Wellbore Seal Repair Using Nanocomposite Materials

Project Number DE-FE0009562

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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.

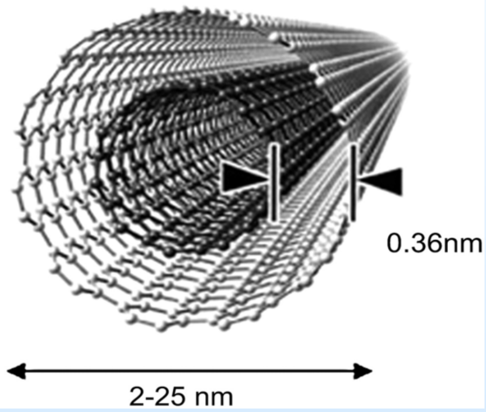
Project Overview:
Goals and Objectives (CONTINUED)

(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.

Nanocomposites - addition of small amounts of nano-scale materials can dramatically alter properties of materials such as polymers, composites, and cements.

- Strength
- Ductility
- Reduce shrinkage
- Thermal stability
- Resistance to degradation



Materials

Base materials

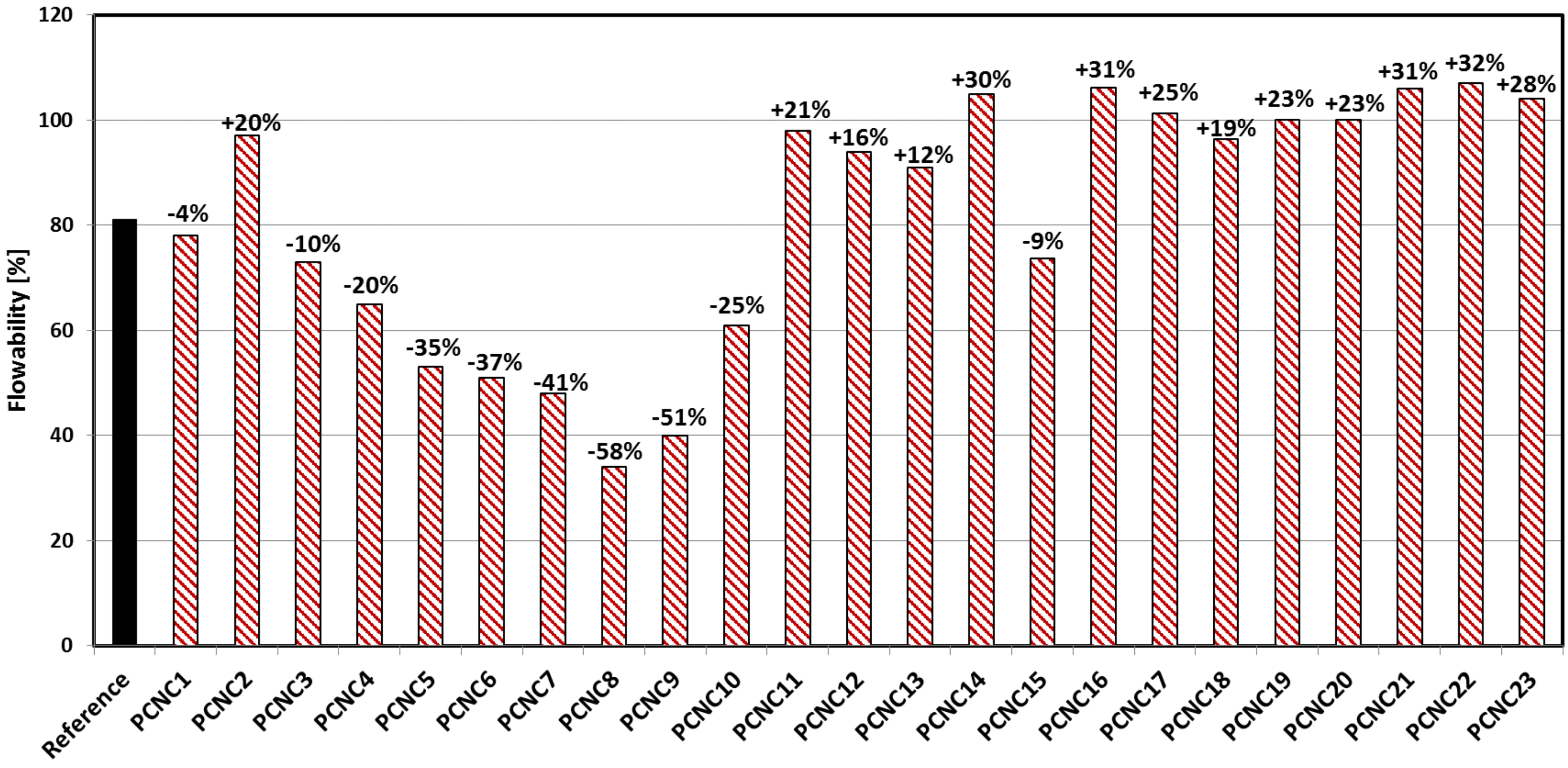
- Siloxane
- Novolac

Nanoparticles

- MWCNTs
- Nanoclay
- Nanoalumina
- Nanosilica

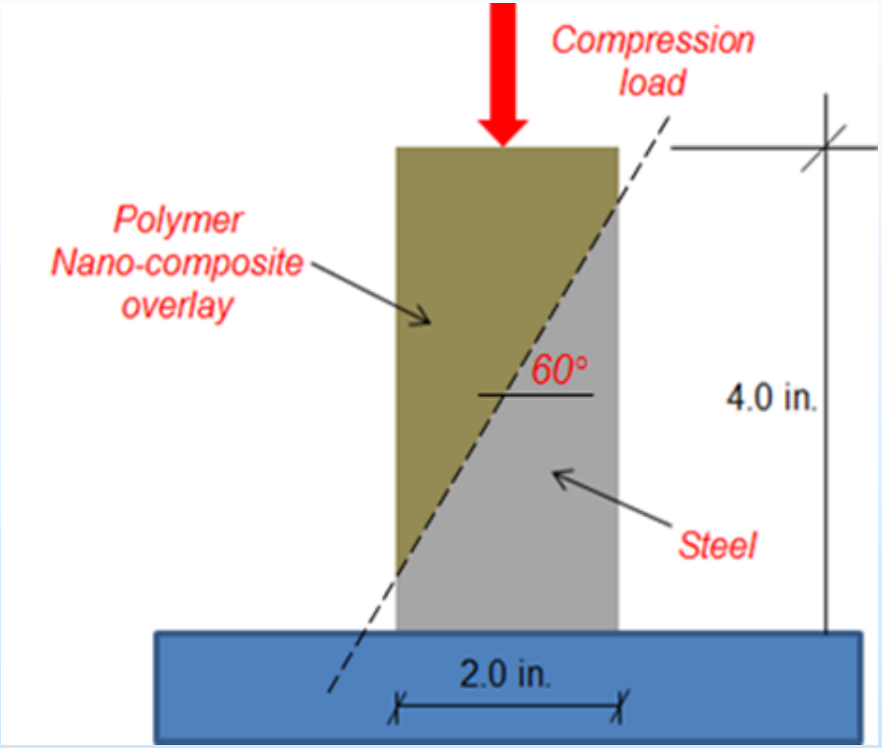
Nanocomposites

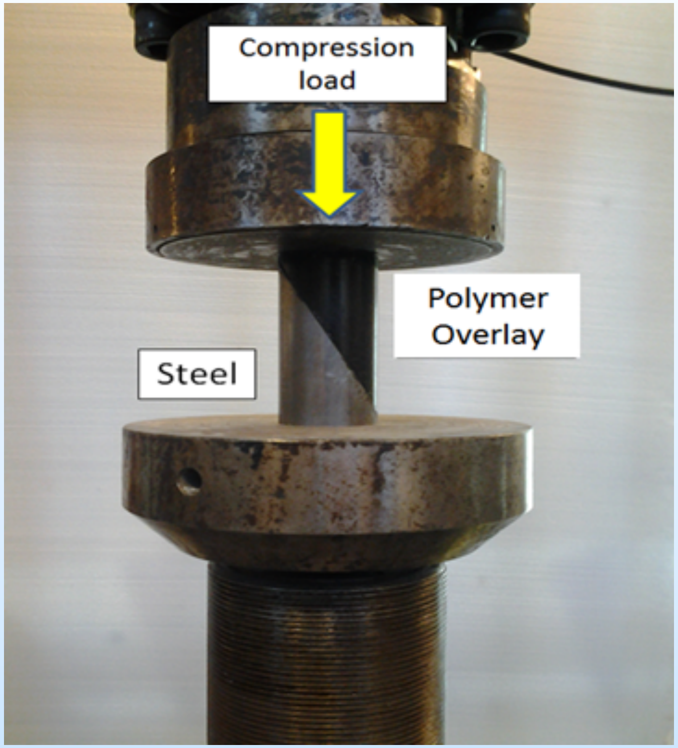
Flowability of PCNC



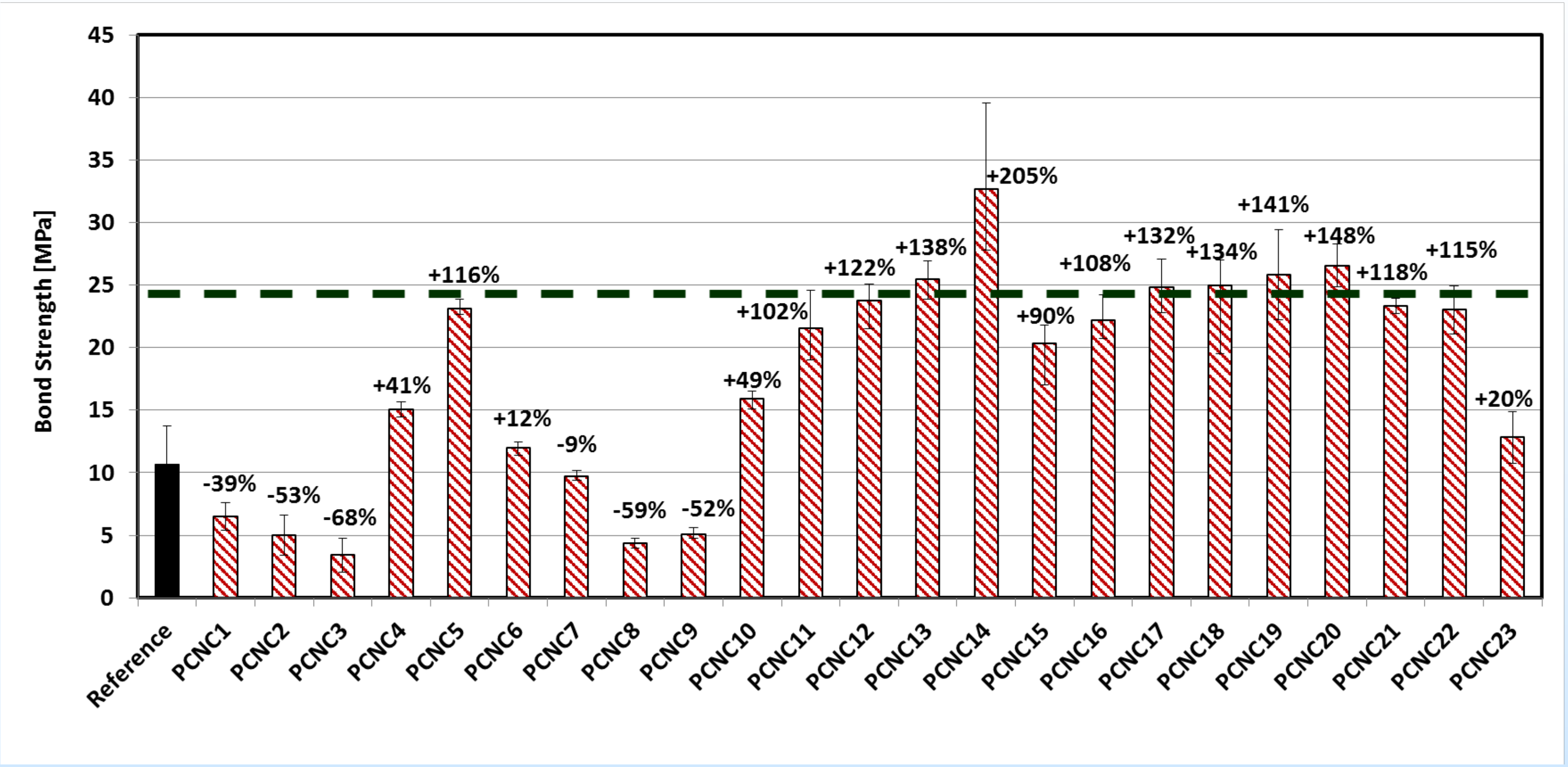
Bond strength characterization

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

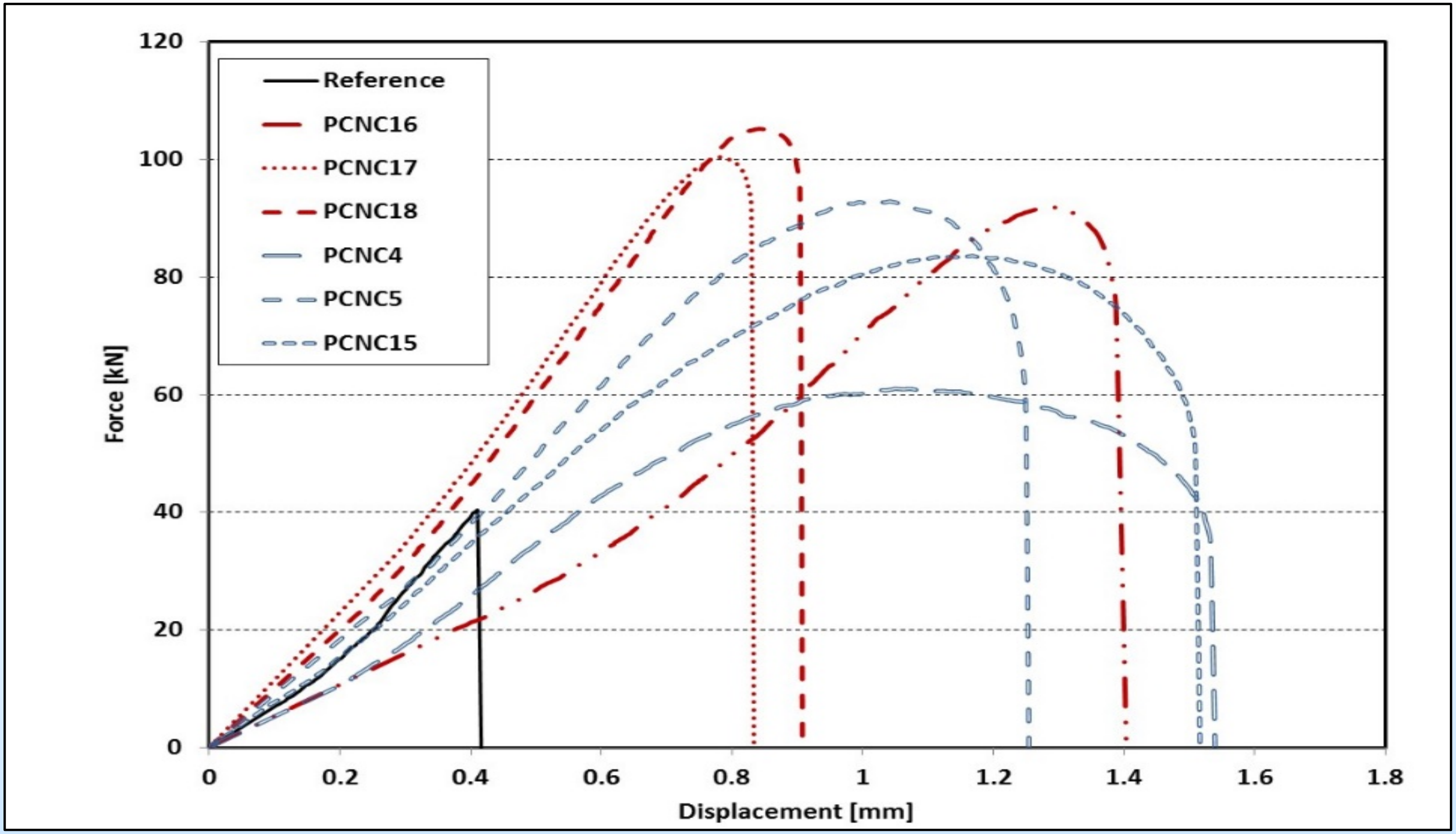




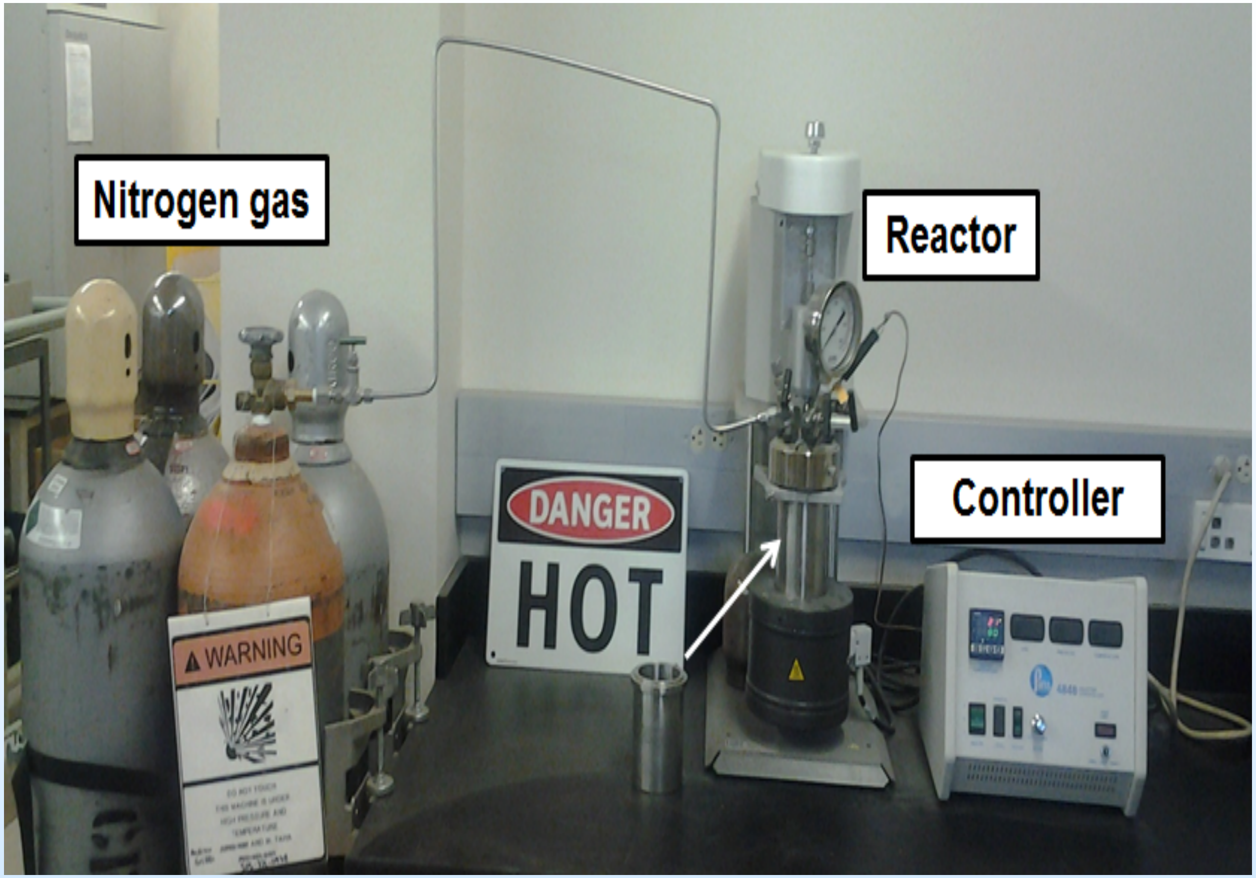
Bond Strength of PCNC and Steel

