SAND2016-7802C

Wellbore Seal Repair Using Nanocomposite Materials

Project Number DE-FE0009562

John Stormont, Mahmoud Reda Taha
University of New Mexico

Ed Matteo, Thomas Dewers
Sandia National Laboratories

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage & Oil & Natural Gas Technologies Review Meeting
August 16-18, 2016

Presentation Outline

- Introduction and overview
- Materials synthesis
- Materials testing and characterization
- Seal system testing
- Numerical simulation
- Summary

Benefit to the Program

- **BENEFITS STATEMENT: The project involves the development and testing of polymer-cement 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 outcome

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

Materials Development

Flowability

↓

Bond strength

↓

Ductility

↓

Push-out tests

↓

Penetrability

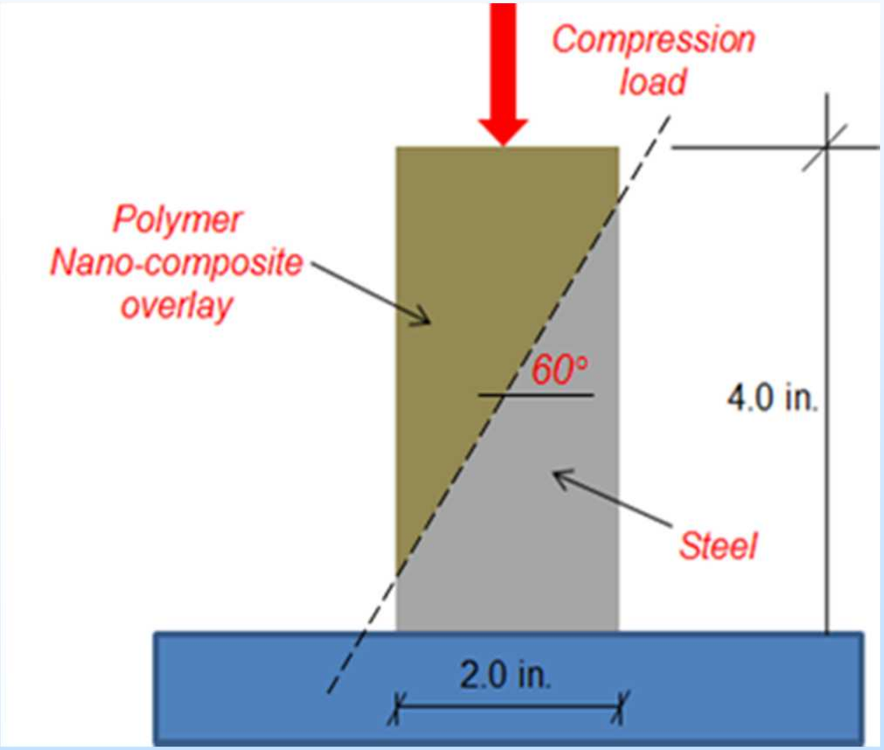
↓

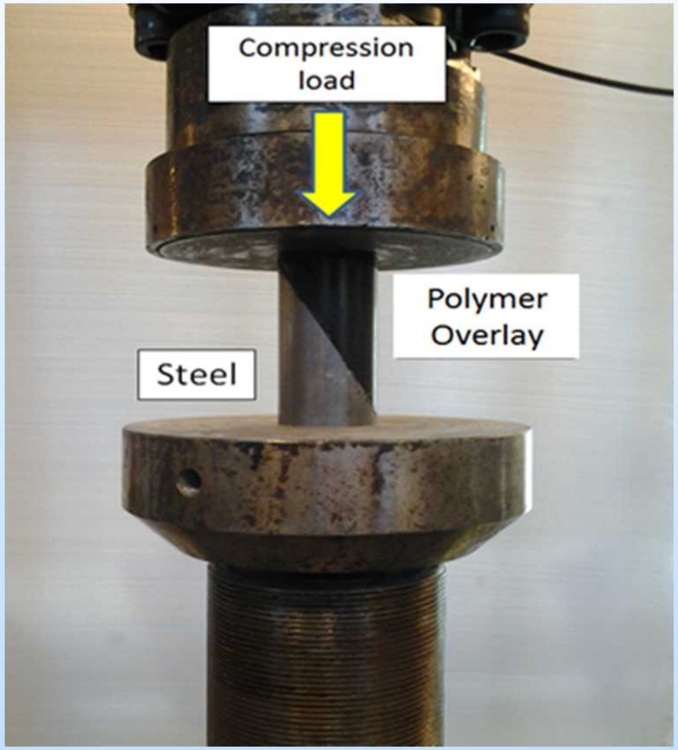
Best repair material

Novolac epoxy with 2% nanoalumina

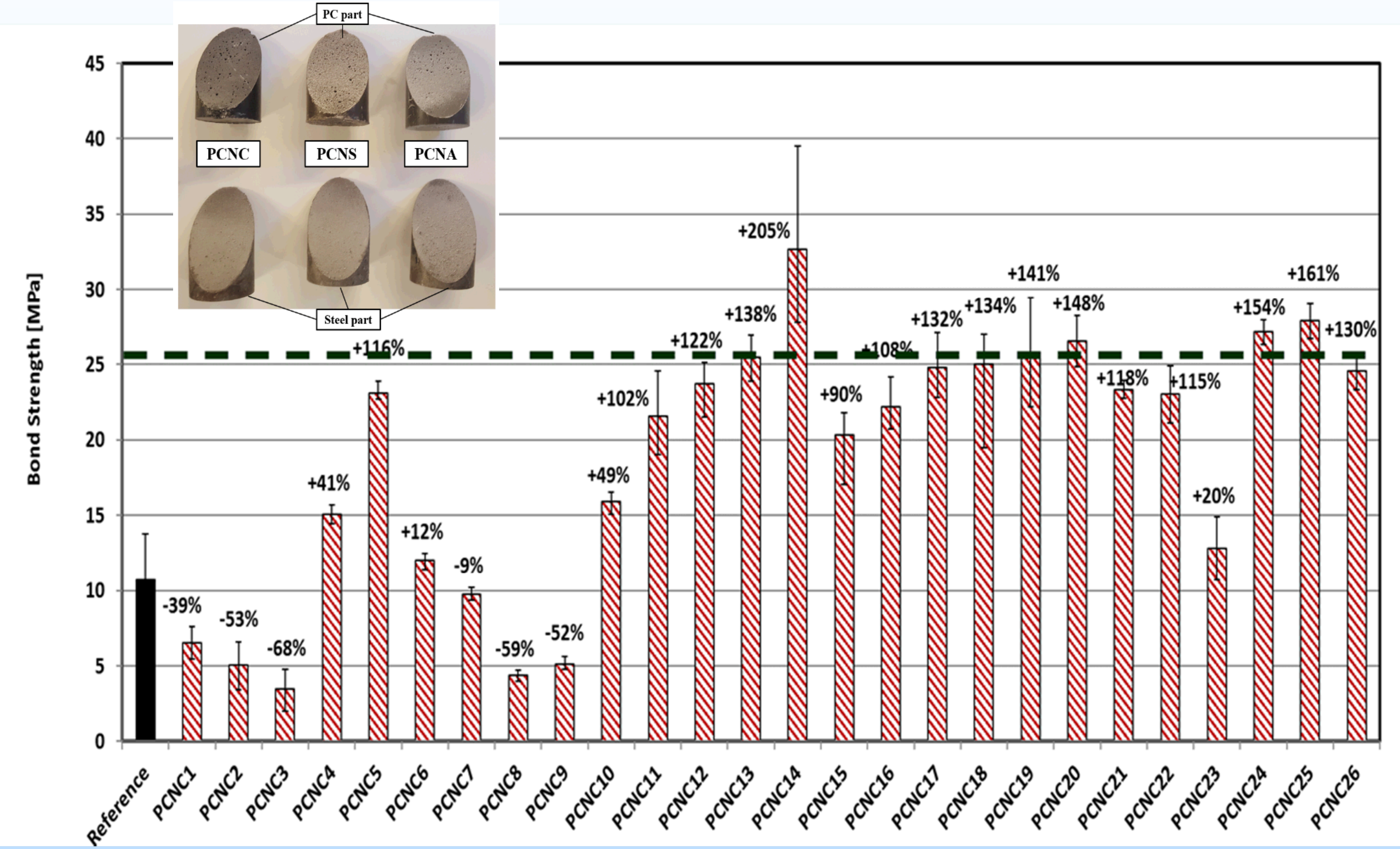
Bond strength characterization

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

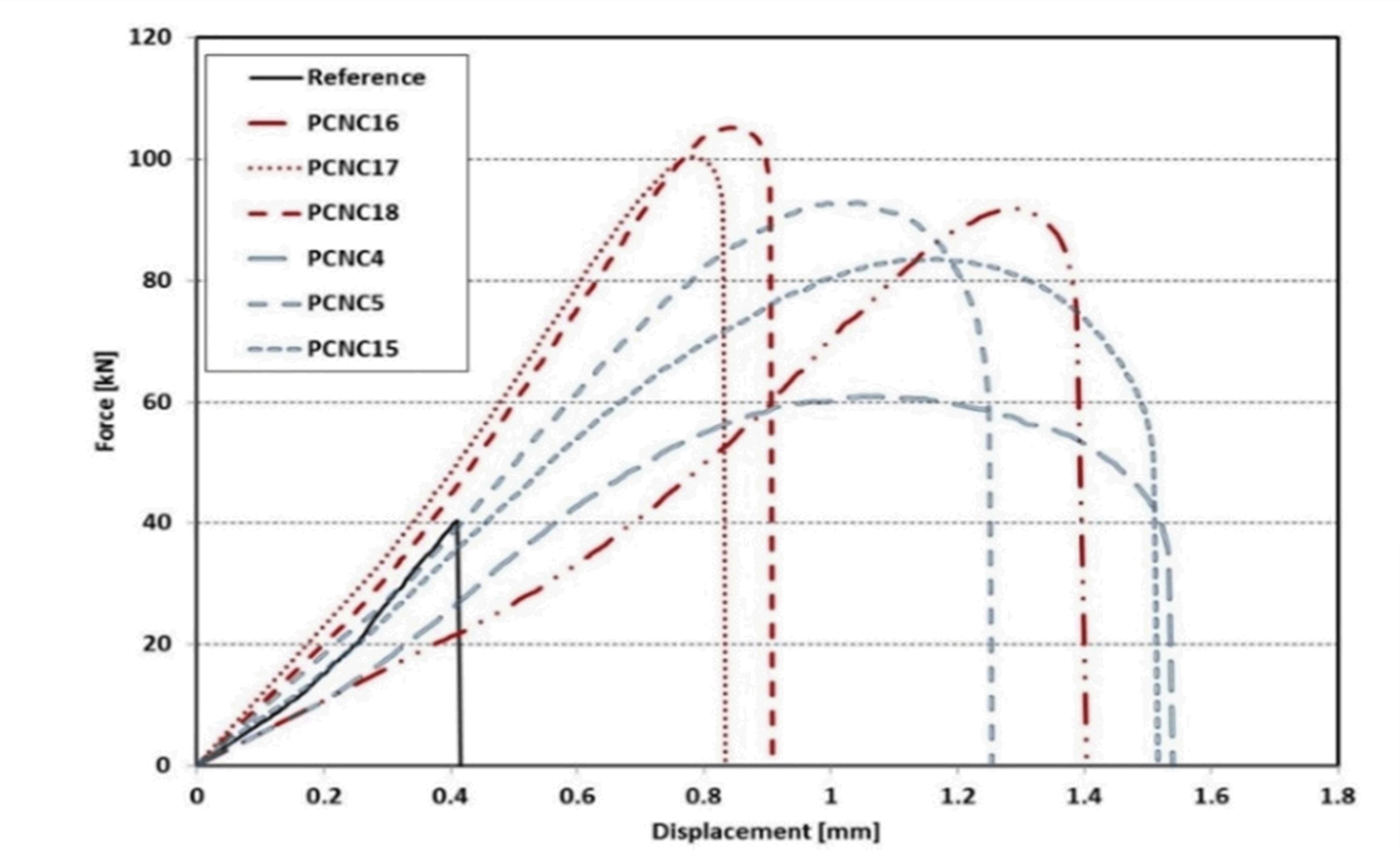




*Slant shear test data reveal many PNCs had **much greater bond strength to steel** than microfine cement.*

