Wellbore Seal Repair Using Nanocomposite Materials

Project Number DE-FE0009562

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U.S. Department of Energy

National Energy Technology Laboratory

Carbon Storage R&D Project Review Meeting

Developing the Technologies and

Infrastructure for CCS

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Presentation Outline

- Introduction and overview
- Materials synthesis
- Materials testing and characterization
- Annular 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.

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Project Task Flow

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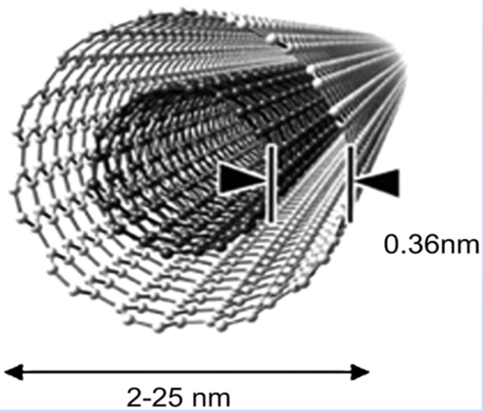
Synthesize nanocomposites
Task 2

Macro- and micro-characterization of materials
Task 3 and 4

Evaluate as repair material in integrated seal tests
Task 5

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

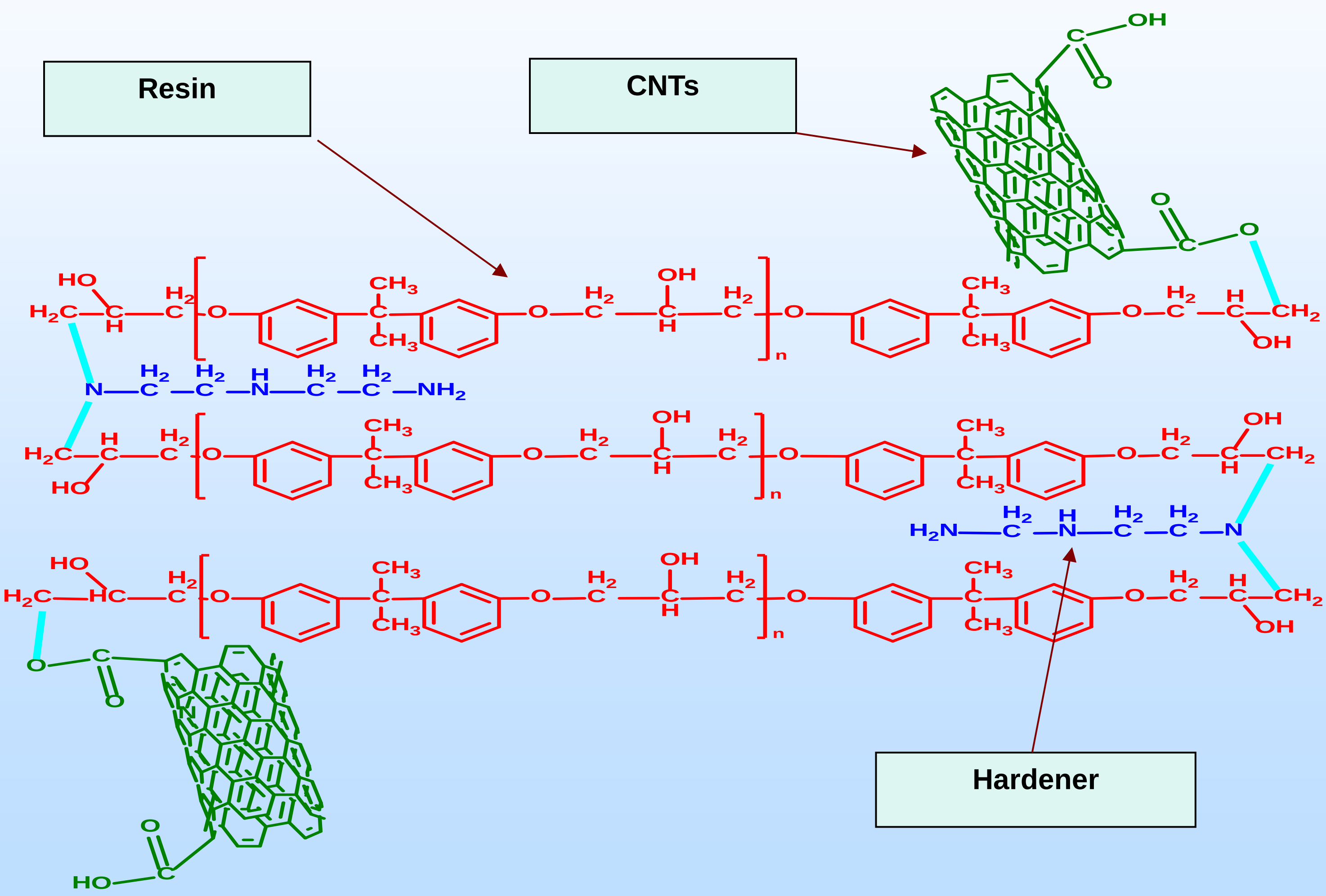
Polymers	Nanomaterials			
	CNTs	Nanoclay	Nanosilica	NanoEG
Epoxy – Siloxane	C	C	U	P
Epoxy-Novolac	U	U	U	P
PA cured Epoxy	P	P	P	P
Epoxy-DPPETES				
Epoxy-Polyarylene esters				

Standard materials	
Neat epoxies	U
Microfine cement	P

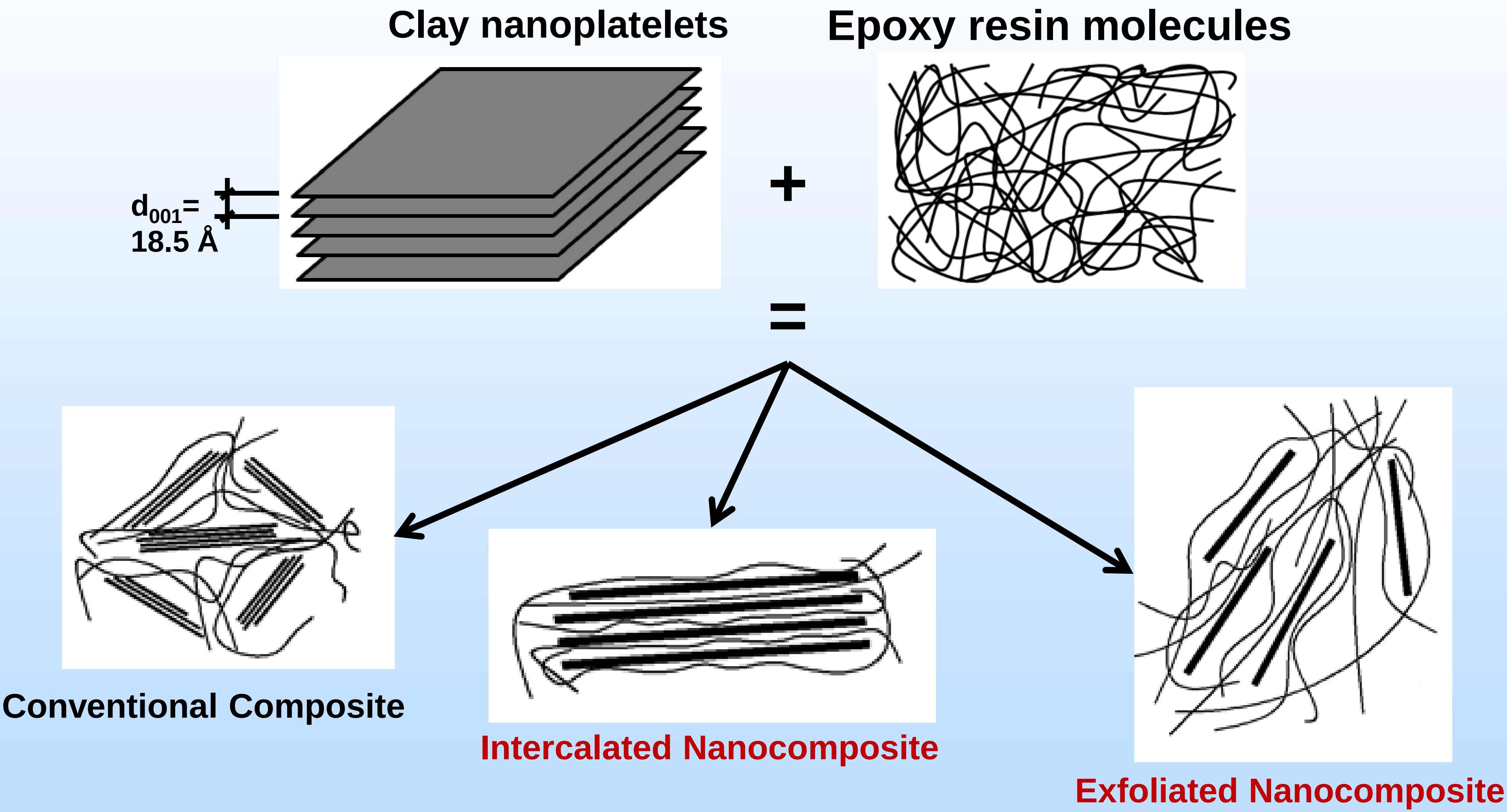
C: completed testing	U: undergoing testing	P: planned in next quarter

