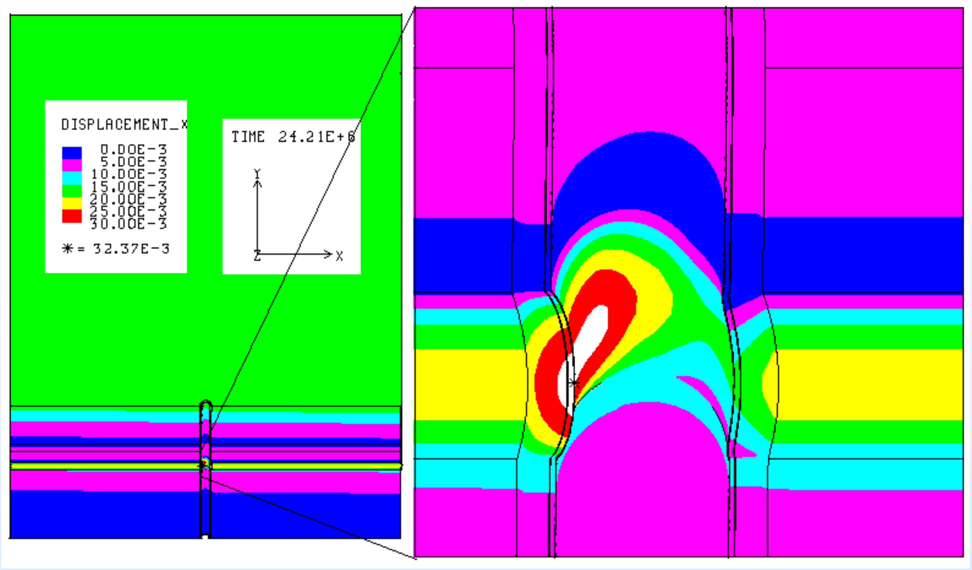
Microannulus model

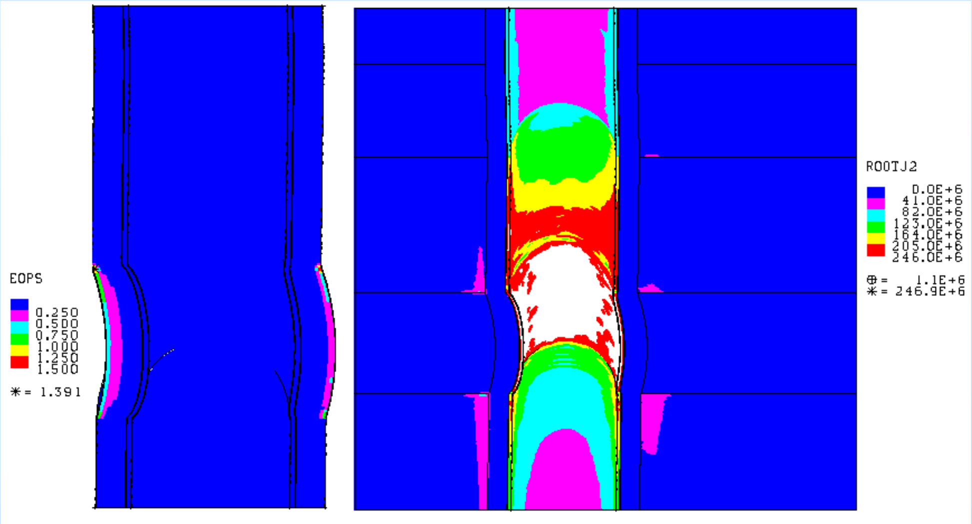
Material model for the microannulus that describes permeability changes in response to changes in confining and/or casing pressure and temperature.



Wellbore-Scale Model coupled with Field Scale to quantify stresses and strains for CO2 Injection at the Cranfield Site

- CO2 injection causes significant porous expansion in Lower Tuscaloosa, inducing large lateral deformation in borehole casing (~3 cm)
- Significant plastic strain in cement, shear stress in steel casing
- Repair material in micorannulus would experience significant strain, transmit shear stress to casing; PNCs evaluated thus far not yet tested to this magnitude of deformation





Accomplishments

- Synthesized and characterized nanocomposite repair materials that had superior properties compared to reference material.
  - Bond strength, fracture toughness and penetrability substantially increased
- Testing of wellbore seal systems
  - Tested pre- and post-repair condition
- Wellbore model developed

Synergy Opportunities

- Wellbore damage
  - Experimental methods and samples are being used in another NETL project led by LANL directed at in situ characterization of wellbore leakage.
- Wellbore repair
  - Developed repair material can be used in field applications.
- Wellbore modeling
  - Model for wellbore behavior that can be applied to large scale applications.

Project summary

- **Polymer nanocomposites** (PNCs) have been developed as repair materials with **<u>superior properties</u>** suitable for expected wellbore environments.

Publications

- Genedy, M., Kandil, U. F., Matteo, E., Stormont, J., Reda Taha, M. M., "A new polymer nanocomposite repair material for restoring wellbore seal integrity", *International Journal of Greenhouse Gas*, Accepted for publication August 2016.
- Gomez, S.P., S. Sobolik, E. N. Matteo, M.R. Taha and J.C. Stormont, "Wellbore Microannulus Characterization and Modeling", In review (*Computers and Geotechnics*).
- Douba, A. E., Genedy, M., Matteo, E., Stormont, J., Reda Taha, M. M., "Apparent vs. True Bond Strength of Steel and PC with NanoAlumina", Proceedings of International Congress on Polymers in Concrete (ICPIC), Singapore, Advanced Materials Research, Vol. 1129, pp. 307-314, October 2015.
- Sobolik, S.R., Gomez, S.P. Matteo, E.N. Dewers, T.A., Newell, P., Reda Taha, M. M., Stormont. J. C. "Geomechanical Modeling to Predict Wellbore Stresses and Strains for the Design of Wellbore Seal Repair Materials for Use at a CO2 Injection Site." *Proceedings of the American Rock Mechanics Association (ARMA) 49th Symposium*, San Francisco, USA, 6p., June 2015.
- Stormont, J. C., Ahmad, R., Ellison, J., Reda Taha, M. M., "Laboratory measurements of flow through wellbore cement-casing microannuli", *Proceedings of the American Rock Mechanics Association (ARMA) 49th Symposium*, San Francisco, USA, 6p., June 2015.
- Genedy, M., Stormont, J., Matteo, E. and Reda Taha, M. M. "Examining Epoxy-based Nanocomposites in Wellbore Seal Repair for Effective CO2 Sequestration", *Energy Procedia*, Vol. 63, pp. 5798-5807, 2014.

Acknowledgements

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