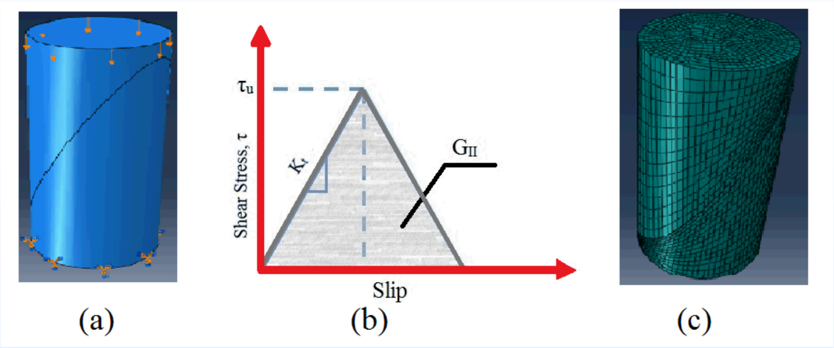


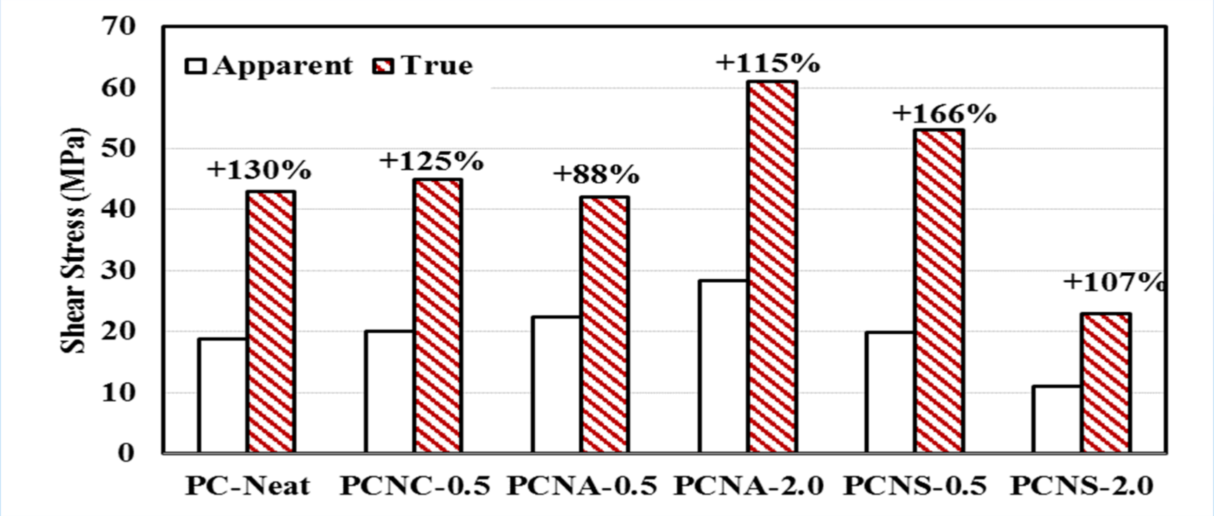
*PNCs are much **more ductile** than cements, and absorb more energy before failure.*



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.

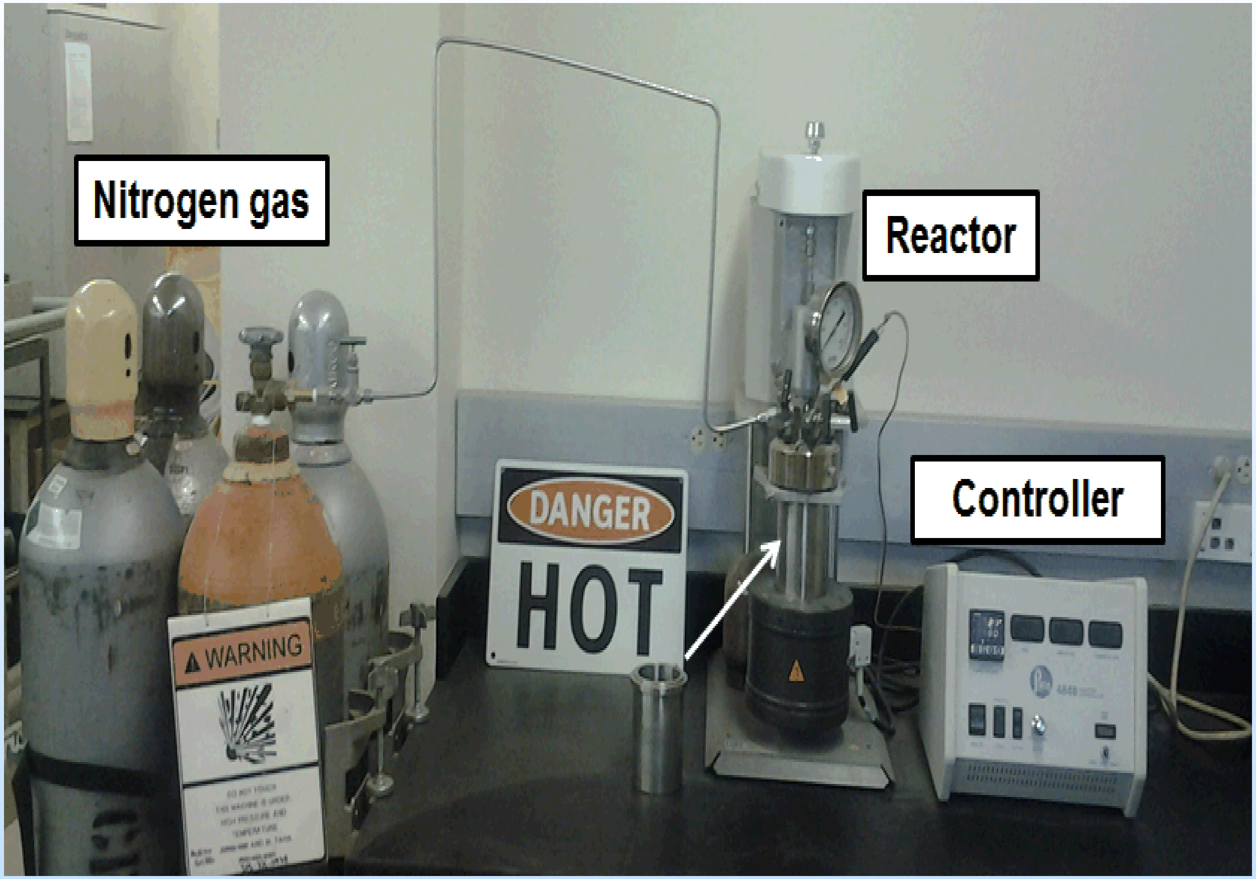
Finite element modeling used to inversely calculate interfacial bond characteristics

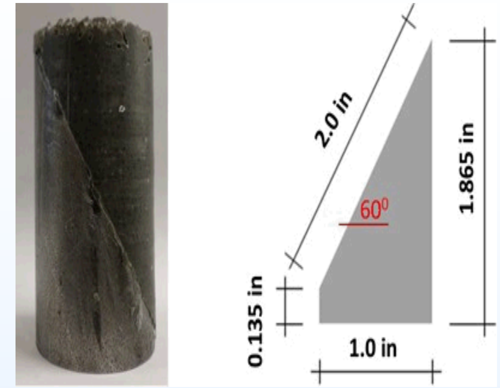




Douba, A. E., Genedy, M., Matteo, E., Stormont, J., Reda Taha, M. M., "Apparent vs. True Bond Strength of Steel and PC with NanoAlumina", Proceedings of International Congress on Polymers in Concrete (ICPIC), Singapore, Advanced Materials Research, Vol. 1129, pp. 307-314, October 2015.