Epoxy-CNT nanocomposite

Dispersion of CNTs is critical



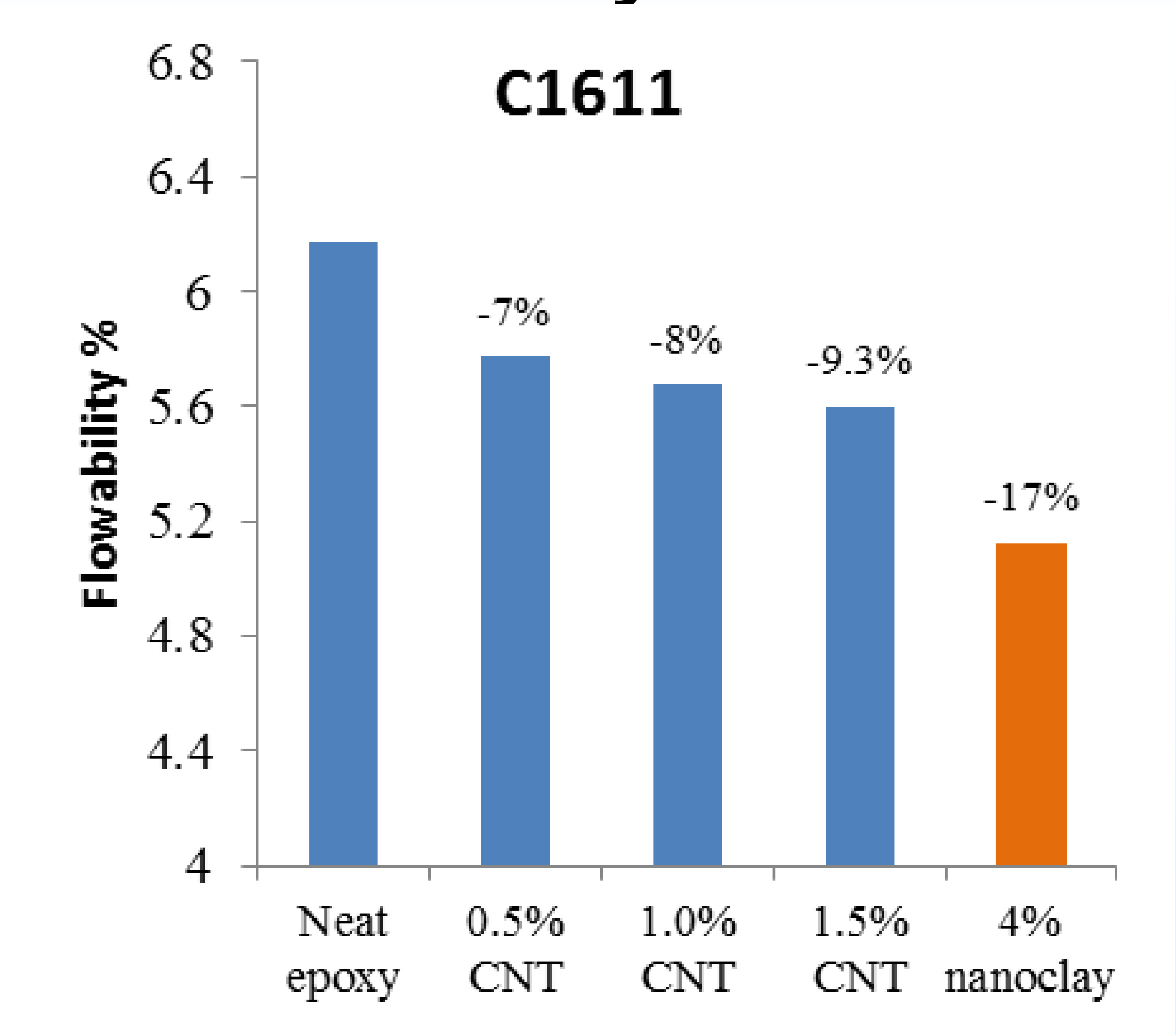
Epoxy-Montmorillonite nanocomposite



Flowability

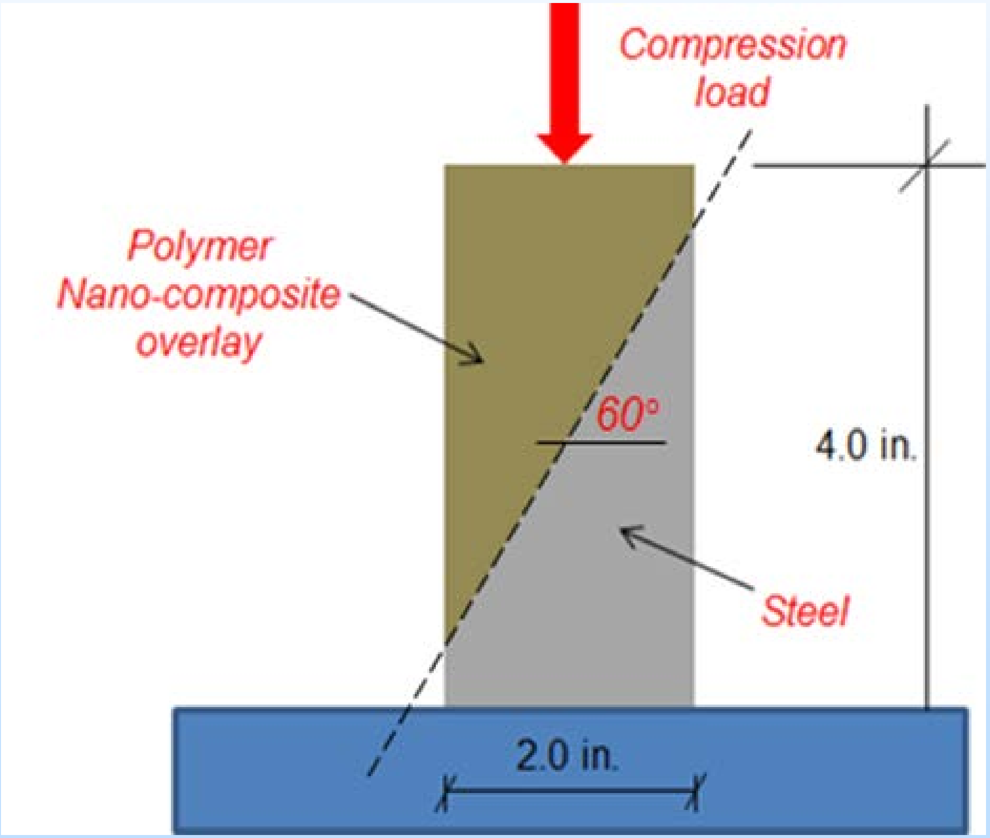
related to ability to inject nanocomposite into flaws.