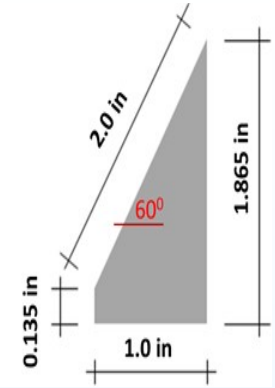


PCNC – Steel slant shear behavior

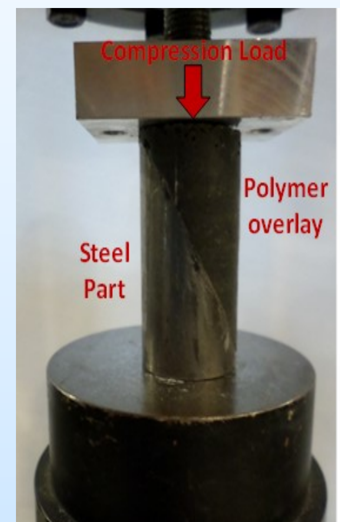


Examining the effect of high temperature and pressure



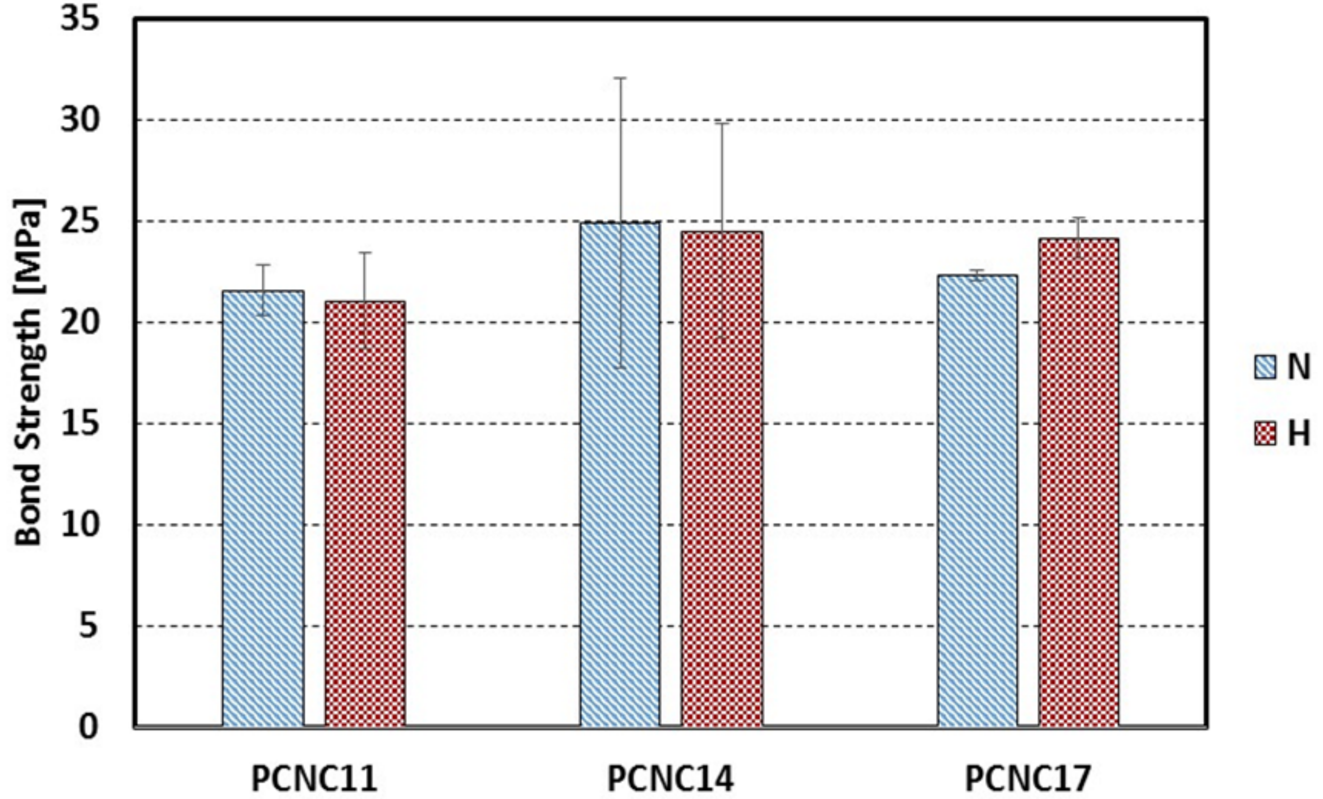


Scaled specimens



Temp: 80 °C, Pressure 10 MPa

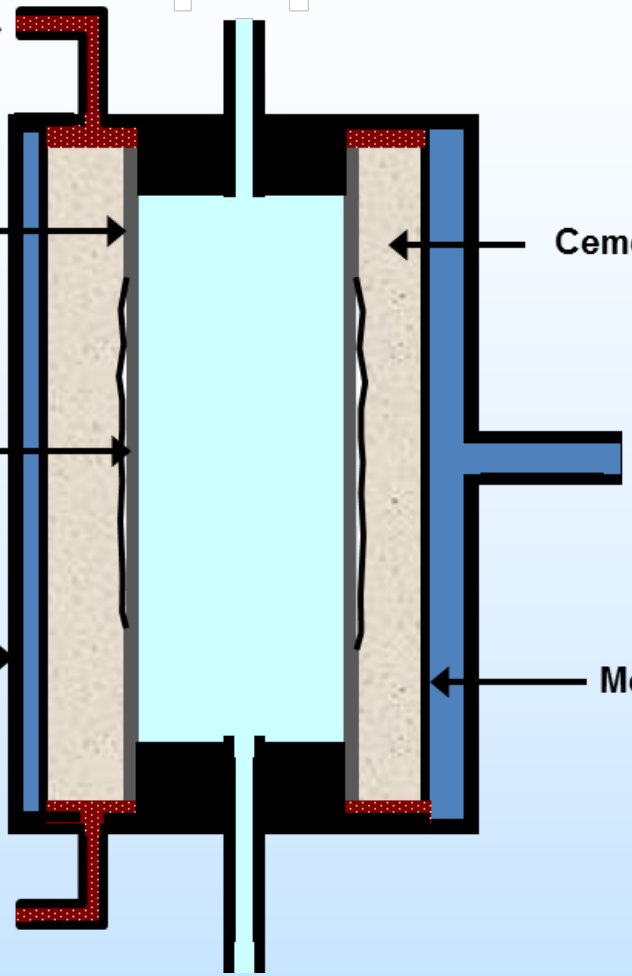
No effect of elevated temperature and pressure on performance of PCNC



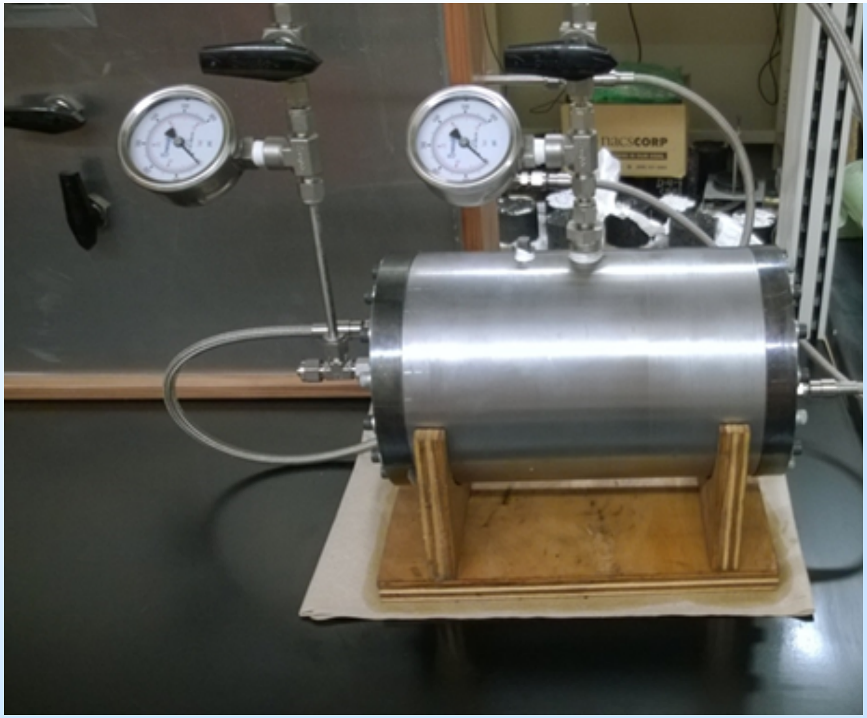
Cured at ambient conditions

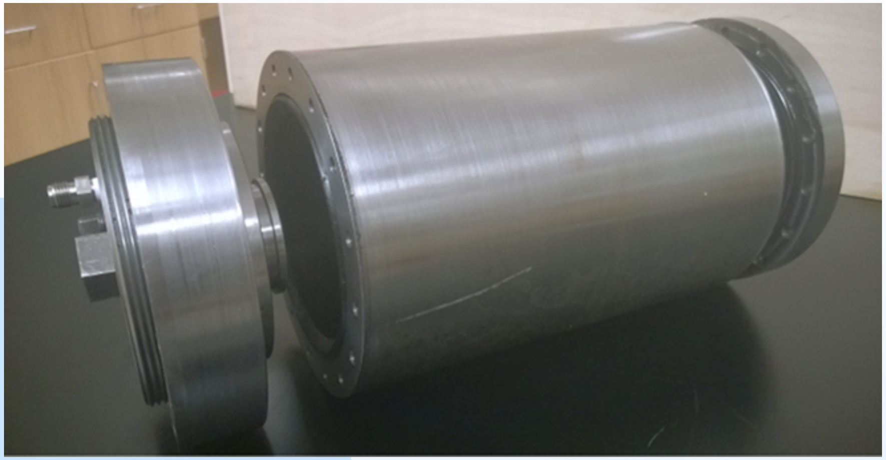
Cured at elevated temperature and pressure