Examining the effect of high temperature and pressure

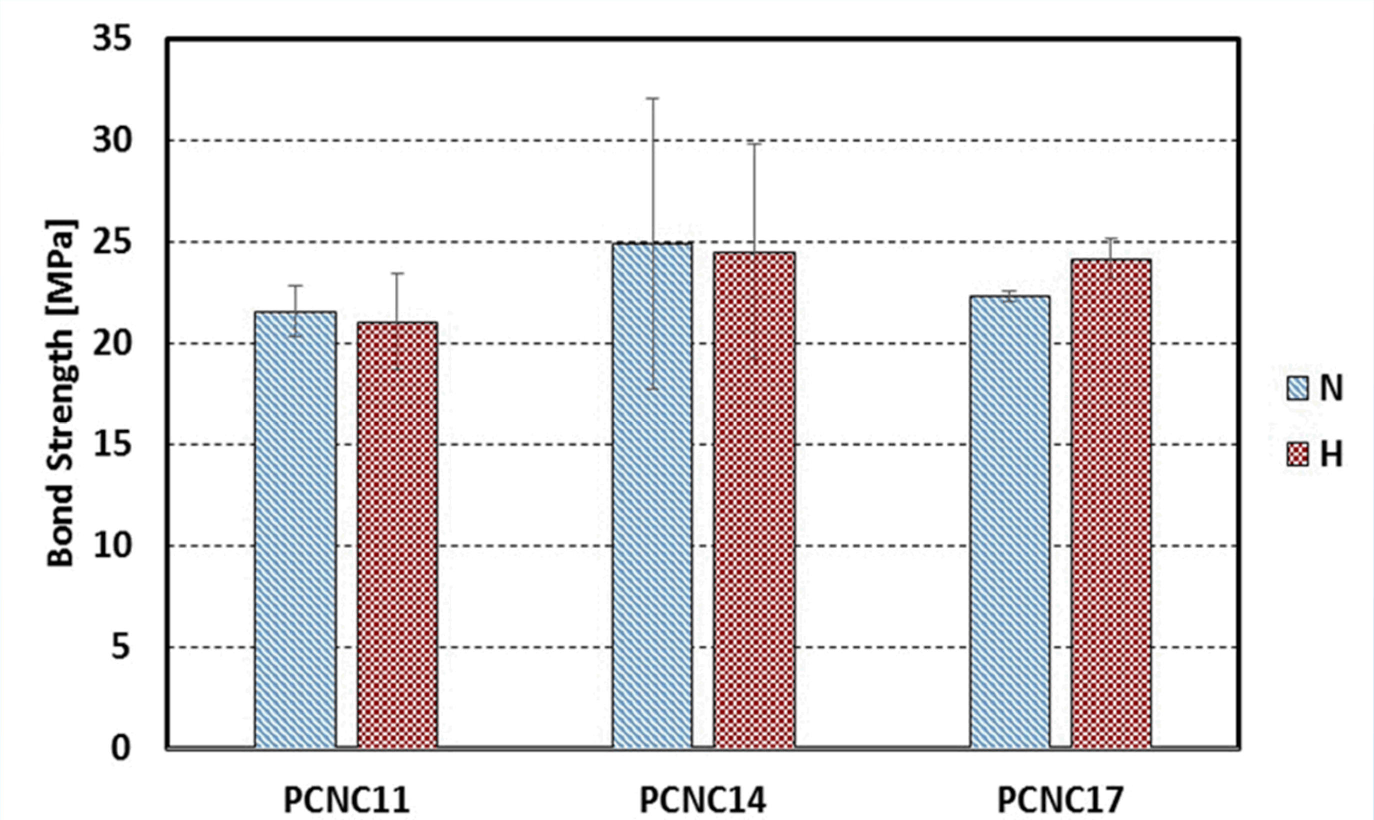




Scaled specimens

Temp: 80 °C, Pressure 10 MPa

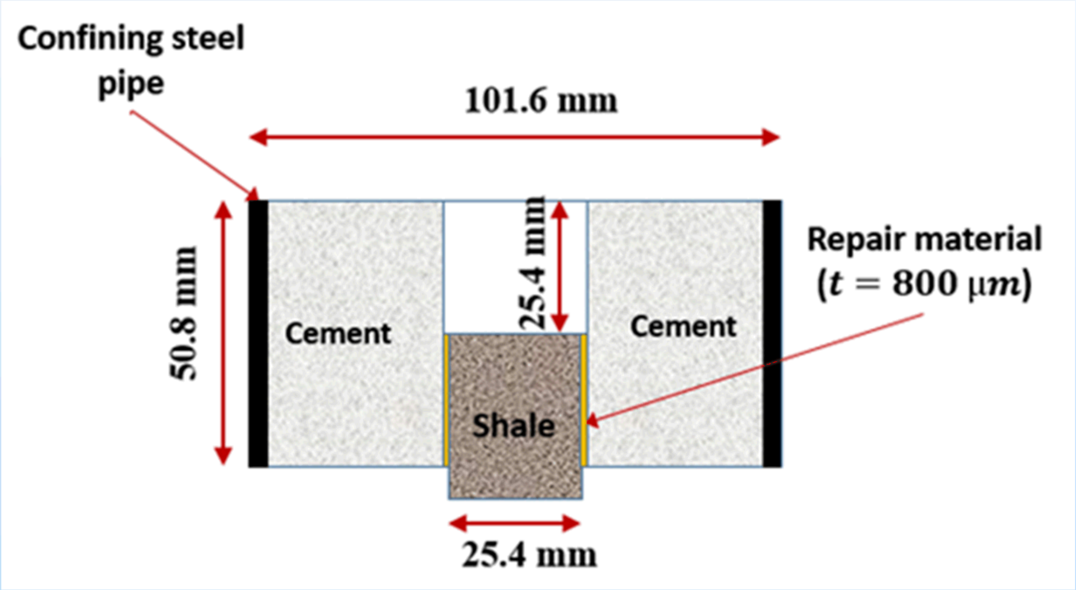
No effect of elevated temperature and pressure on performance of PCNC