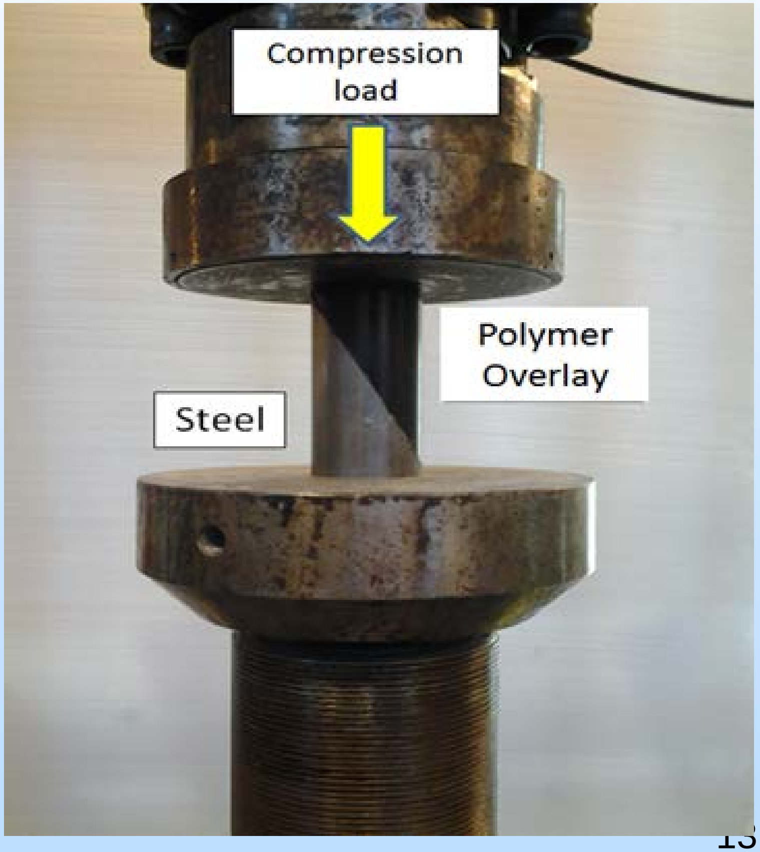
Flowability results



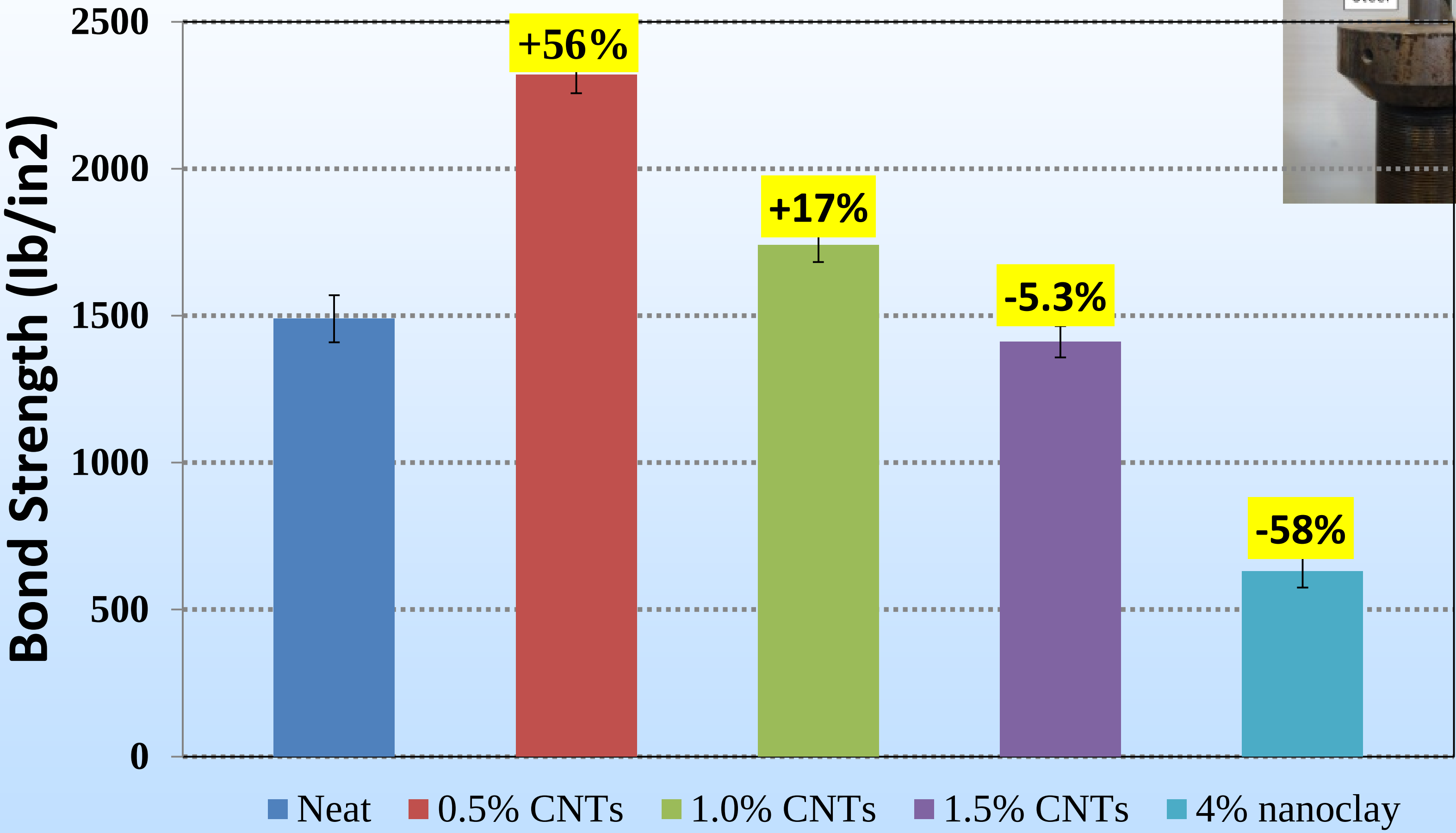
Bond strength characterization

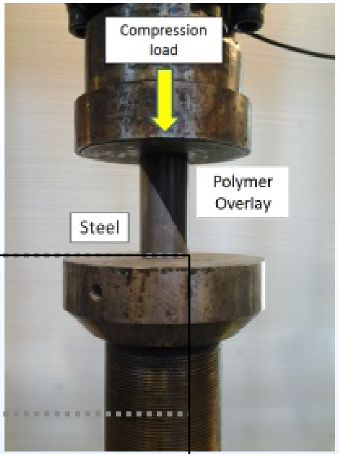
- Slant shear test – a direct measure of nanocomposite – steel bond strength