Flow through damaged and repaired wellbore systems



Pressure vessel





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

Gas Permeameter

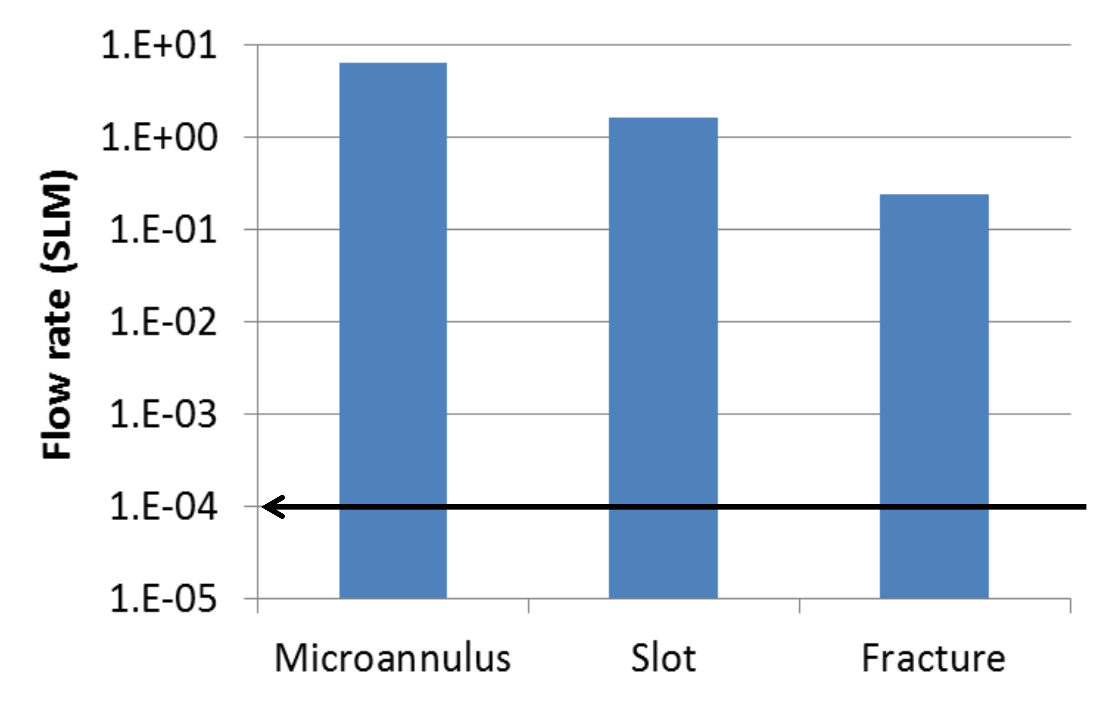
Gas pressures to 14 MPa.