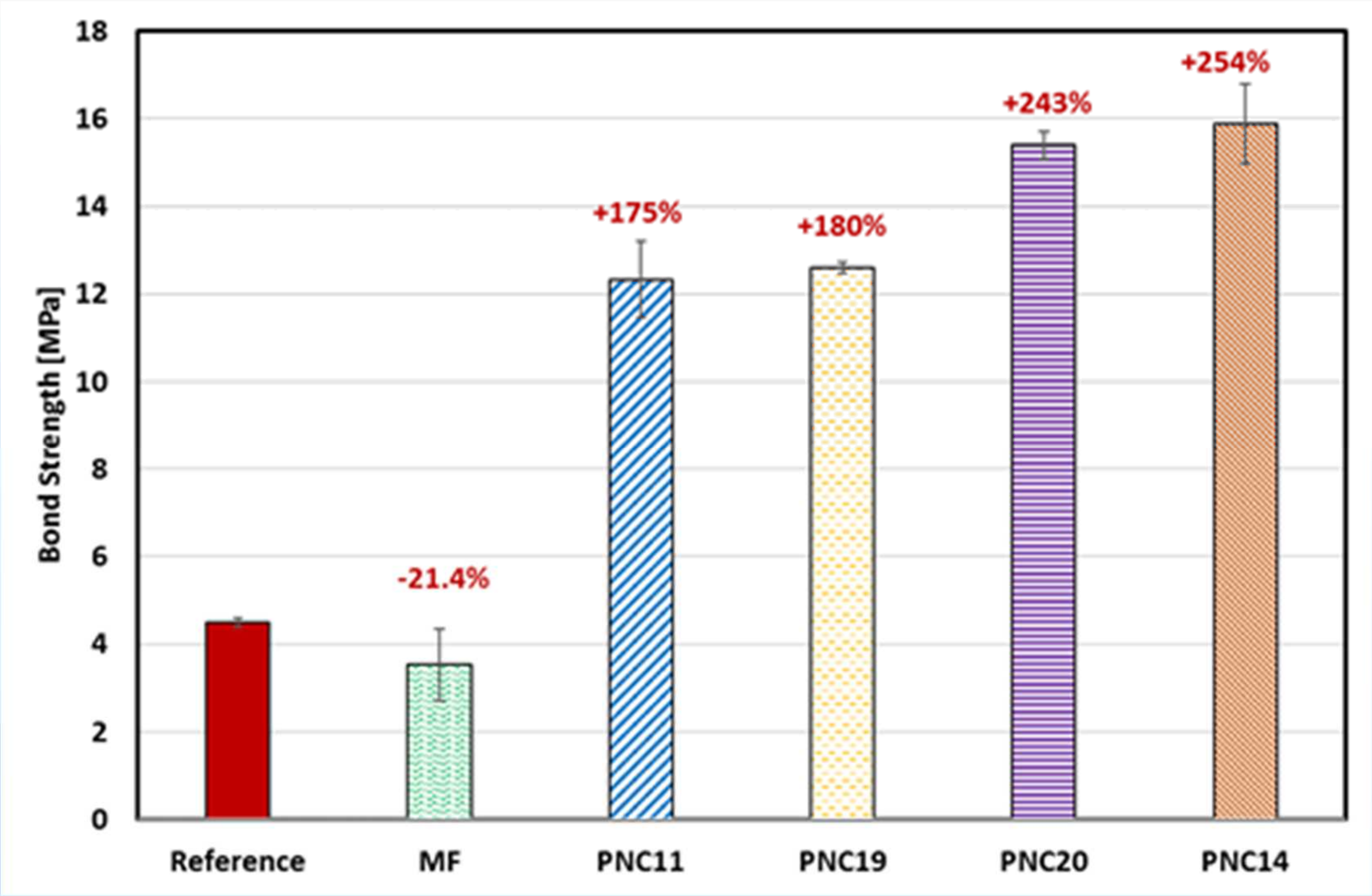
Cured at ambient conditions

Cured at elevated temperature and pressure

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

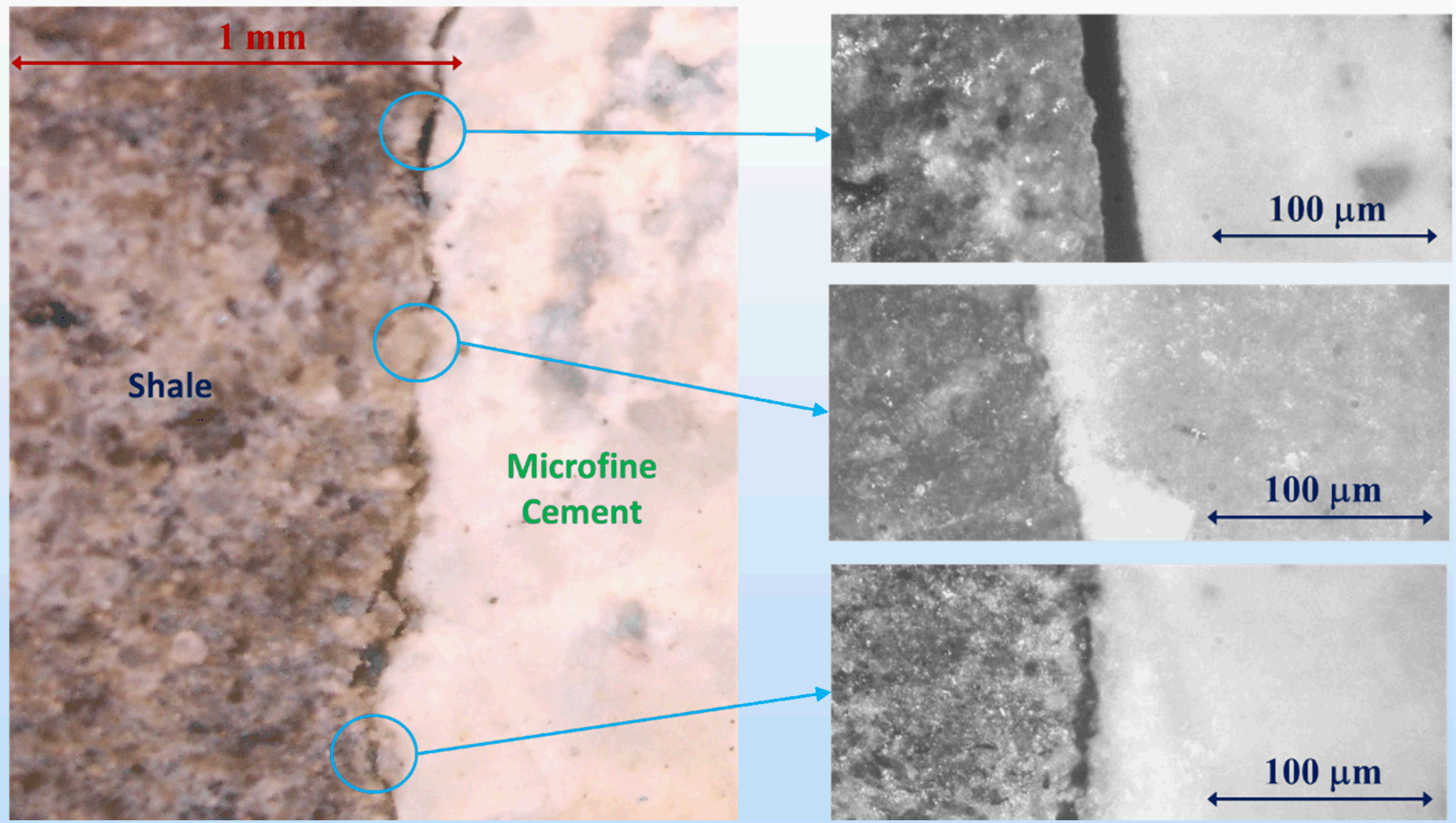


*PNCs had much **greater push-out strength** compared to microfine cement.*



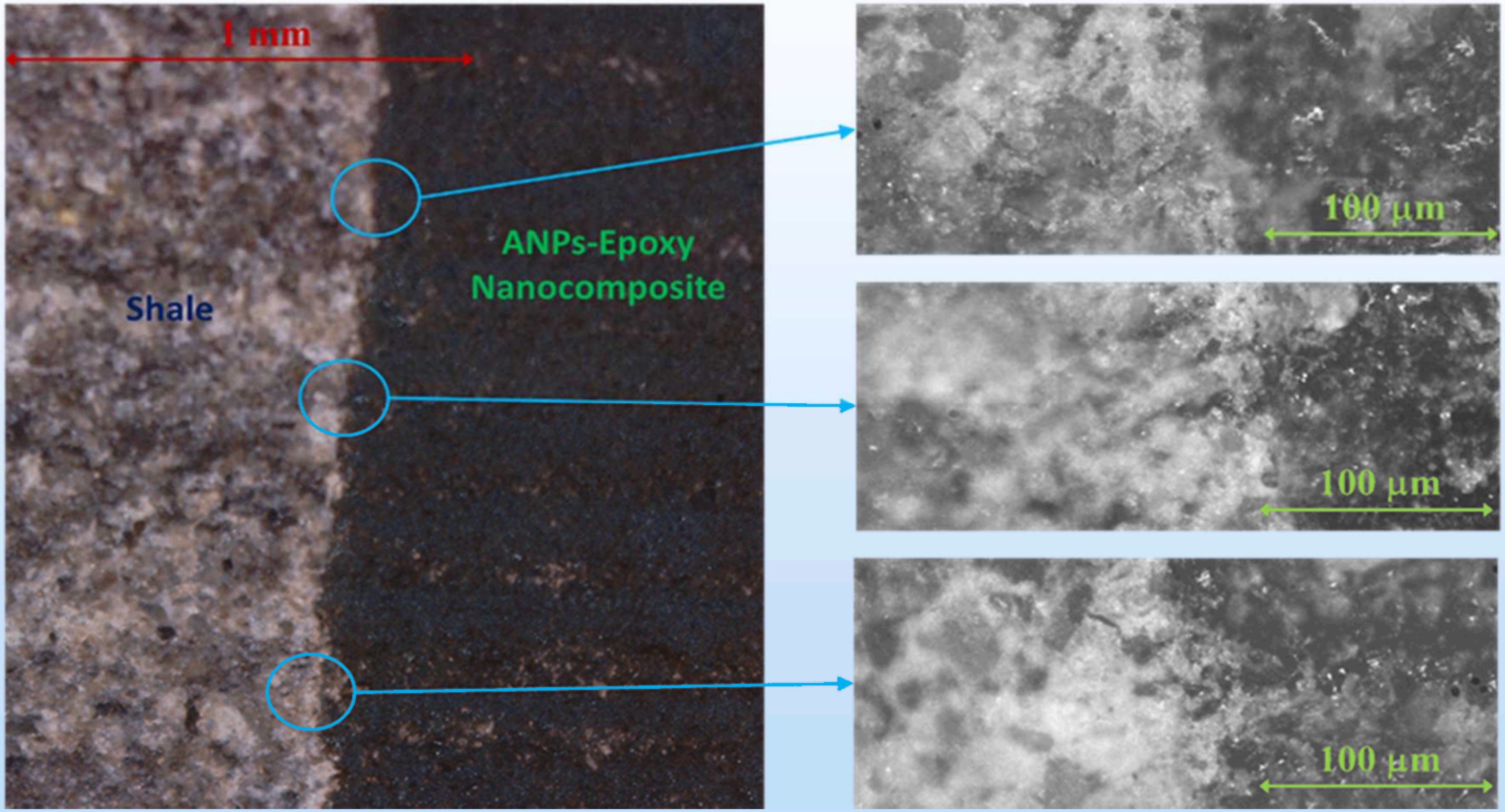
Genedy, M., Kandil, U. F., Matteo, E., Stormont, J., Reda Taha, M. M., "A new polymer nanocomposite repair material for restoring wellbore seal integrity", International Journal of Greenhouse Gas, Accepted for publication, 2016.

Repair of shale-cement interface with microfine cement



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.

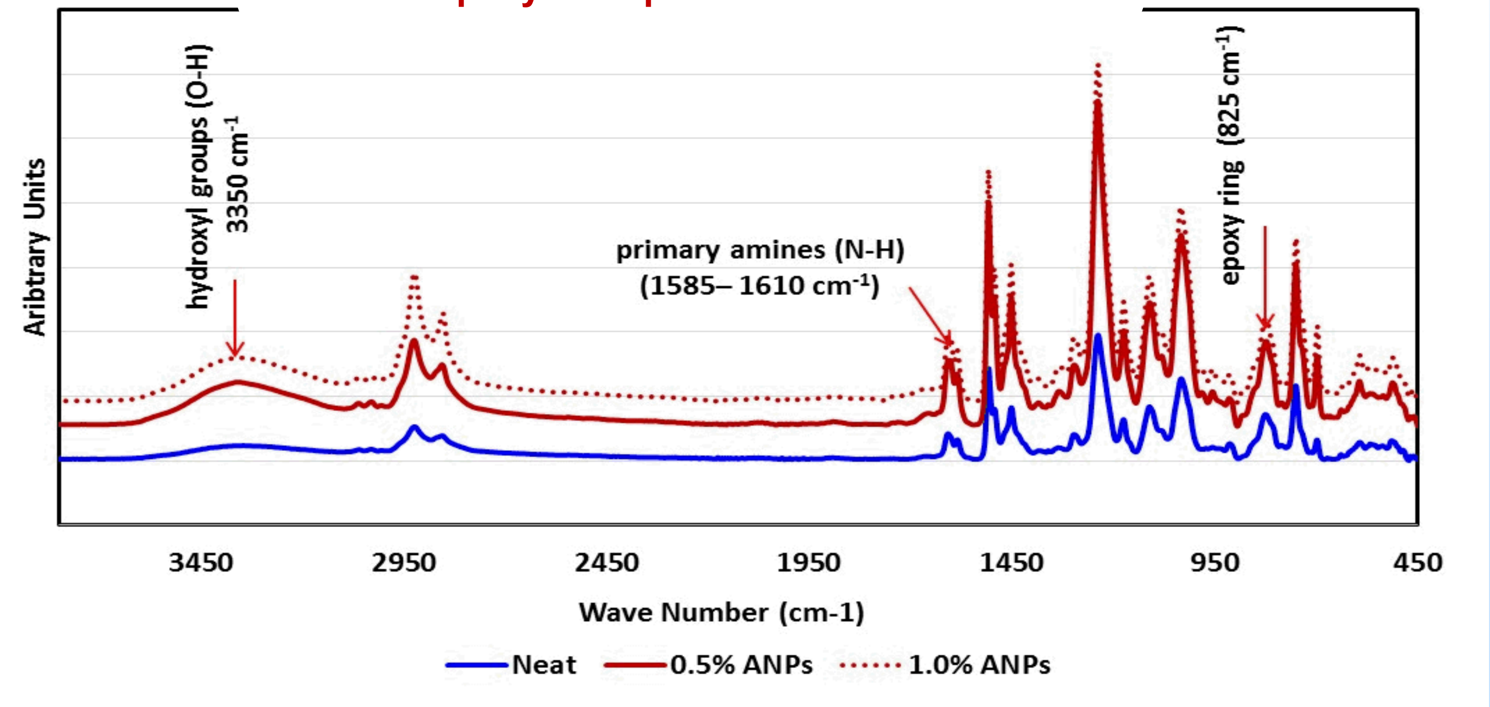
Repair of shale-cement interface with polymer nanocomposite



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.

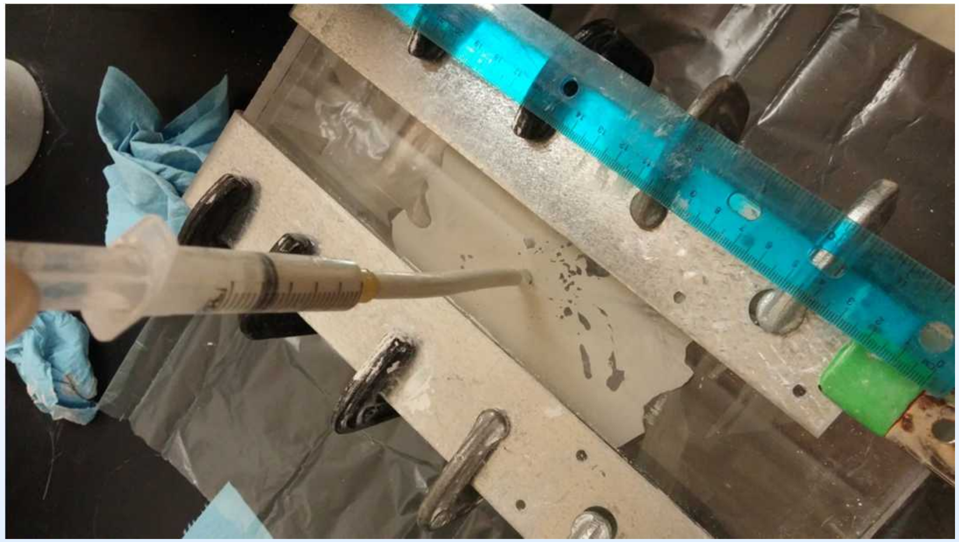
Nanomaterials enable synthesizing a polymer nanocomposite with improved characteristics

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

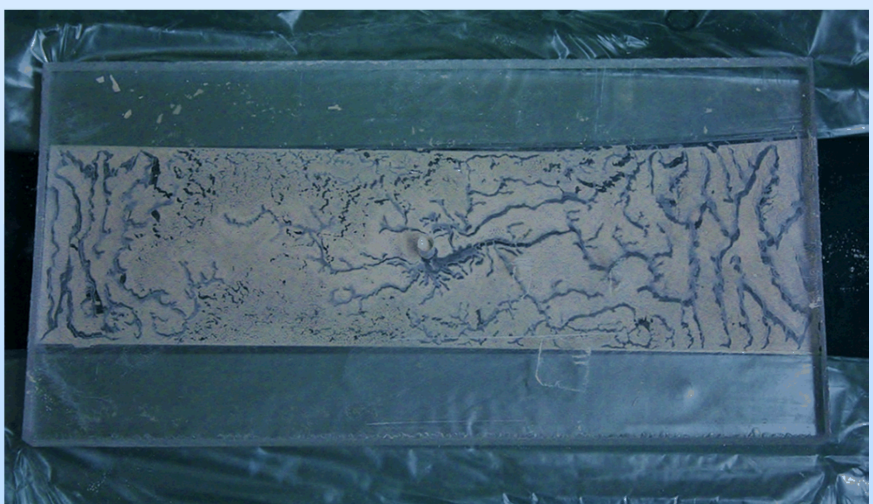


Genedy, M., Kandil, U. F., Matteo, E., Stormont, J., Reda Taha, M. M., "A new polymer nanocomposite repair material for restoring wellbore seal integrity", International Journal of Greenhouse Gas, Accepted for publication, 2016.