Slant shear test results





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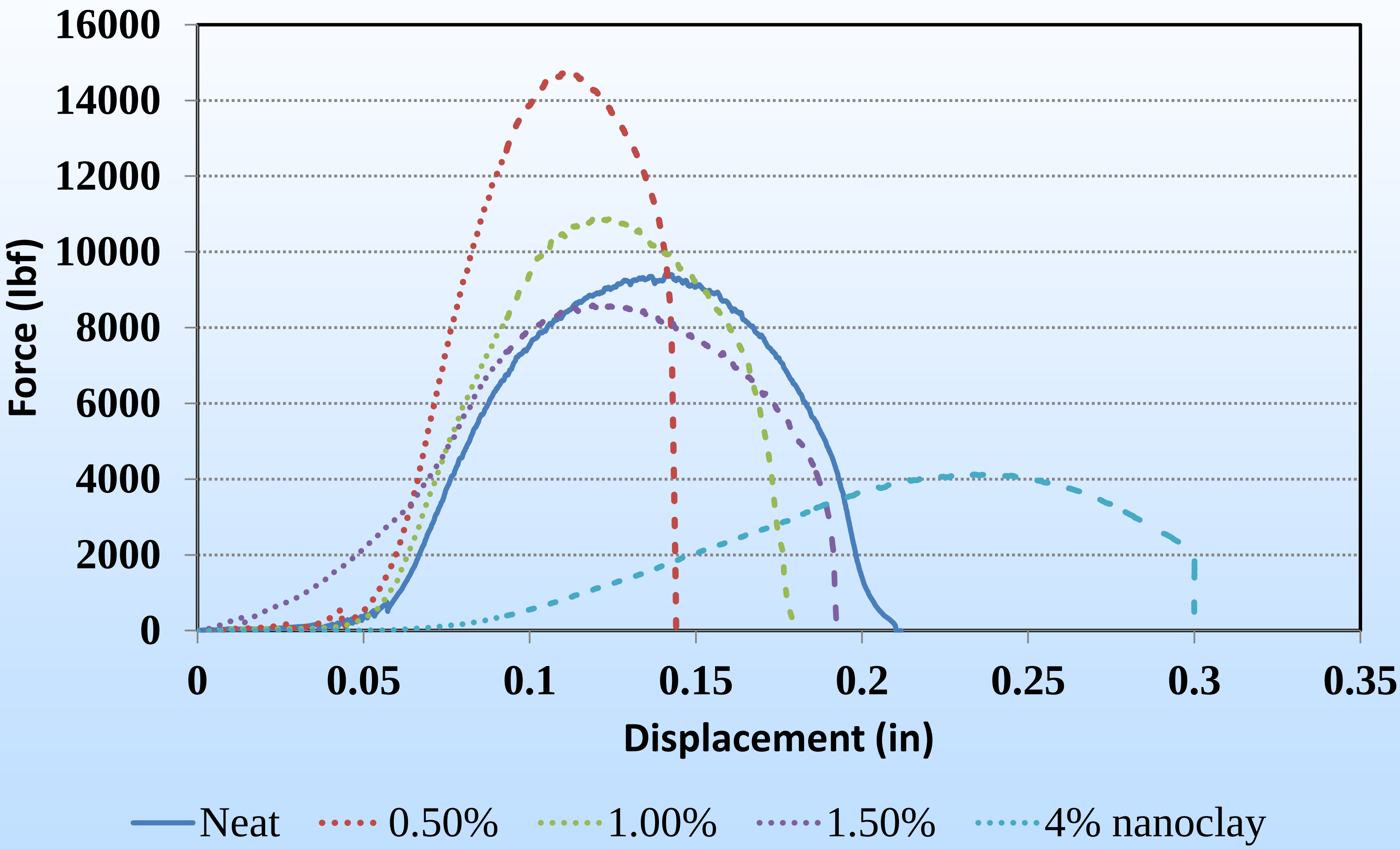
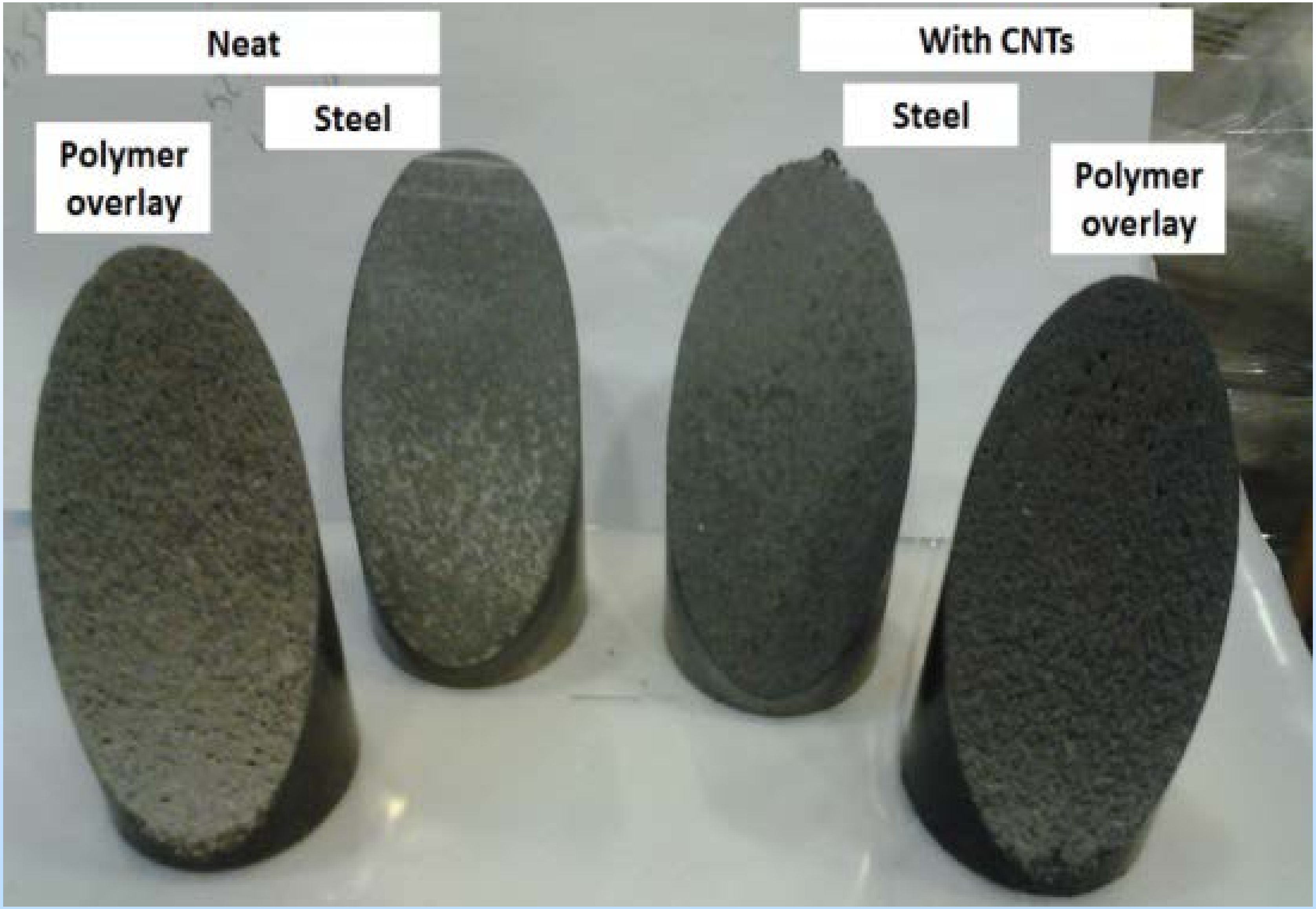
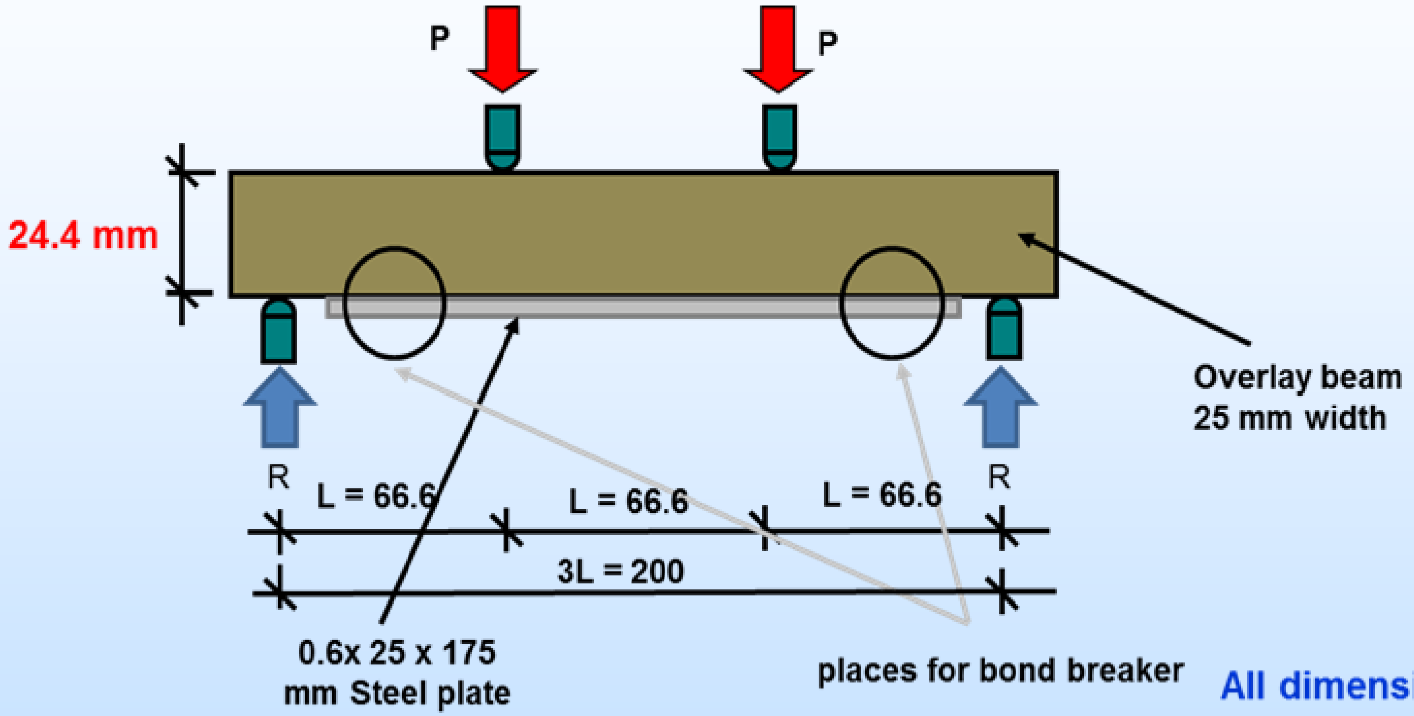
Slant shear test results