Permeability range $>10^{-12}$ to $<10^{-21}$ m^2

Specimen preparation

- Microannulus
  - Large
  - Small
- Cement fracture

Flow dominated by flaws



Approximate flow rate for intact specimen

Cubic law for hydraulic aperture

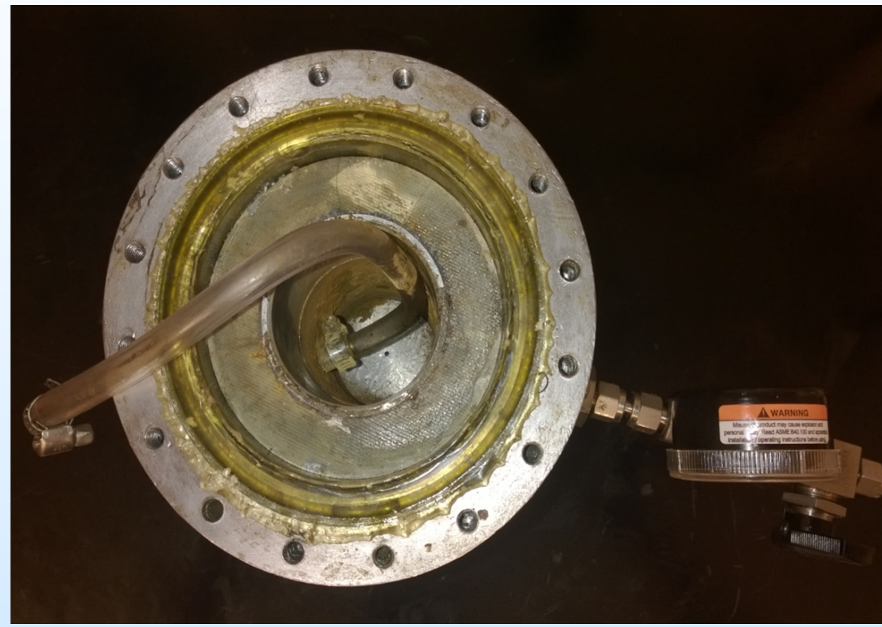
$$h^3 = \frac{12\,k\,A}{w}$$

Repair of damaged wellbores

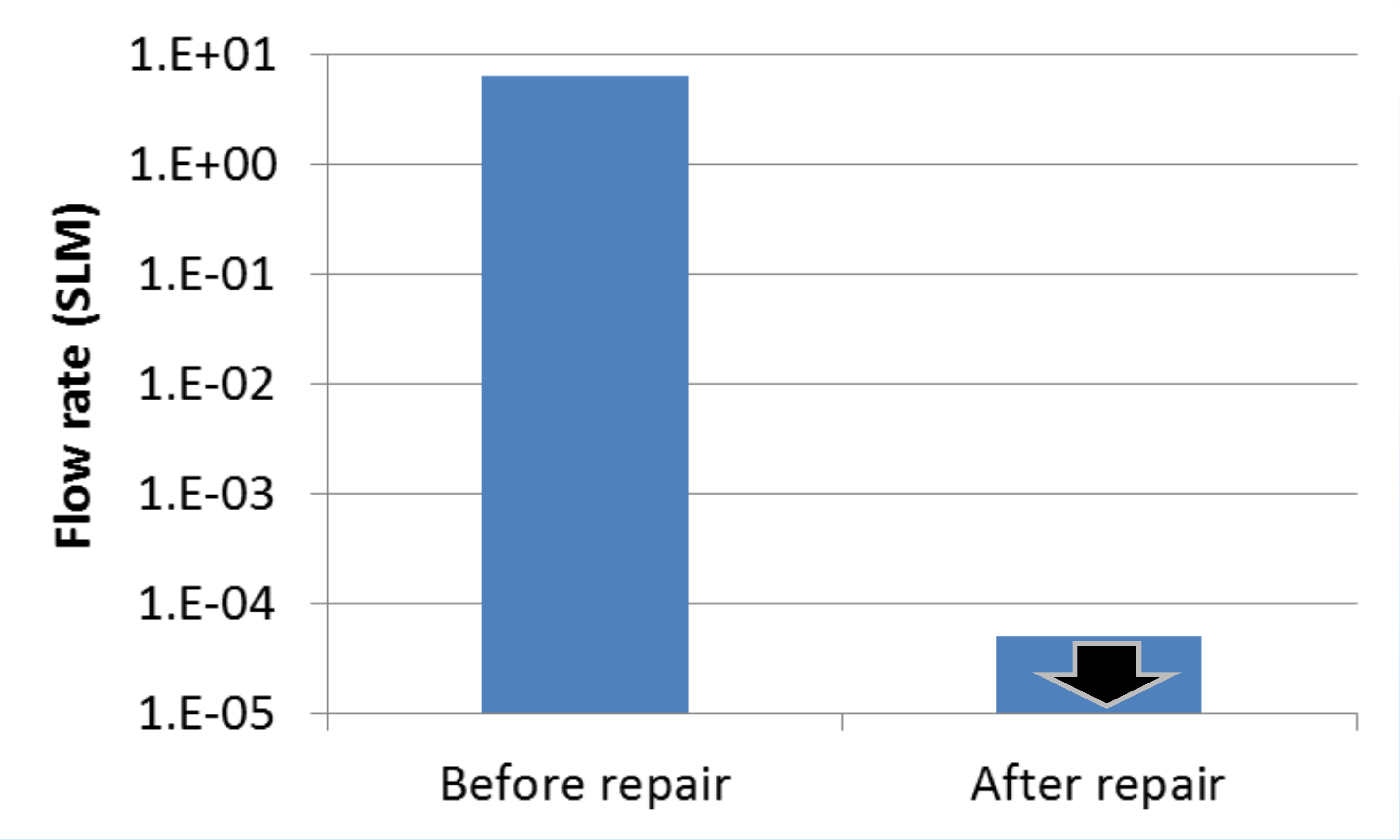
1. No pressure

2. Separate pressurized system

3. In pressure vessel

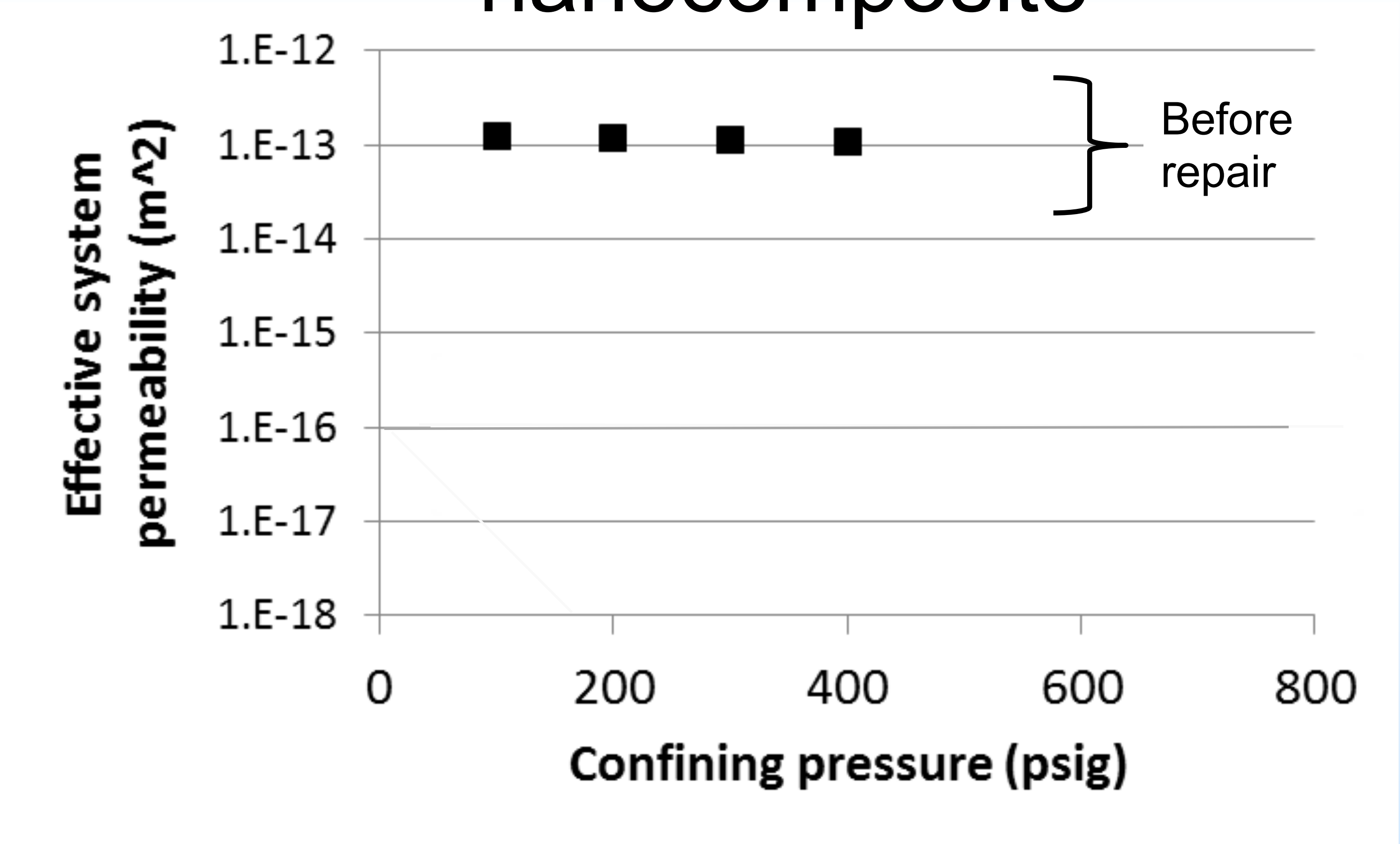


Microannulus repair using nanocomposite



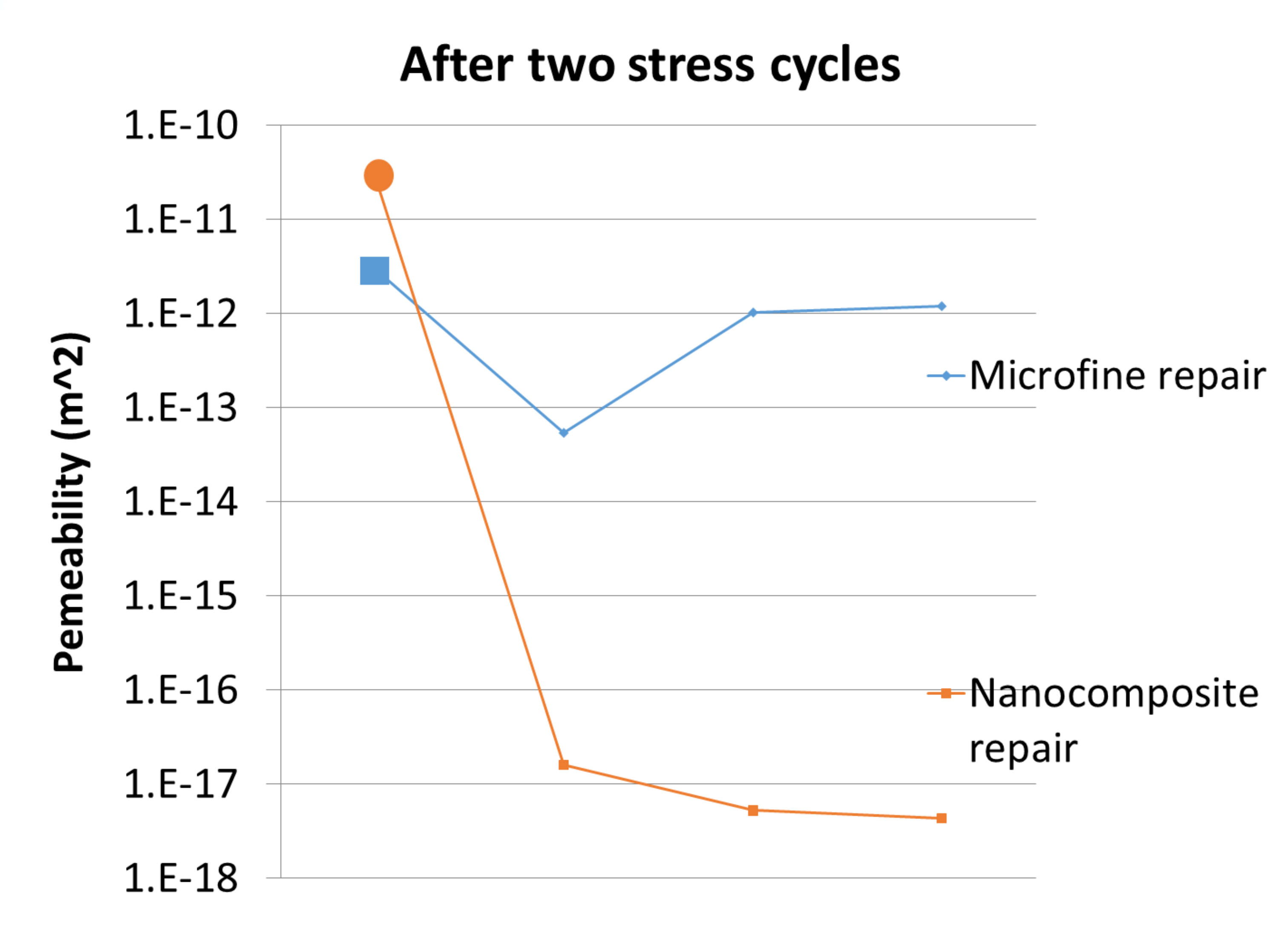
Confining pressure = 200 psig
Internal pressure = 200 psig
Pore pressure = 100 psig