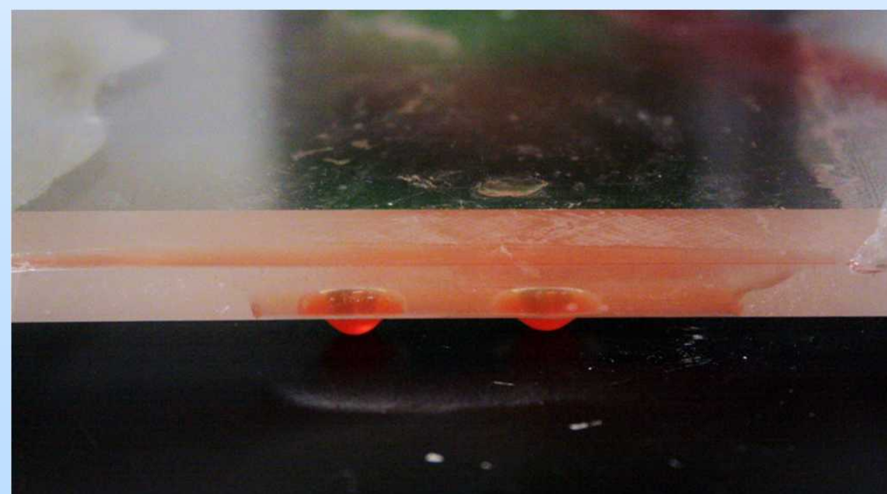
Penetrability



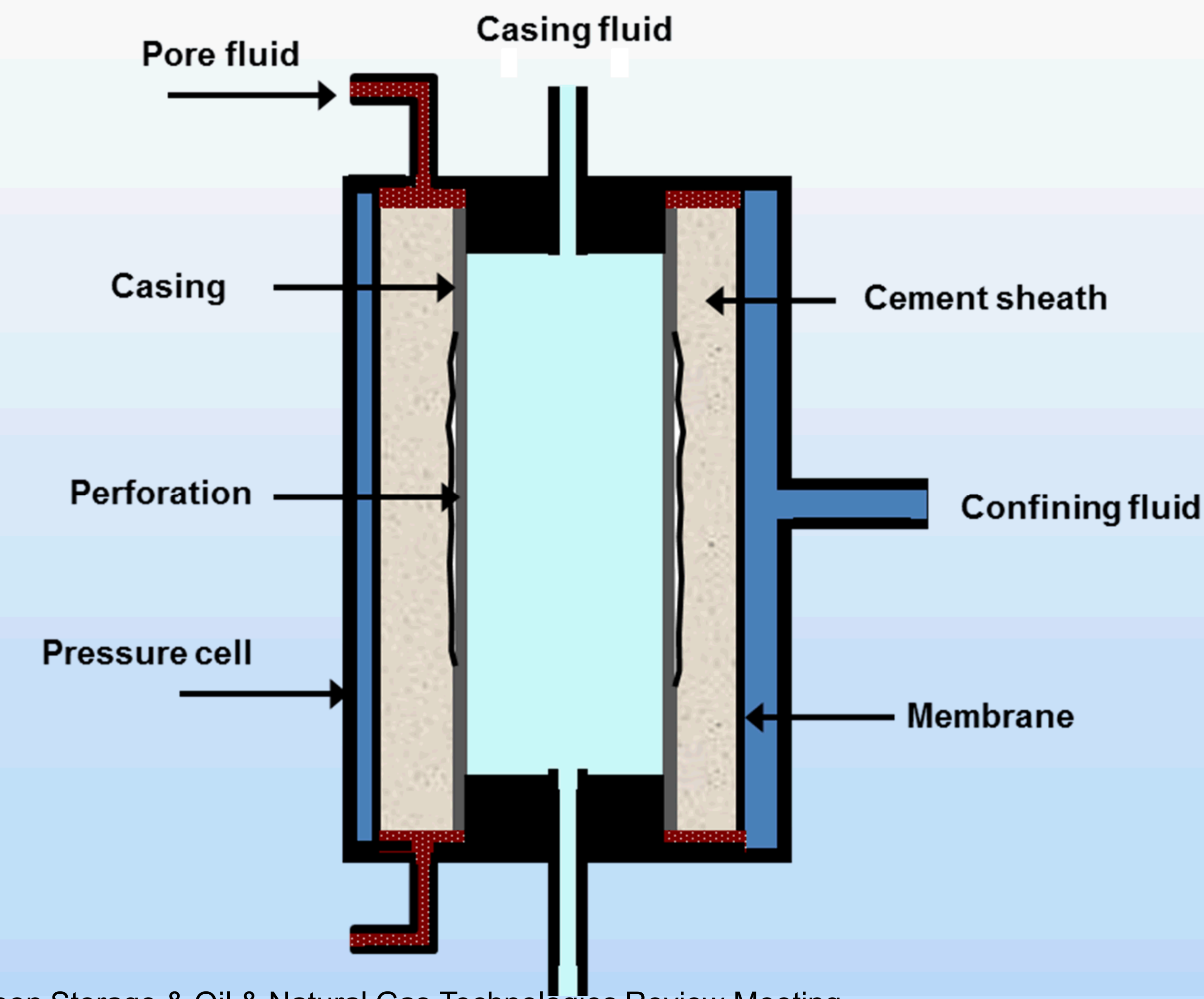
Microfine penetrated 75 μm gap



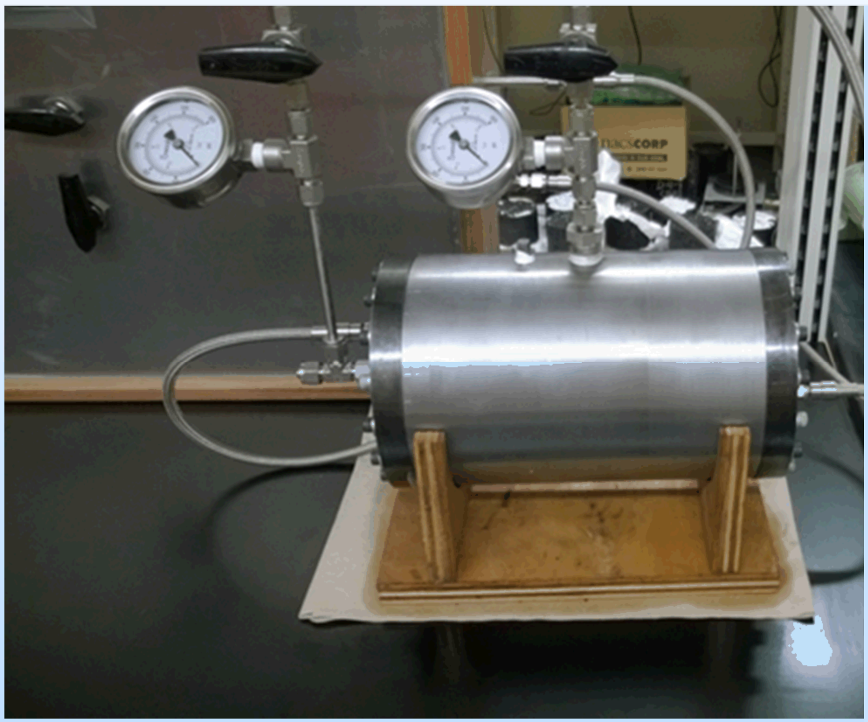
Nanocomposite penetrated 13 μm gap

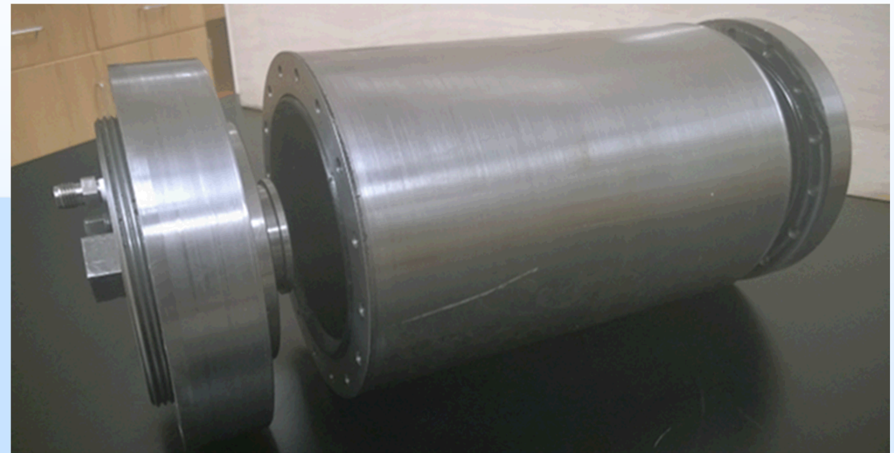


Flow through damaged and repaired wellbore systems



Pressure vessel



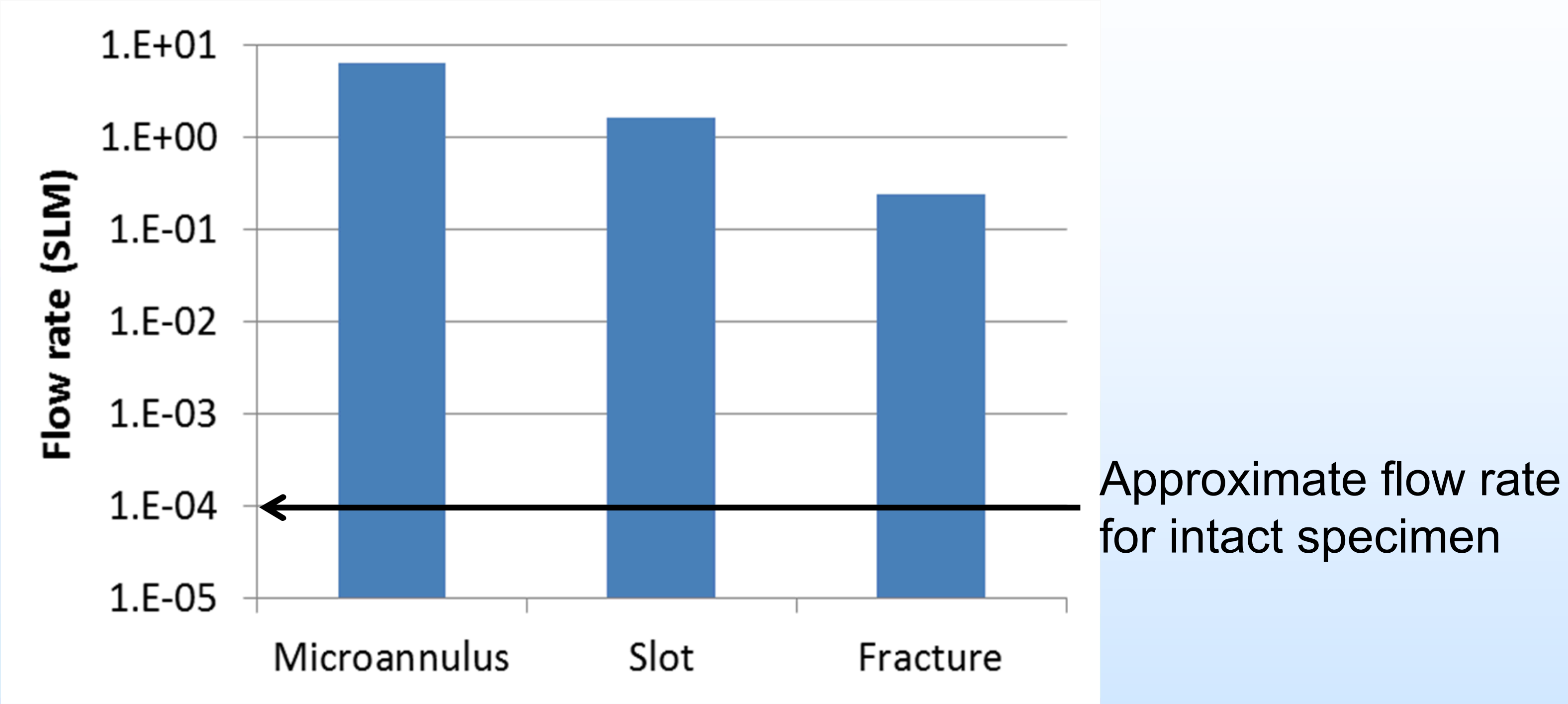


Independent control of confining pressure to 30 MPa and casing pressure to 20 MPa.