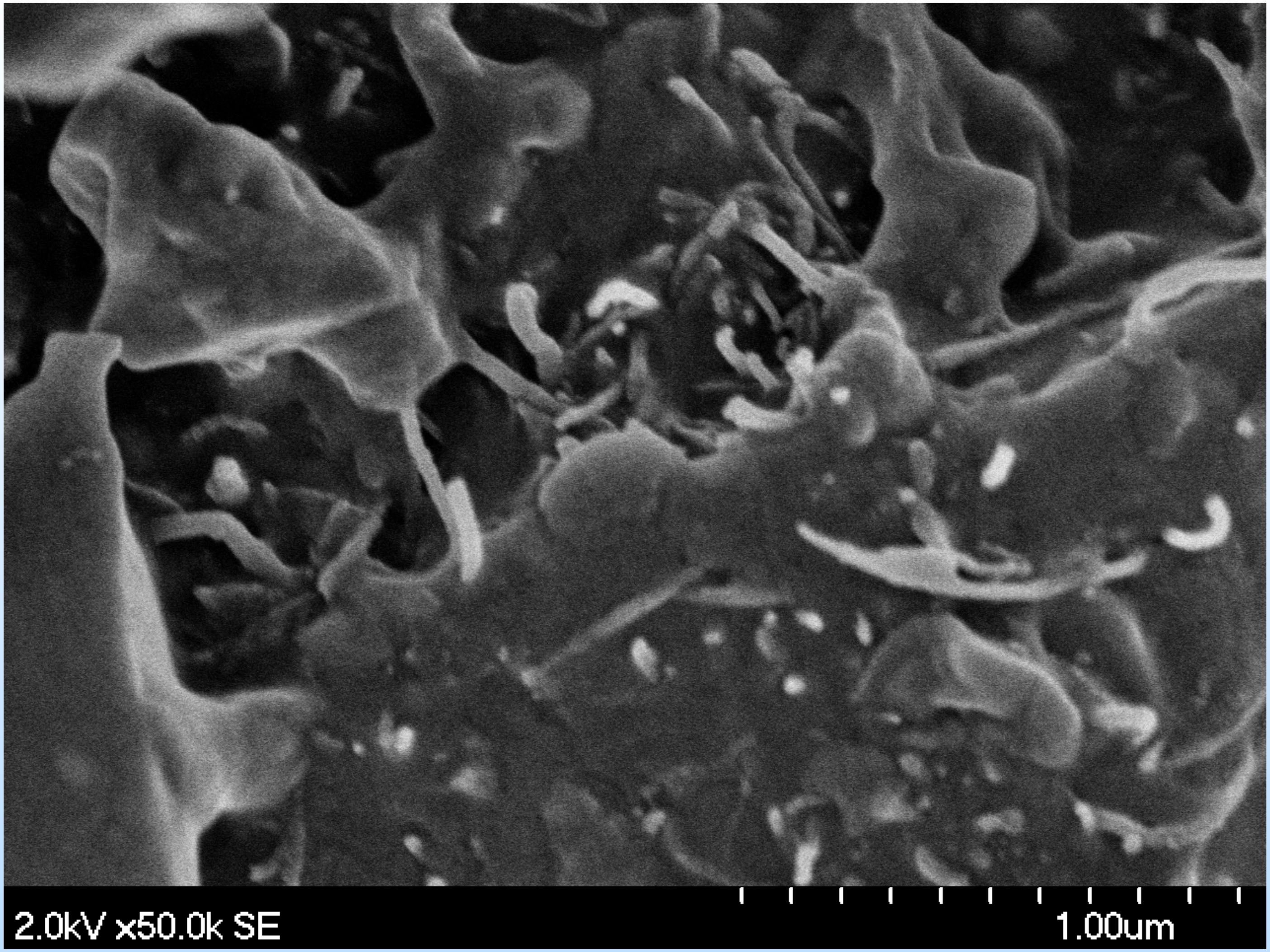

Neat
With CNTs
Steel
Steel
Polymer overlay
Polymer overlay

Fatigue test



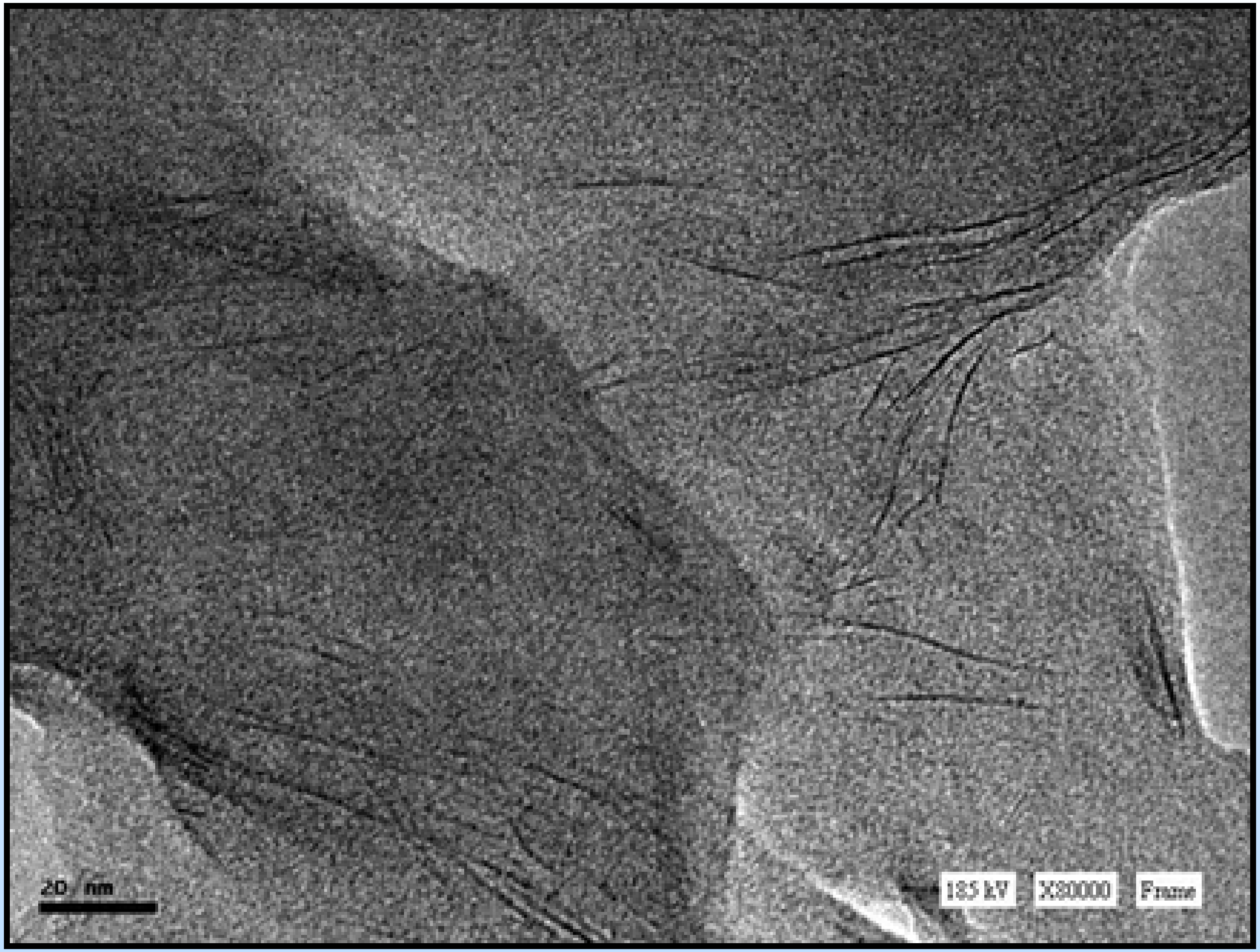
All dimensions in mm

Microstructural investigations



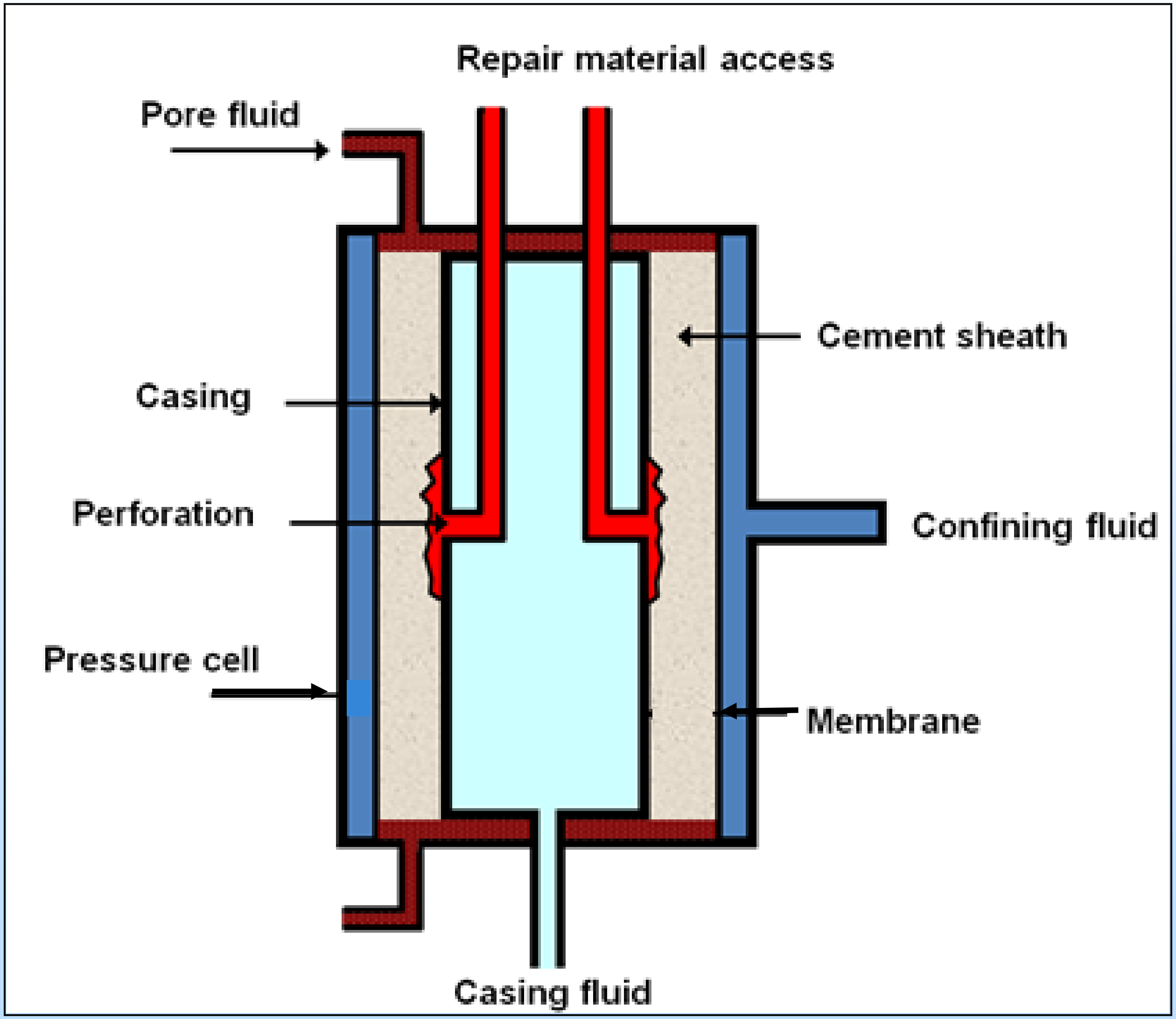
Epoxy-CNTs nanocomposite

Microstructural investigations



Exfoliated epoxy-nanoclay nanocomposite

Integrated seal system testing

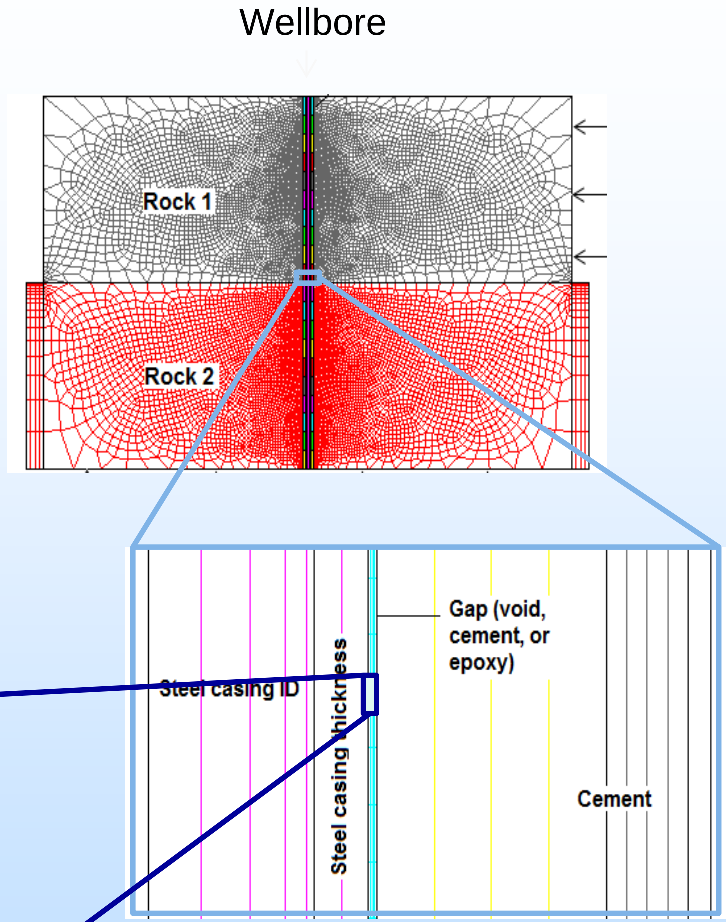


Annular seal system specimen preparation

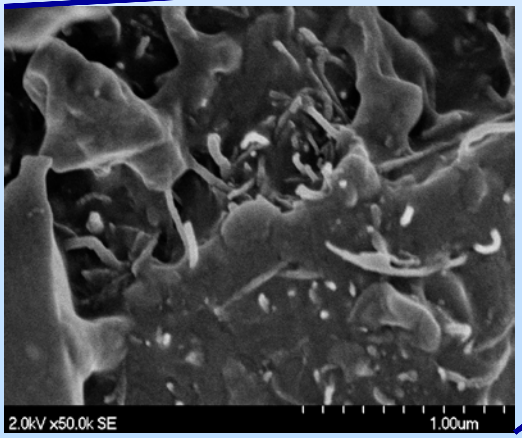
- Microannulus (flaw) created at casing-cement interface.

Numerical simulations