Cement fracture repair using nanocomposite

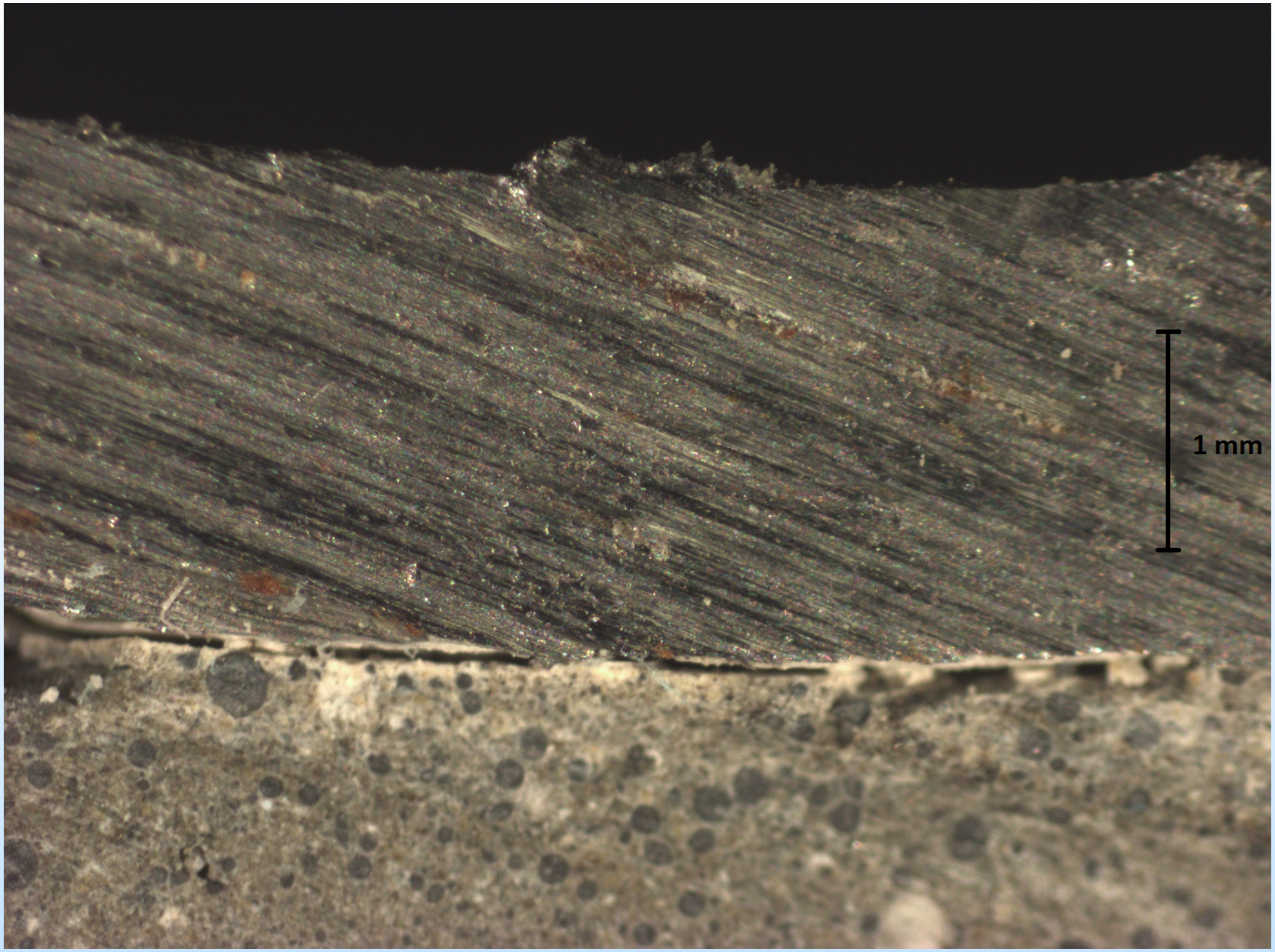


Internal pressure = confining pressure
Gas pressure = 50 psig

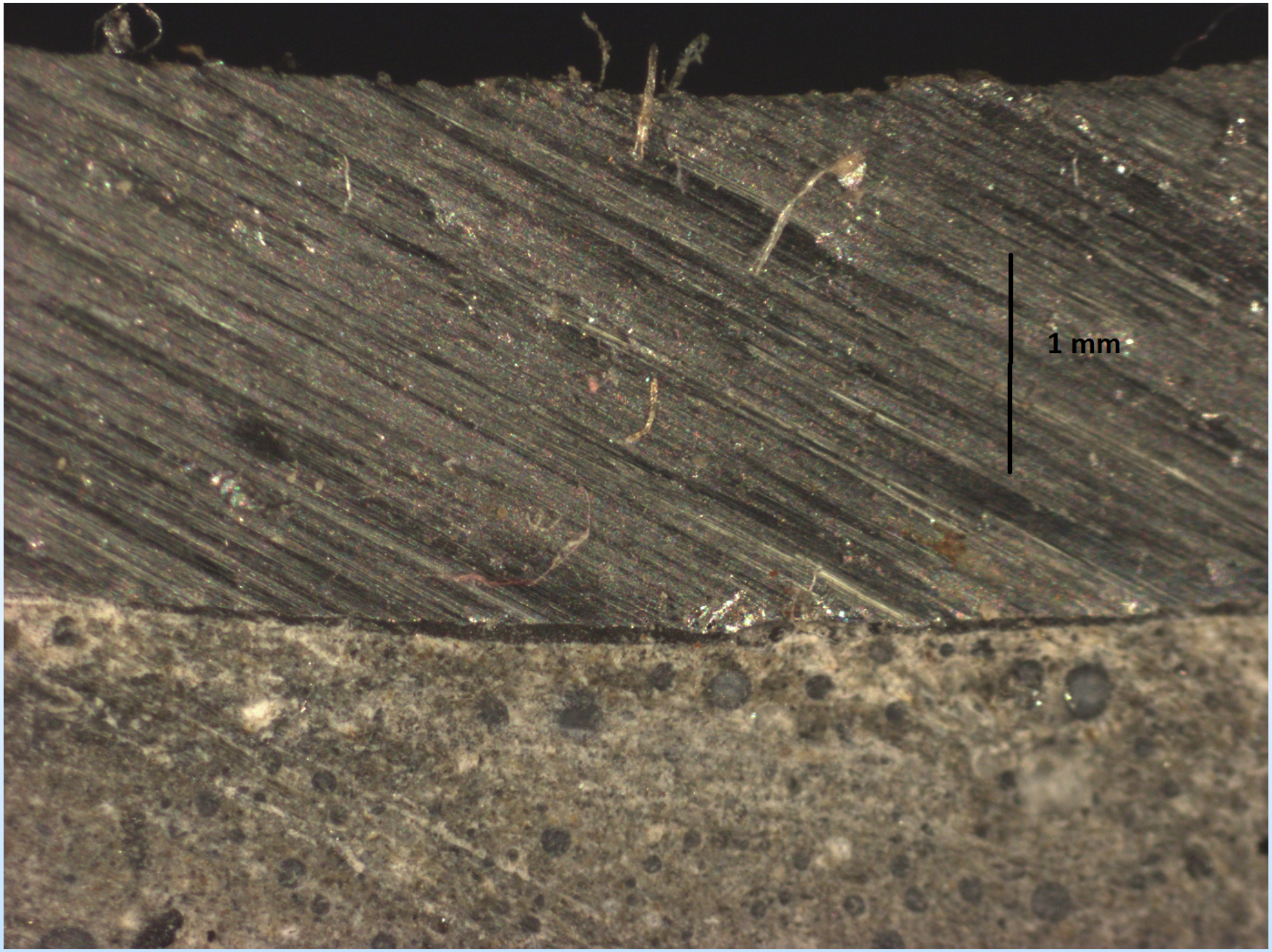
Repair response to stress cycles



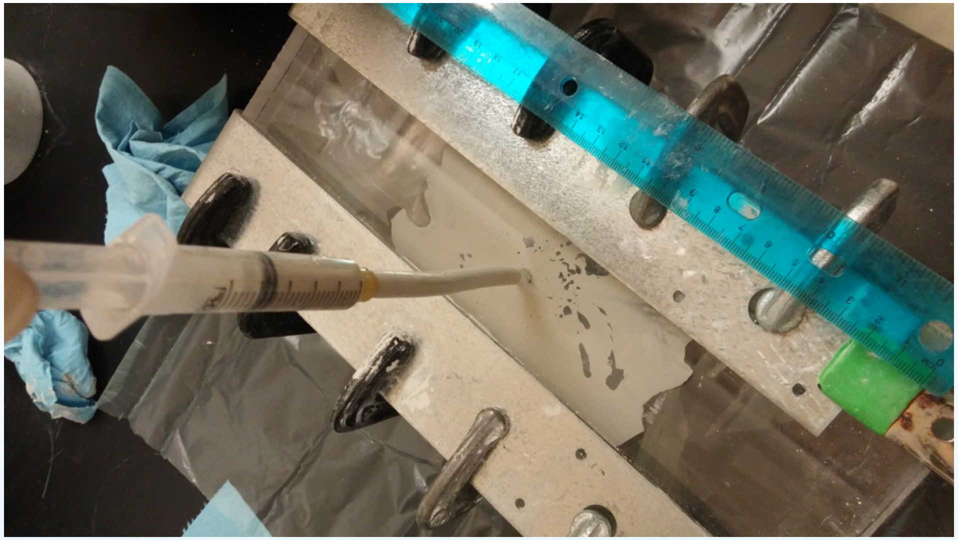
Repaired with microfine cement



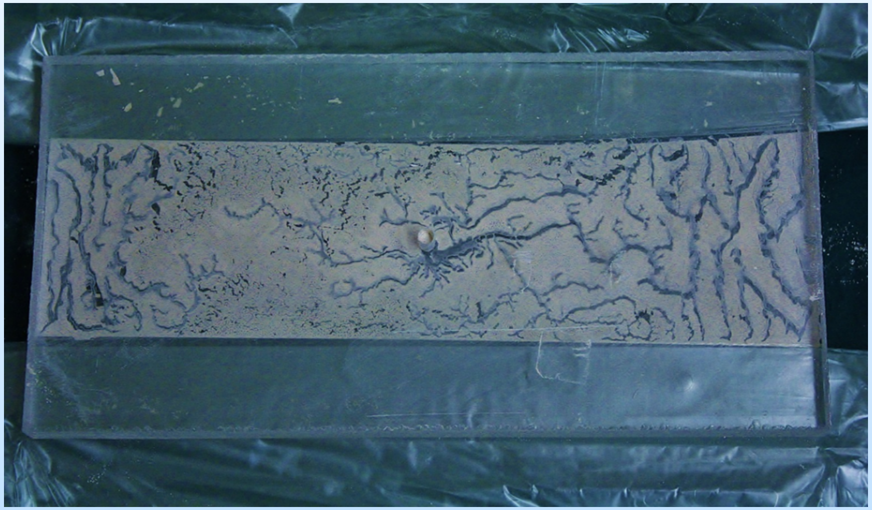
Repaired with nanocomposite



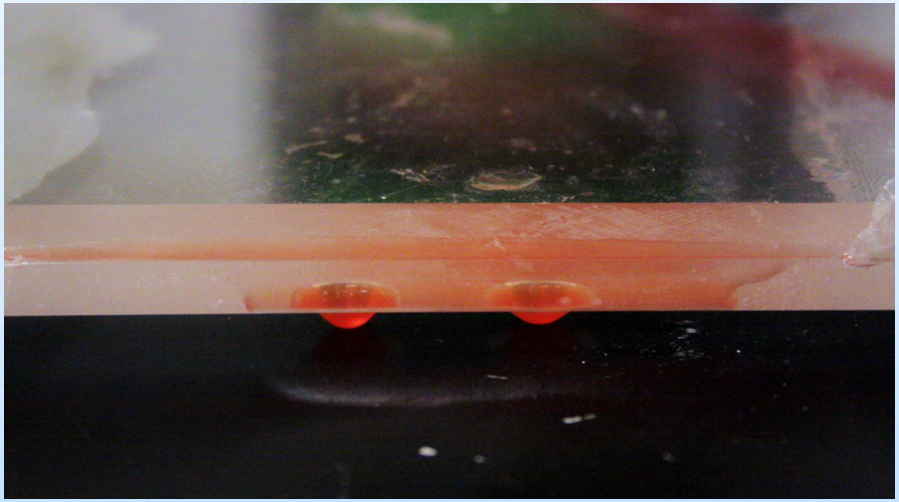
Penetrability



Microfine penetrated 75 μm gap

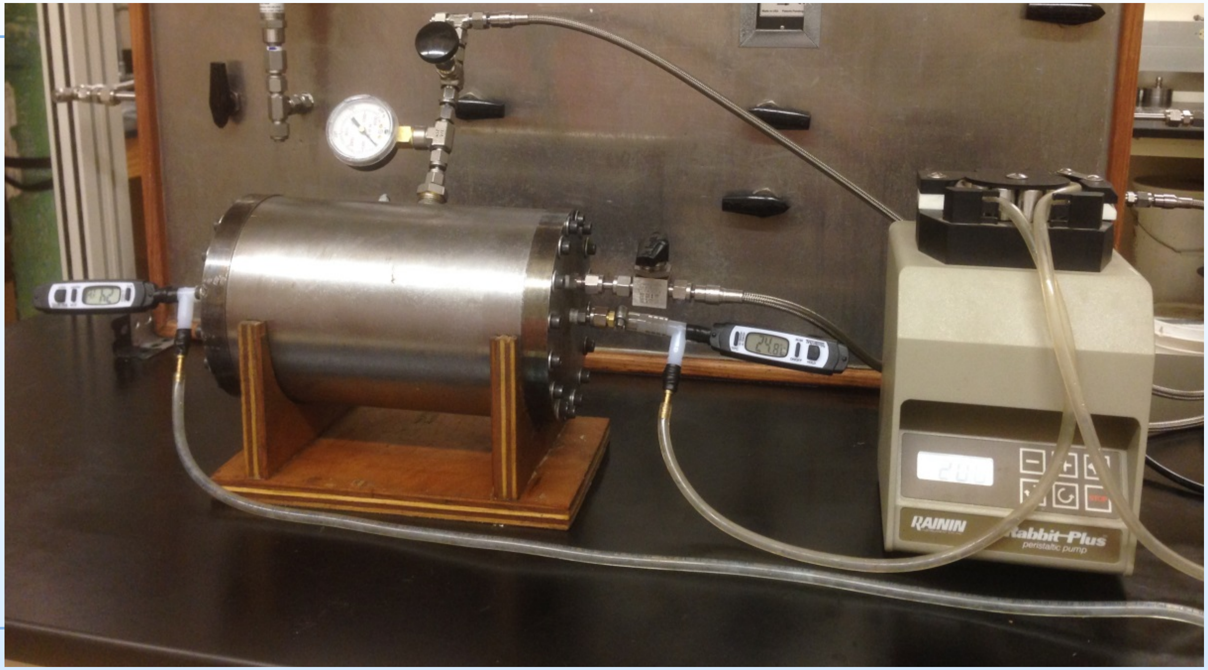


Nanocomposite penetrated 13 μm gap



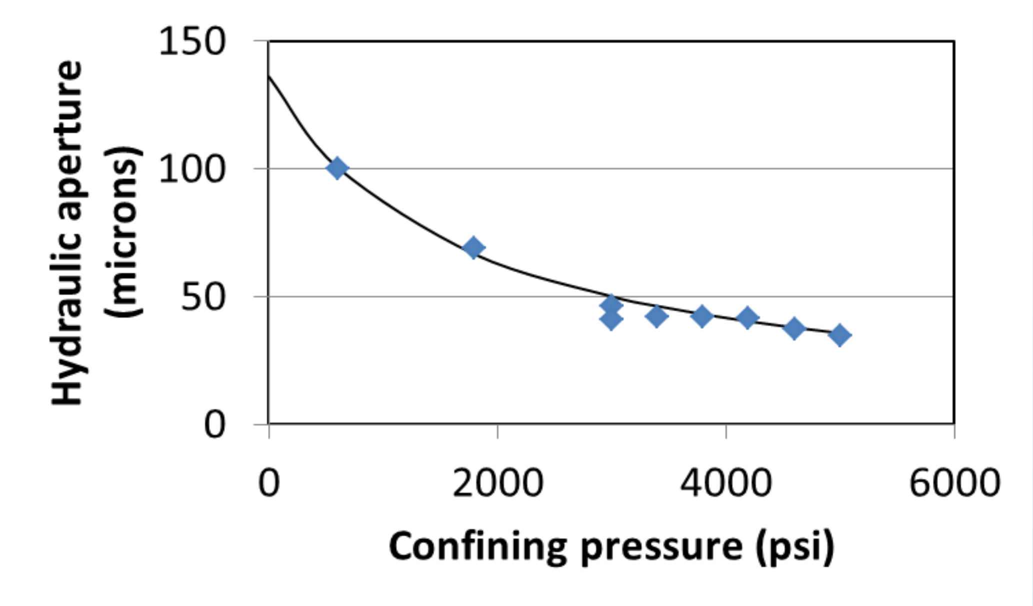