Specimen preparation

- Microannulus
  - Large
  - Small
- Cement fracture

Flow dominated by flaws



Cubic law for hydraulic aperture

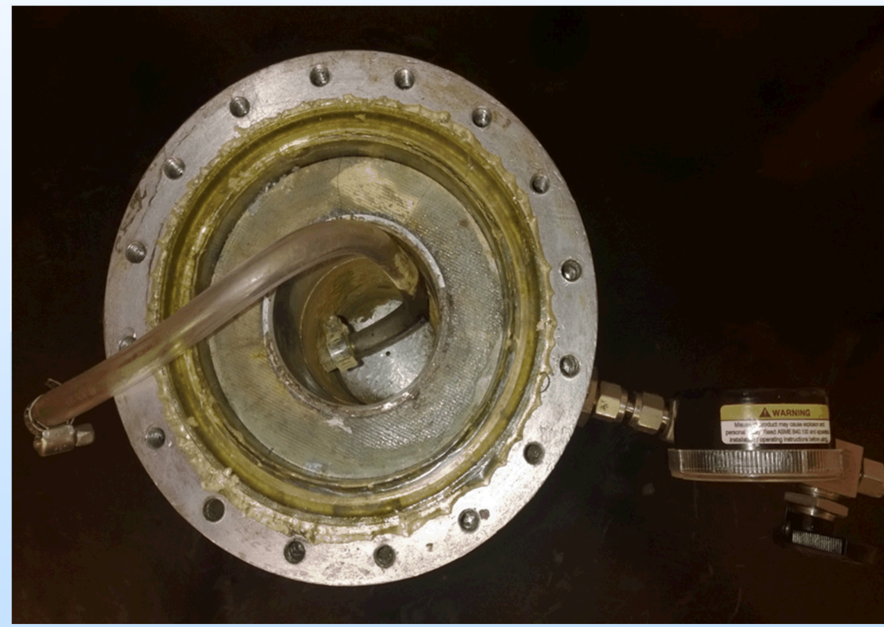
$$h^3 = \frac{12\,k\,A}{w}$$

Repair of damaged wellbores

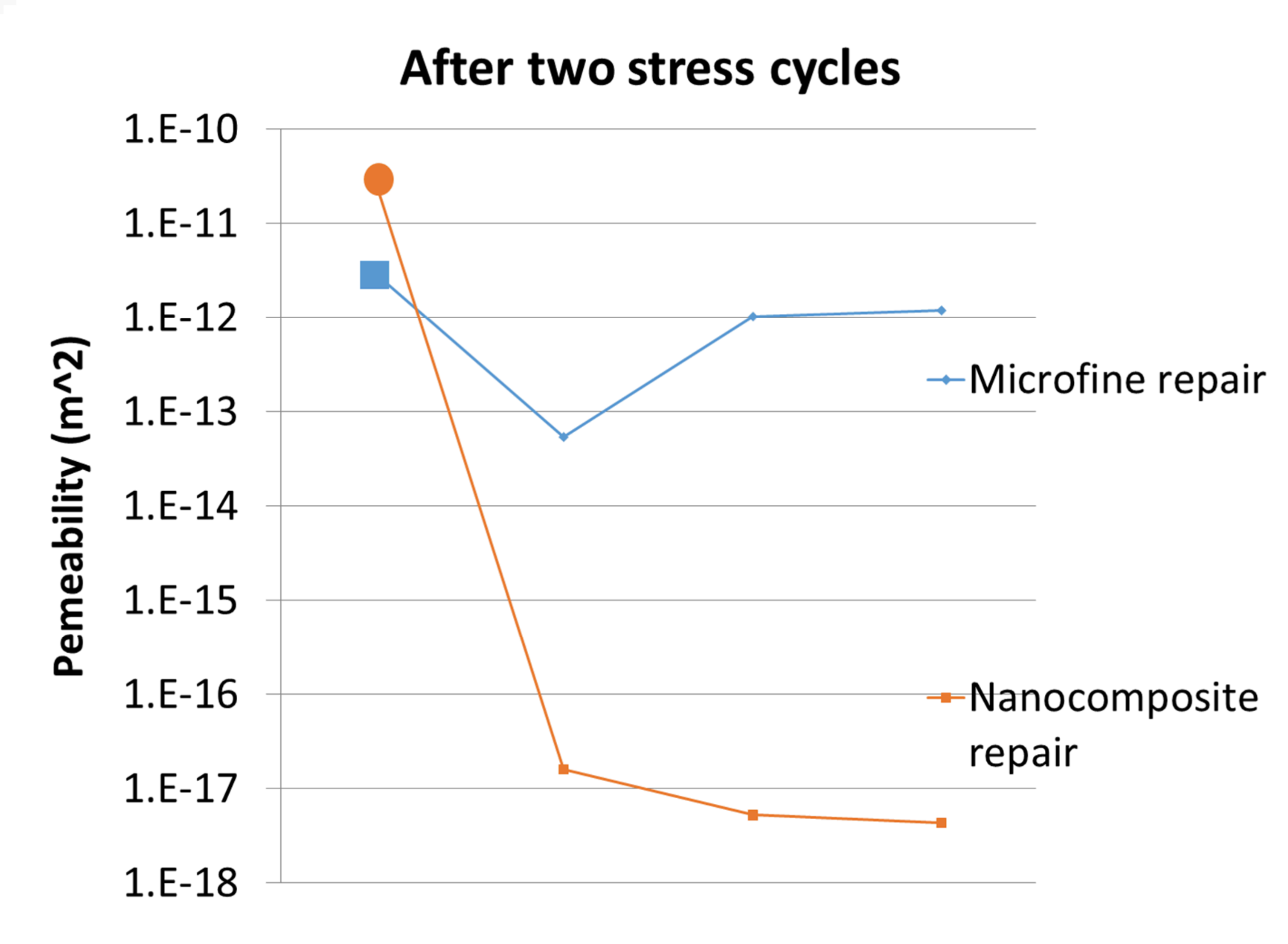
1. No pressure

2. Separate pressurized system

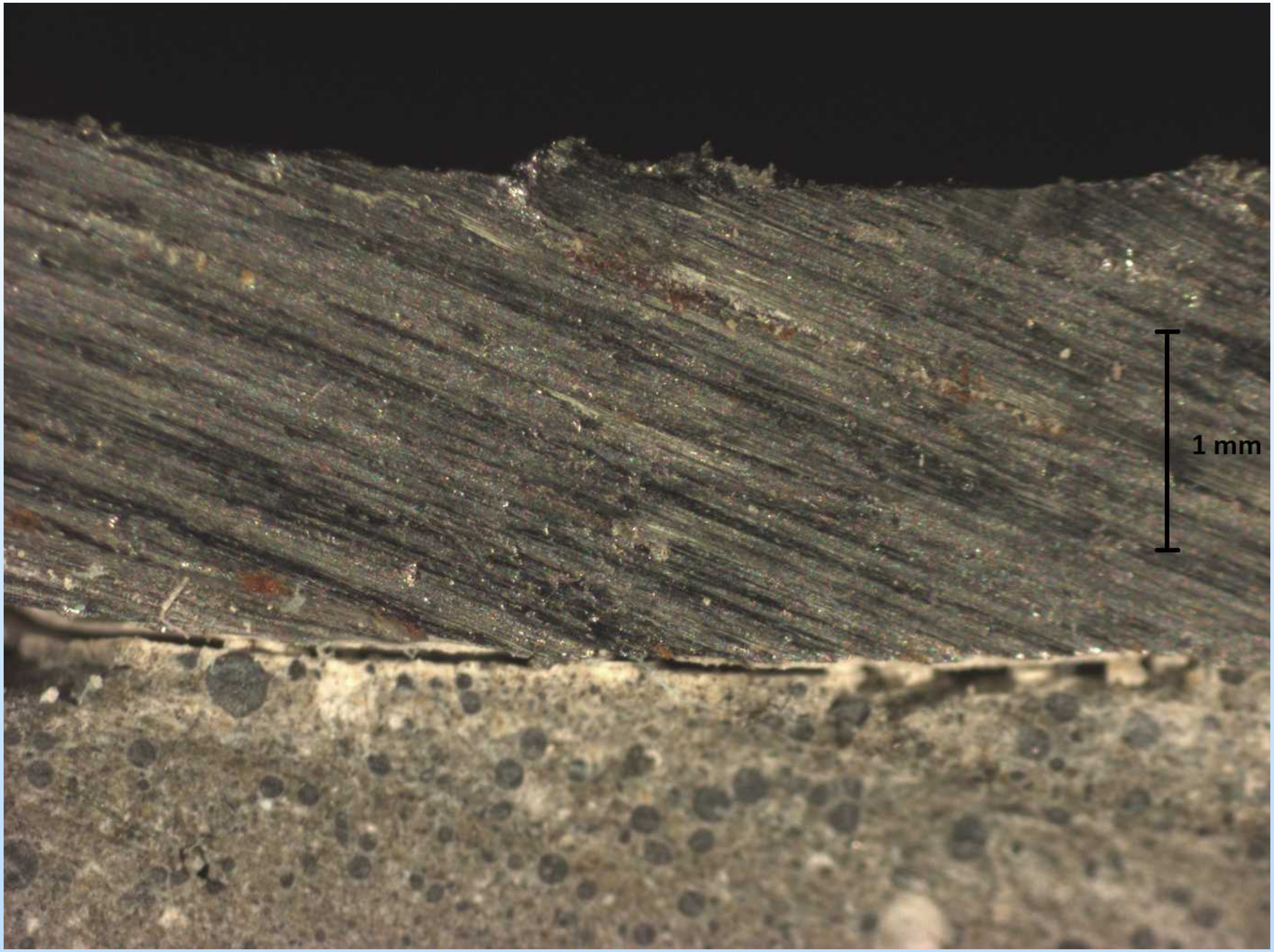
3. In pressure vessel