- Simulate wellbore condition, including interfaces and surrounding flaws
- Next step: Predict response of nanocomposites



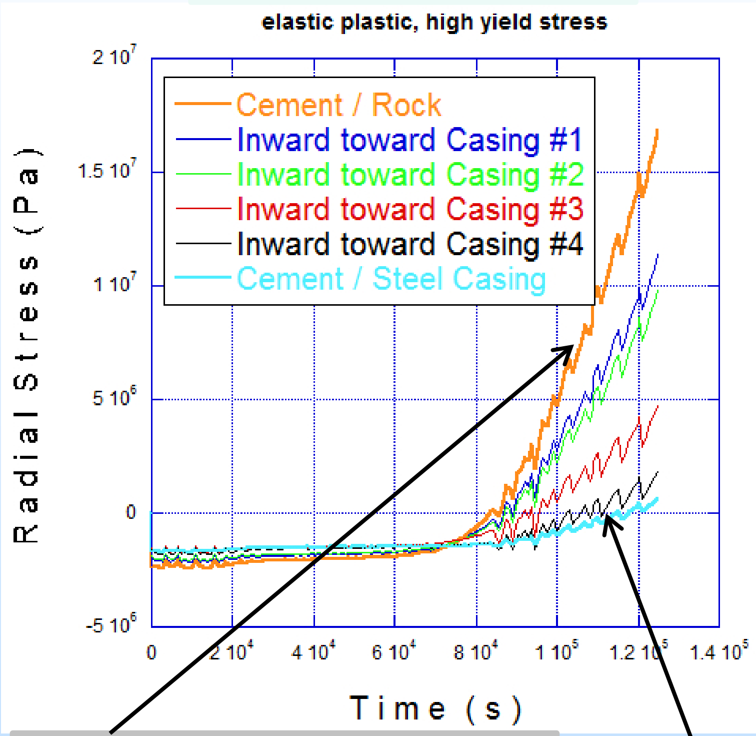
3D Geomechanical Modeling of Wellbore Interfaces



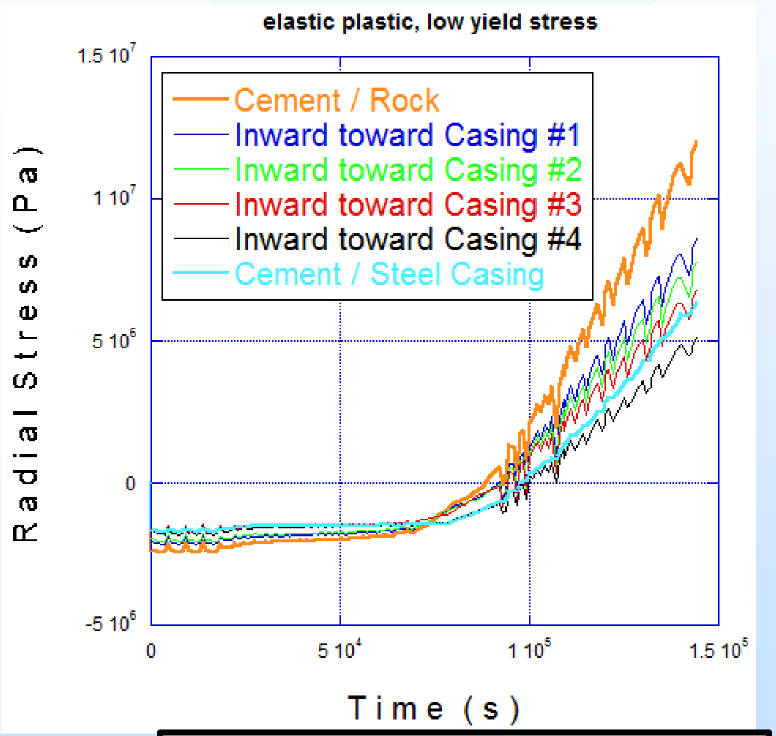
Epoxy-CNTs nanocomposite

Results show importance of material properties on wellbore conditions

High yield stress



Low yield stress



Cement/rock interface (orange curve)

Cement/casing interface (light blue curve)

Stress at cement/casing interface is greater when yield stress of cement is low

Accomplishments to Date

- Synthesized and tested flowability and bond strength of a number of nanocomposite and baseline materials. For some nanocomposites:
  - Minimal impact on flowability
  - Bond strength substantially increased
- Simulation model developed
- Initial integrated test samples fabricated

Summary

– Nanocomposites are being developed with favorable properties as seal repair material.
– Future Plan: Continue material synthesis and testing, leading to testing and evaluation of seal system repair.

Acknowledgements

We thank Steve Sobolik for his contributions to the modeling work, and Sherif Dagnash and Sherif Aboubakr for their help with the laboratory work.