Response of microannulus and repaired microannulus to thermal stress

- Circulate cold and hot water through casing to induce casing expansion and contraction



Microannulus model

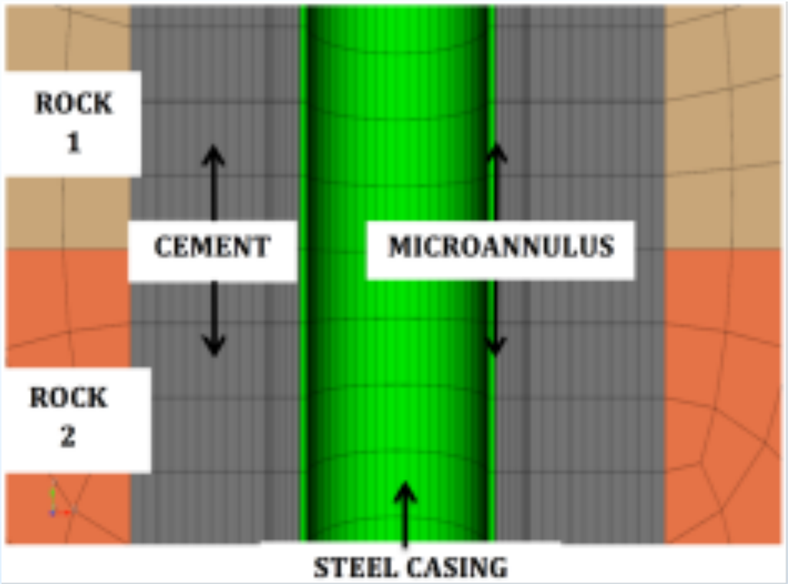
Material model for the microannulus that describes permeability changes in response to changes in confining and/or casing pressure and temperature.

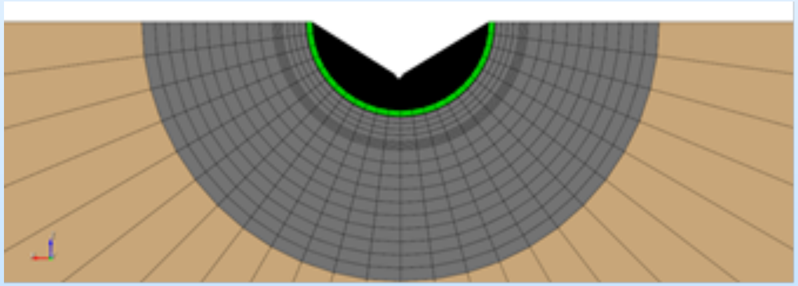


Wellbore model incorporating microannulus

Microannulus space can be modeled as

- Microannulus
- Open
- Cement
- Repair material





Accomplishments to Date

– 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.