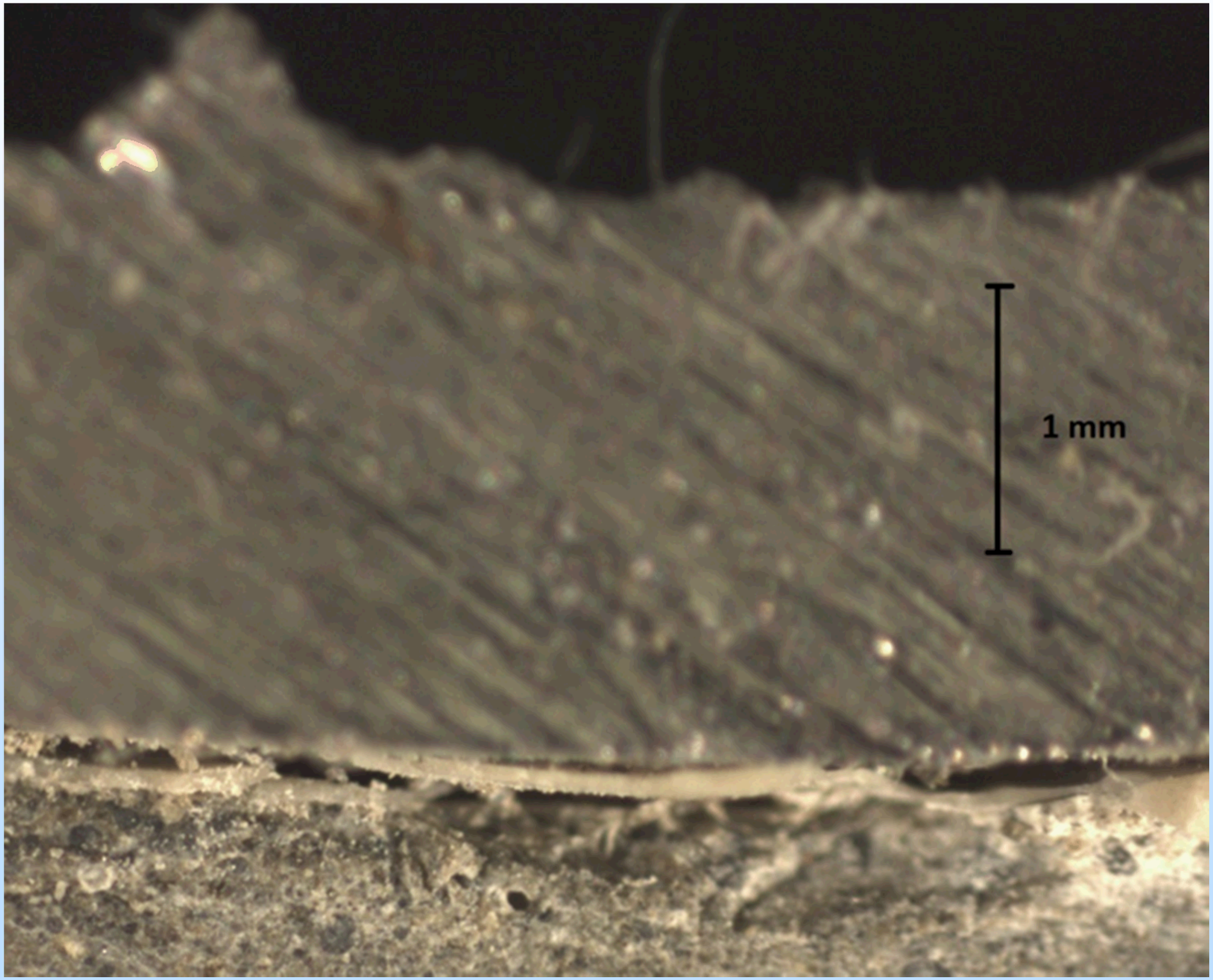
Repair response to stress cycles



Repaired with microfine cement



Repaired with microfine cement



Repaired with polymer nanocomposite

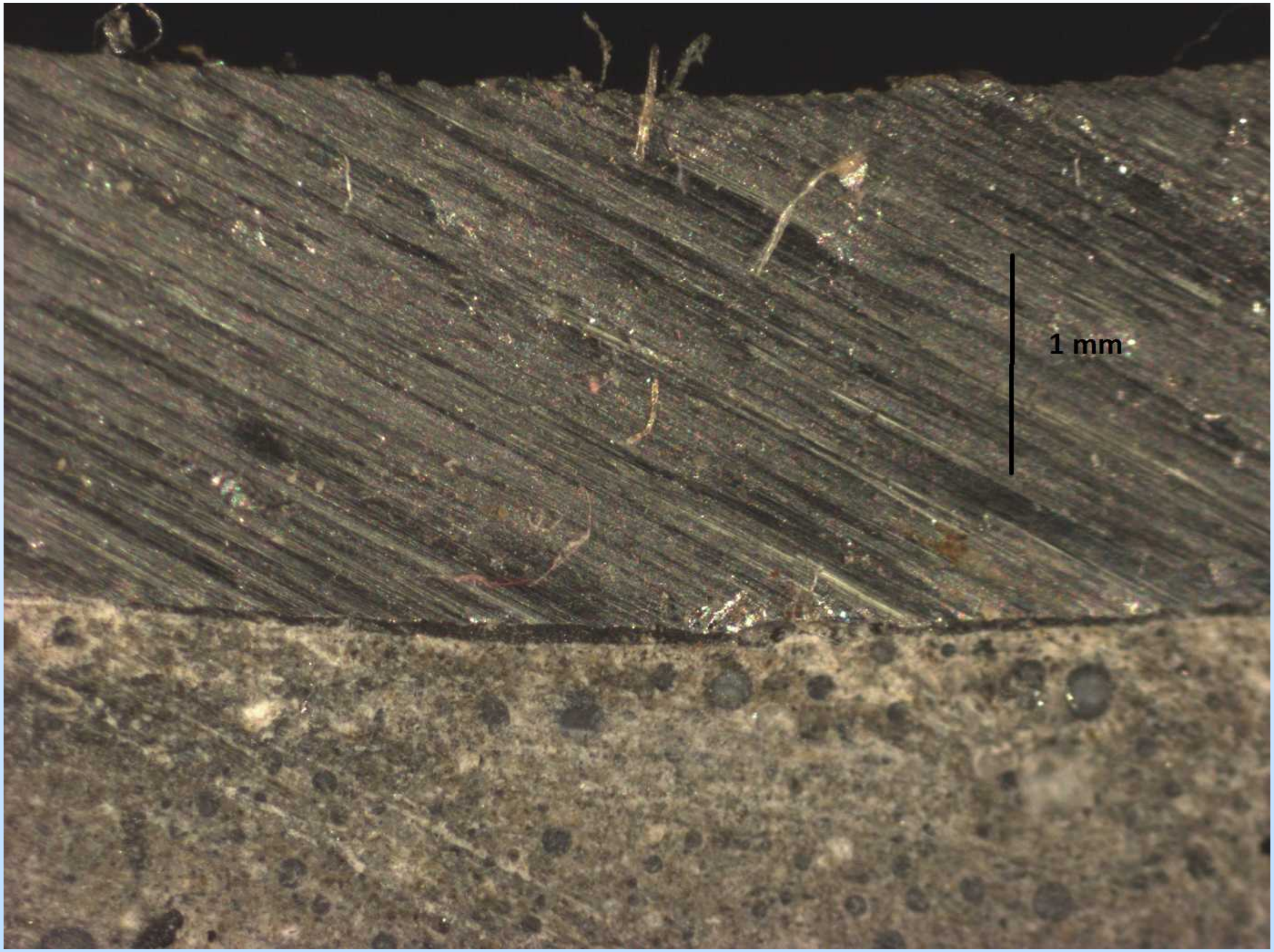
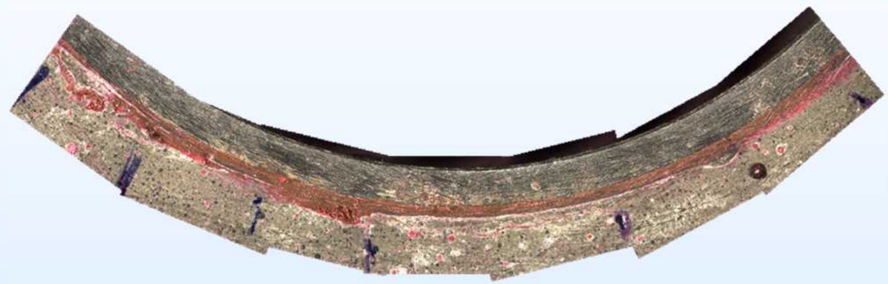
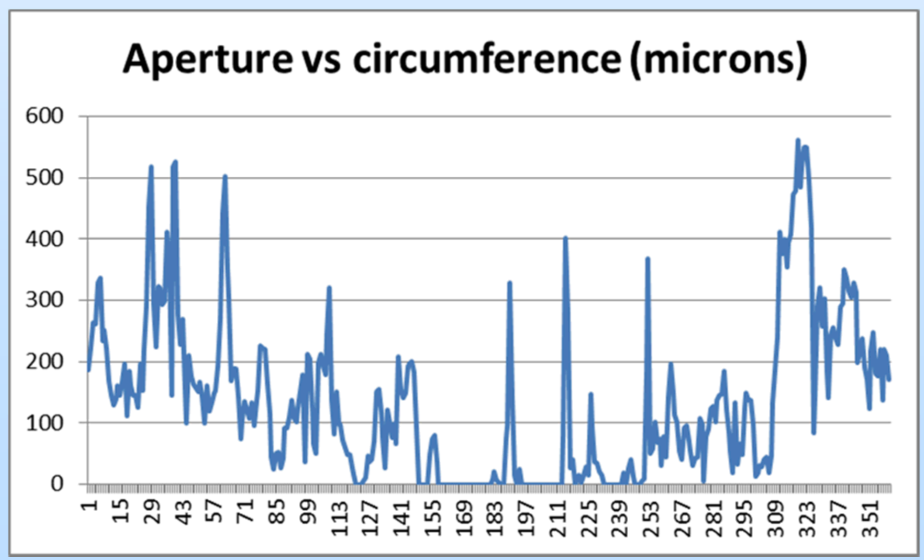
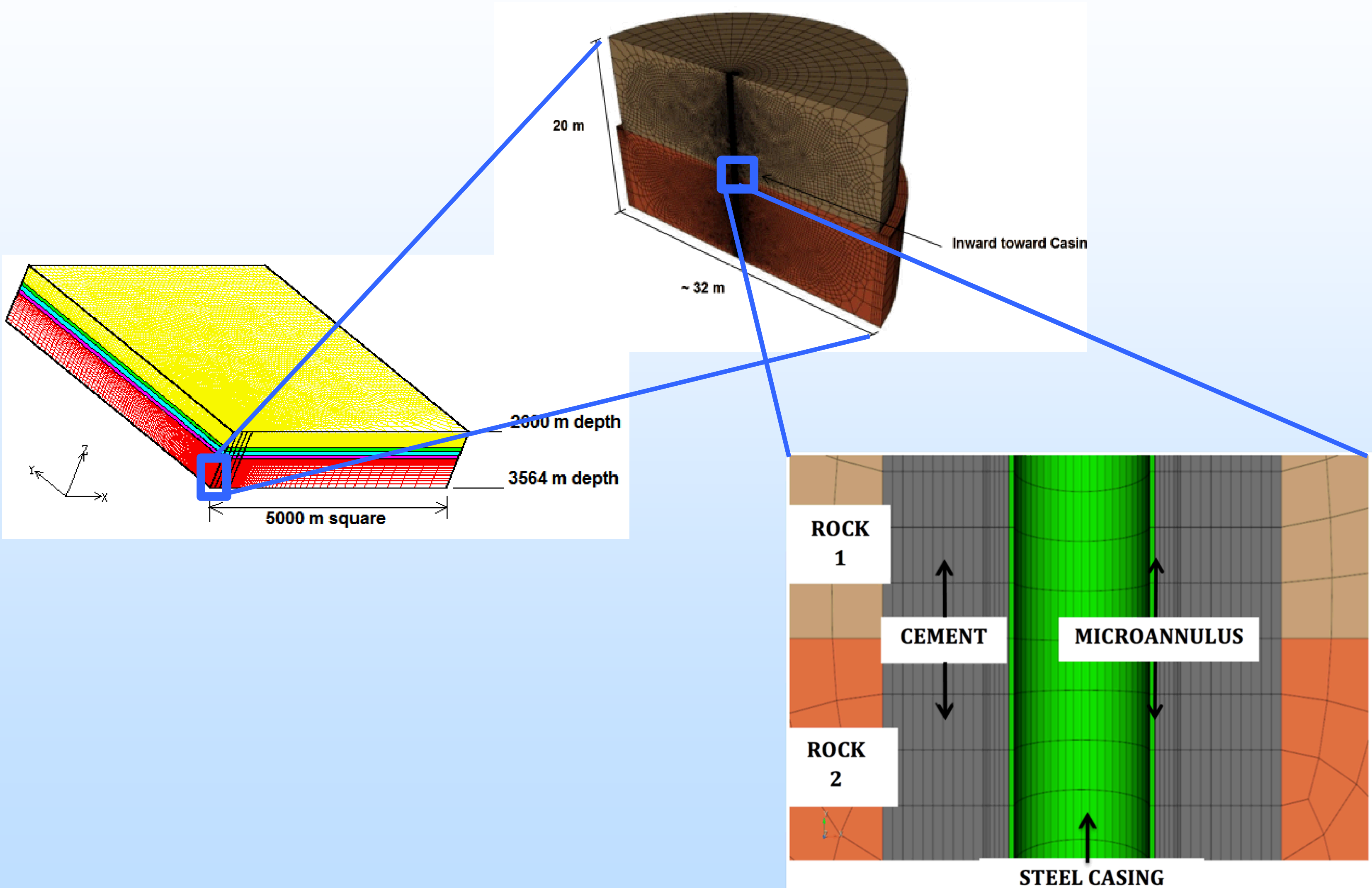


Image analysis of microphotographs to obtain microannulus aperture distribution.