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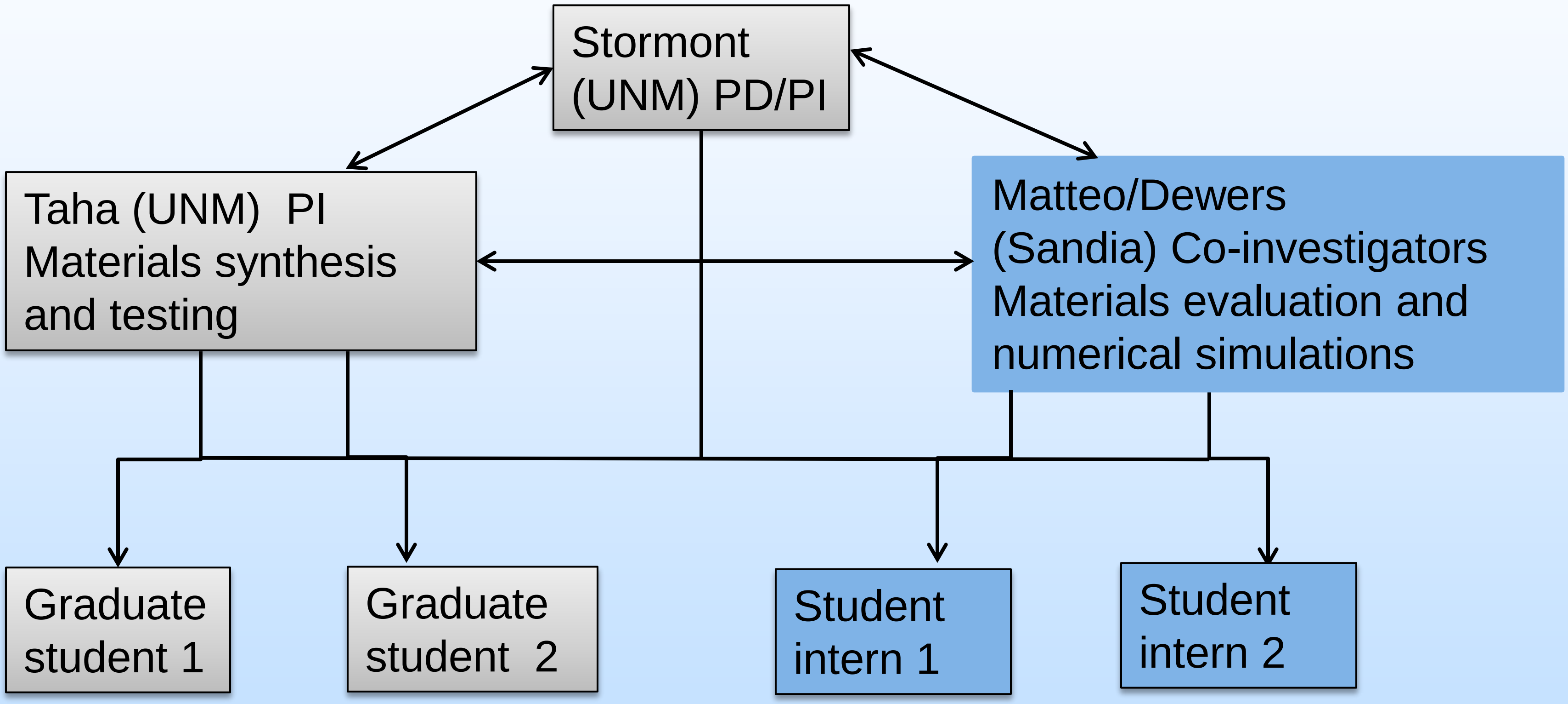
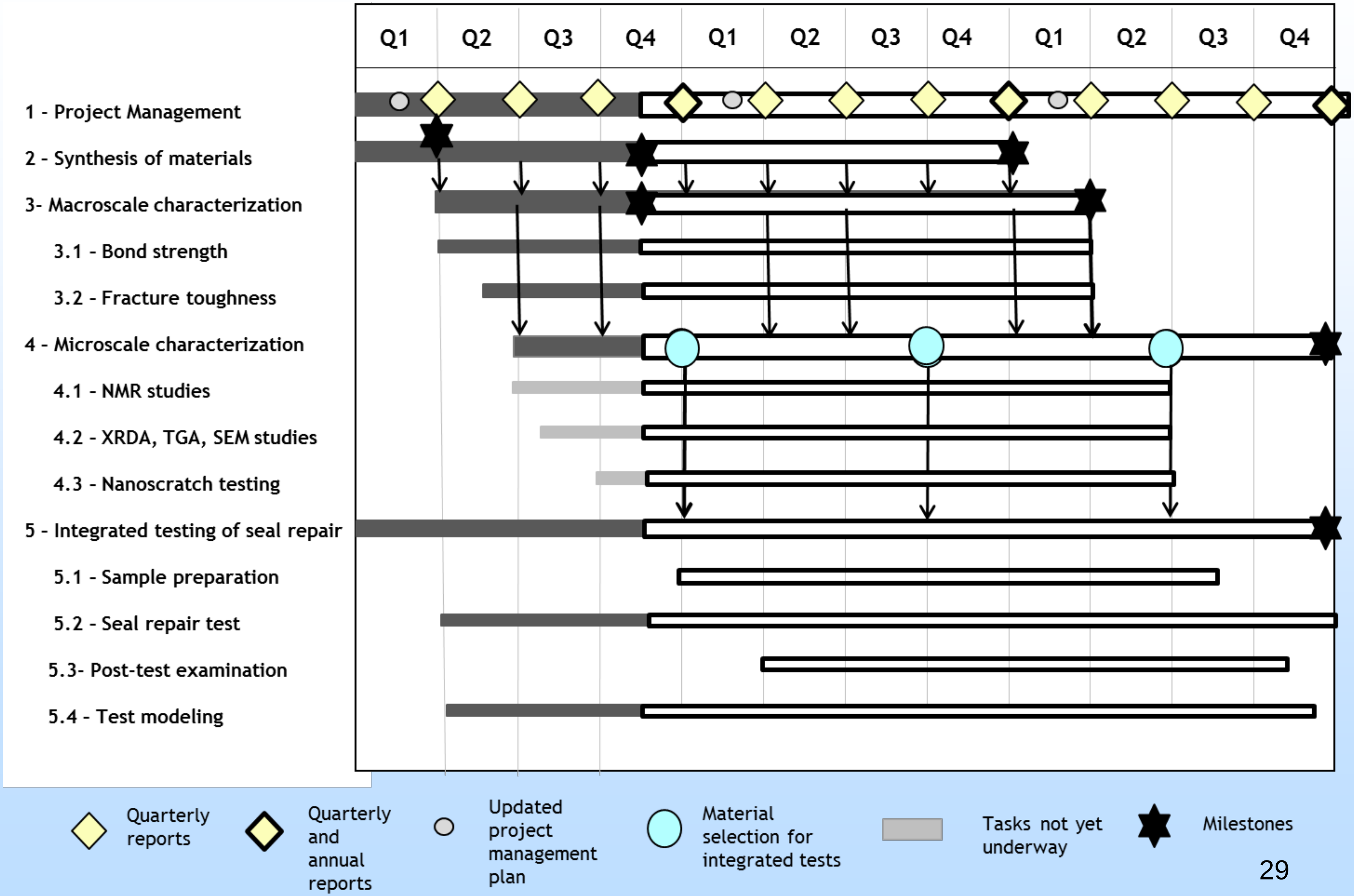
Appendix

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. available at: elsevier.com.