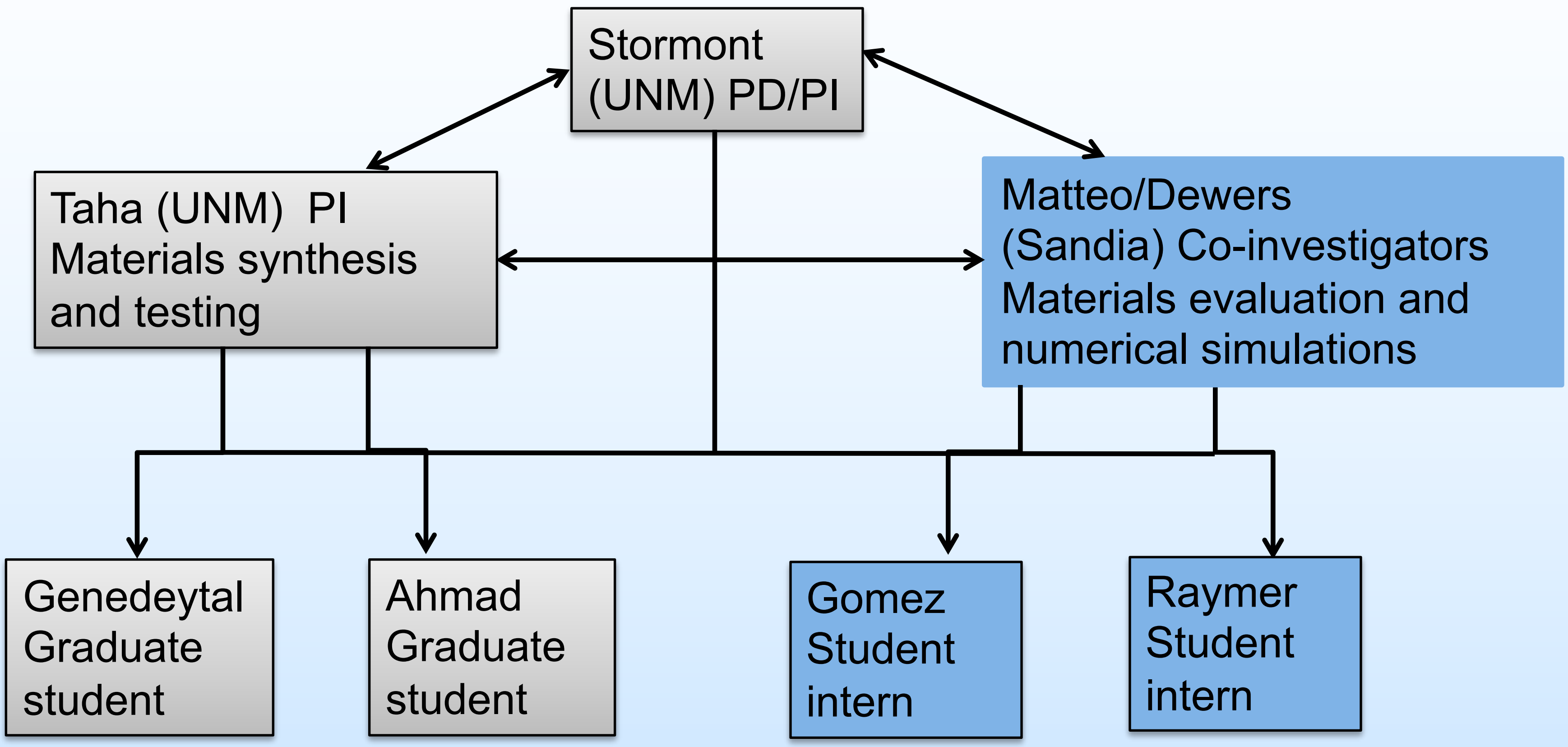
Summary

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

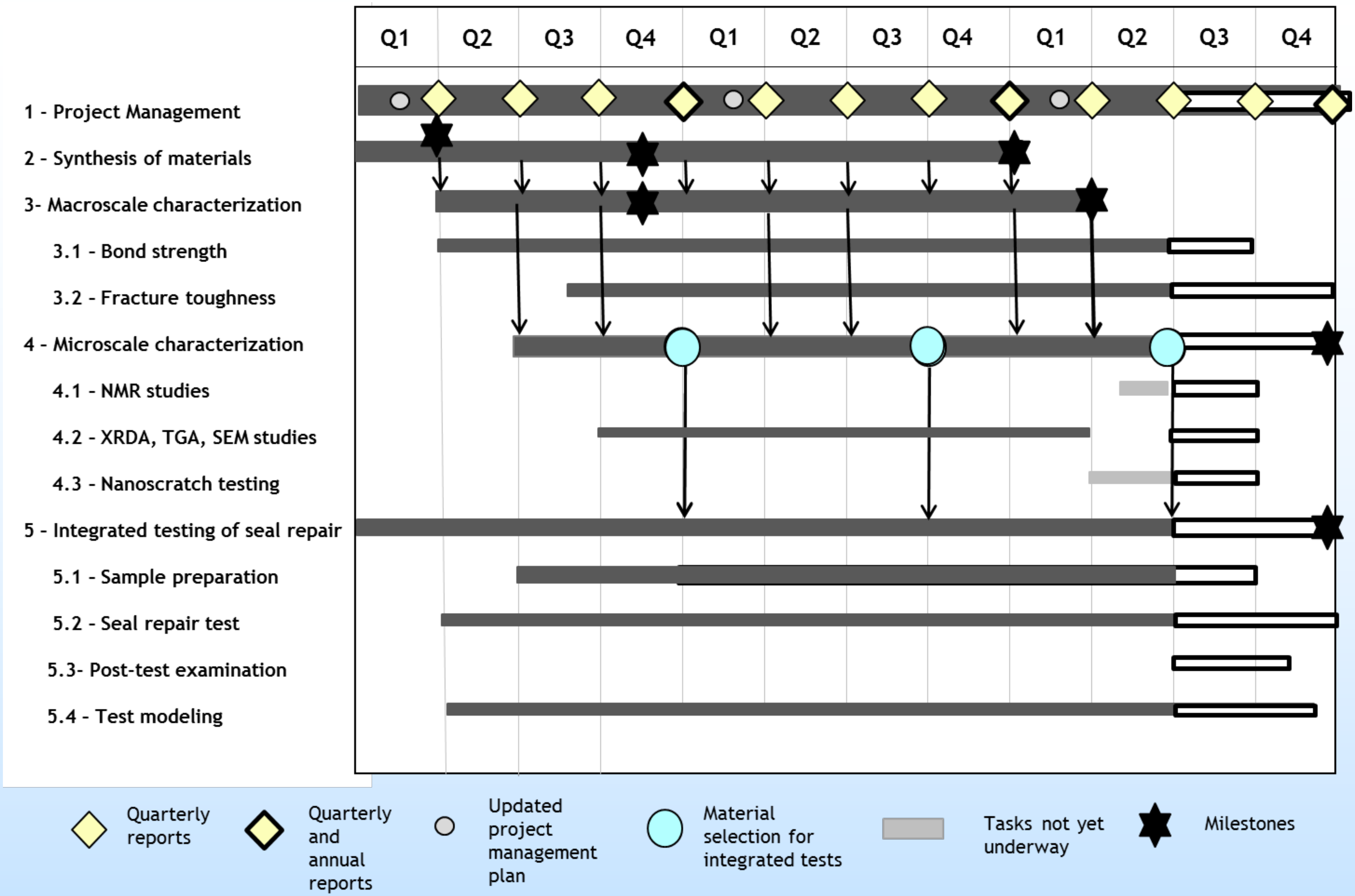
– Future Plan: Continue material synthesis and testing with accompanying testing and evaluation of seal system repair.

Appendix

Organization Chart



Gantt Chart



Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
1 - Project Management
2 - Synthesis of materials
3- Macroscale characterization
3.1 - Bond strength
3.2 - Fracture toughness
4 - Microscale characterization
4.1 - NMR studies
4.2 - XRDA, TGA, SEM studies
4.3 - Nanoscratch testing
5 - Integrated testing of seal repair
5.1 - Sample preparation
5.2 - Seal repair test
5.3- Post-test examination
5.4 - Test modeling
Quarterly reports
Quarterly and annual reports
Updated project management plan
Material selection for integrated tests
Tasks not yet underway
Milestones

Bibliography

Publications generated from project

- Aboubakr, S., Kandil, U. and Reda Taha, M. M. "Creep of Epoxy-Clay Nanocomposite at the FRP Interface", *Proceedings of the 9th International Conference of Composite Science and Technology, Meo, M. Ed., Sorrento, Naples, Italy, pp. 791-801, April 2013.*
- Kim, J. J., Rahman, M.K., Abdulaziz, A.A., Al-Zahrani, M. and Reda Taha, M.M "Nanosilica Effects on Composition and Silicate Polymerization in Hardened Cement Paste Cured under High Temperature and Pressure", *Cement and Concrete Composites*, Vol. 43, pp.78-85, 2013.
- 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.

Bibliography

Publications generated from project

- Stormont, J.C., Ahmad, R., Ellison, J., Reda Taha, M.M., Matteo, E. (2015) "Laboratory measurements of flow through wellbore cement-casing microannuli," *Proceeding of the 49th US Rock Mechanics/Geomechanics Symposium*, San Francisco, June.
- Sobolik, S., Gomez, S.P., Matteo, E.N., Dewers, T.A., Newell, P., Stormont, J.C., Reda Taha, M.M., (2015) "Geomechanical modeling to predict wellbore stresses and strains for the design of wellbore seal repair materials for use at a CO2 Injection site," *Proceeding of the 49th US Rock Mechanics/Geomechanics Symposium*, San Francisco, June.
- Gomez, S.P. (2015) *Wellbore Microannulus Characterization and Seal Repair: Computational and Lab Scale Modeling*. Master's Thesis, University of New Mexico.

Bibliography

Publications generated from project

- Griffin, A., Kim, J., Rahman, M., and Reda Taha, M.M. "Microstructure of a Type G Oil Well Cement-Nanosilica Blend." *Journal of Materials in Civil Engineering*, Vol. 27, No. 5, 04014166. 2015.
- 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, October 2015, 9 p.

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