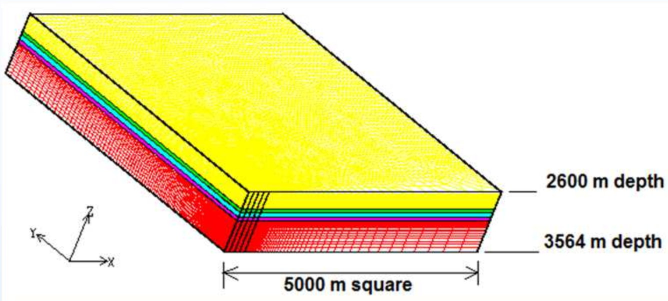


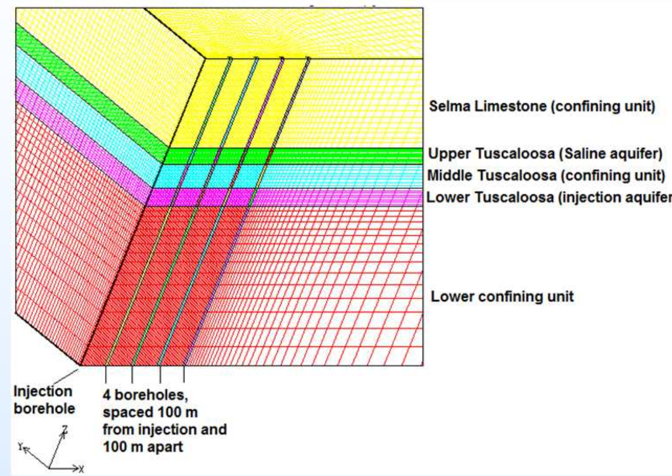


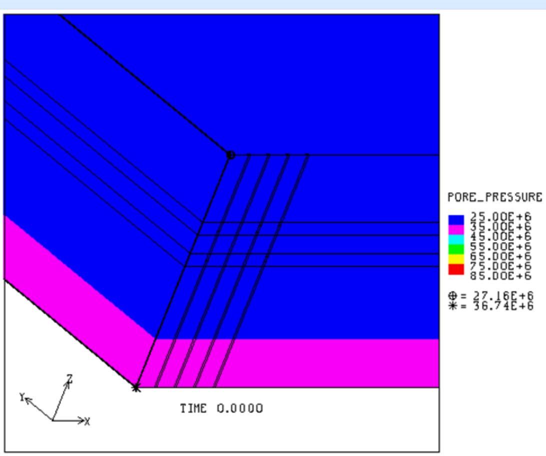
Multi-scale Geomechanical Modeling of Wellbores



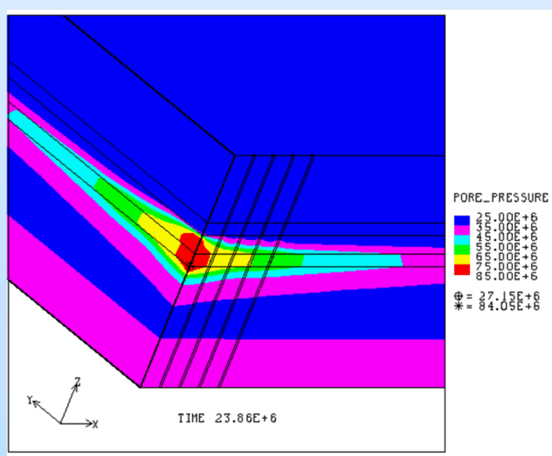
Field-scale Mesh and Model



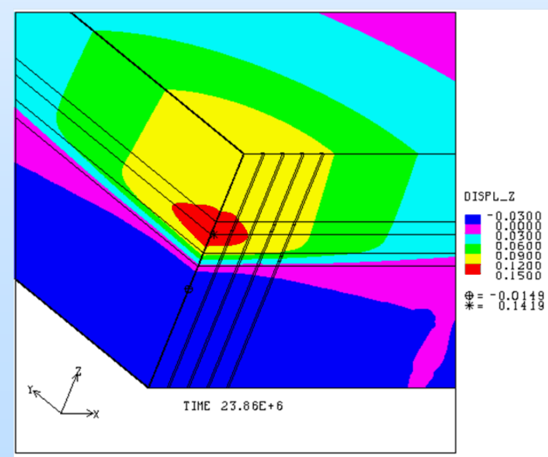




Pore Pressure
t=0

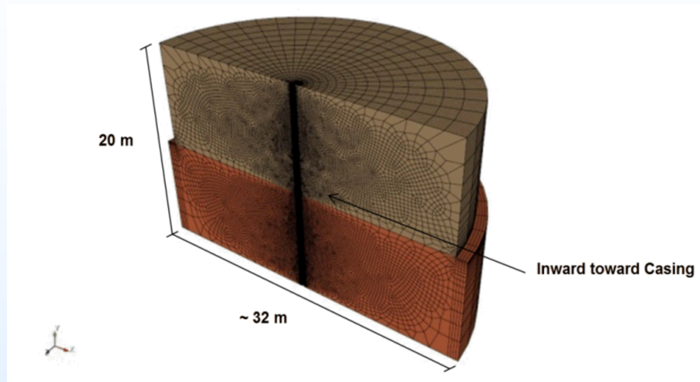


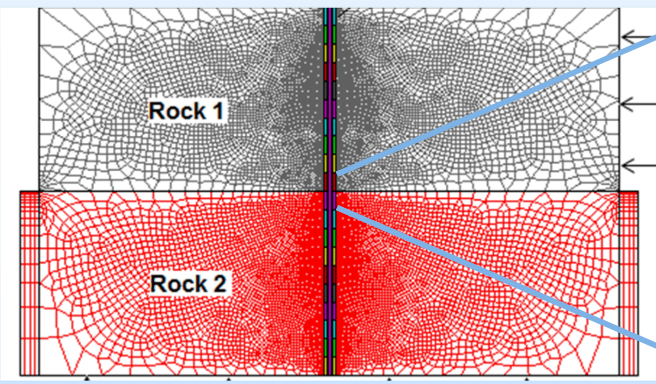
Pore Pressure
t=270 days

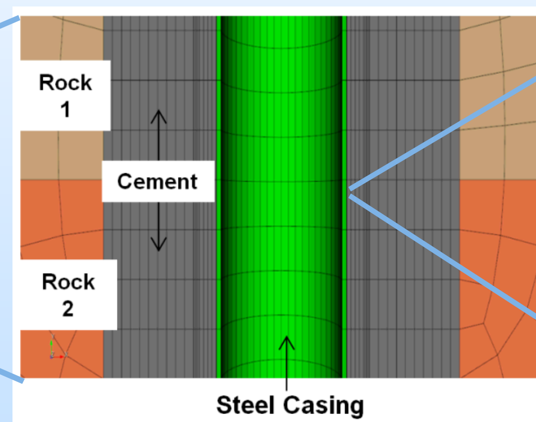


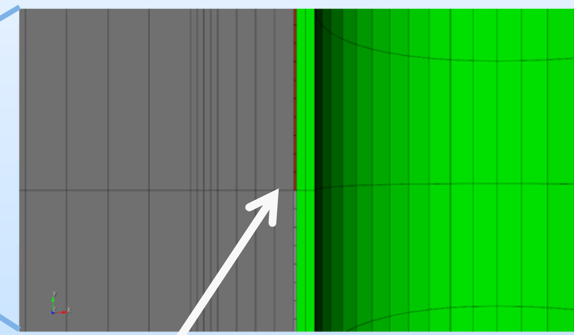
Vertical Displacement
t=270 days

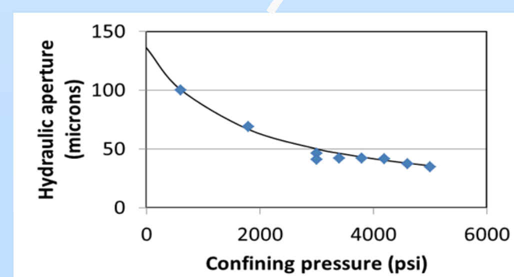
Wellbore Model





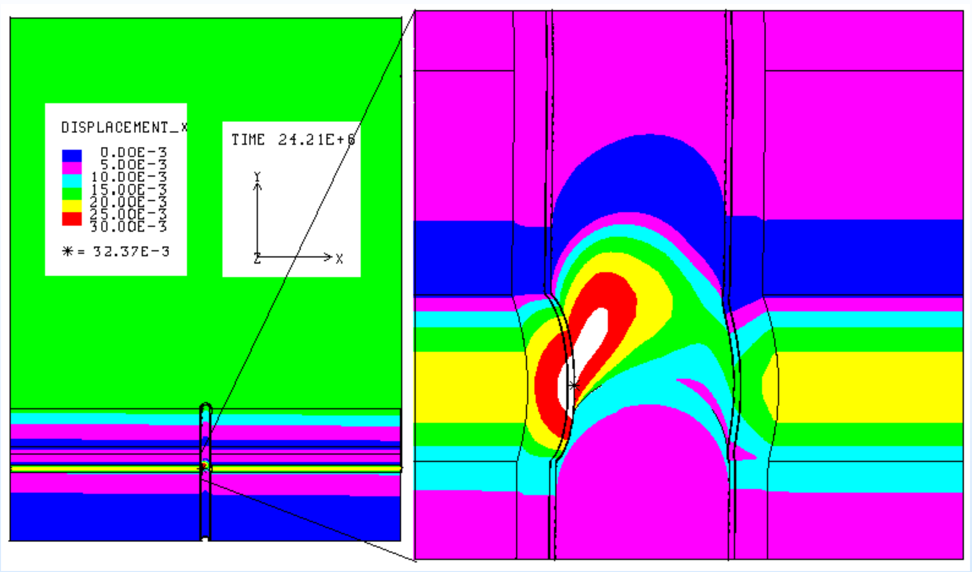


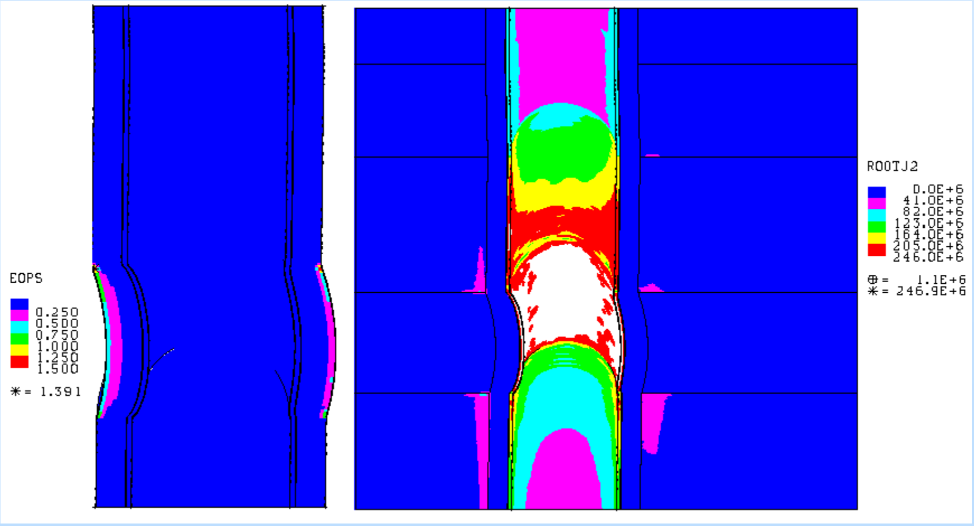




Wellbore-Scale Model coupled with Field Scale to quantify stresses and strains for CO2 Injection at the Cranfield Site

- 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 a number of nanocomposite and reference materials. For some nanocomposites:
  - Acceptable flowability
  - Bond strength and fracture toughness substantially increased
– Testing of wellbore seal systems
  - Developed experimental methods
  - Testing pre- and post-repair condition
– Simulation model developed

Synergy Opportunities

- Wellbore damage
  - Experimental methods and data set on permeability under different stress conditions can be used by/compared to work of others.
- 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.

Summary

– Polymer nanocomposites are being developed and tested with favorable properties as seal repair materials.

– Future Plan: Continue material synthesis and testing with accompanying testing and evaluation of seal system repair.

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

We thank Steve Sobolik and Steven Gomez for their contributions to the modeling work, and Moneeb Genedy, Rashid Ahmad, and Serafin Garcia Fernandez for their help with the laboratory work.

We thank Transpo Industries Inc. (New York) and Epoxy Chemicals (Illinois) for donating most of the materials used in this research.

This material is based upon work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Grant Number DEFE0009562.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.