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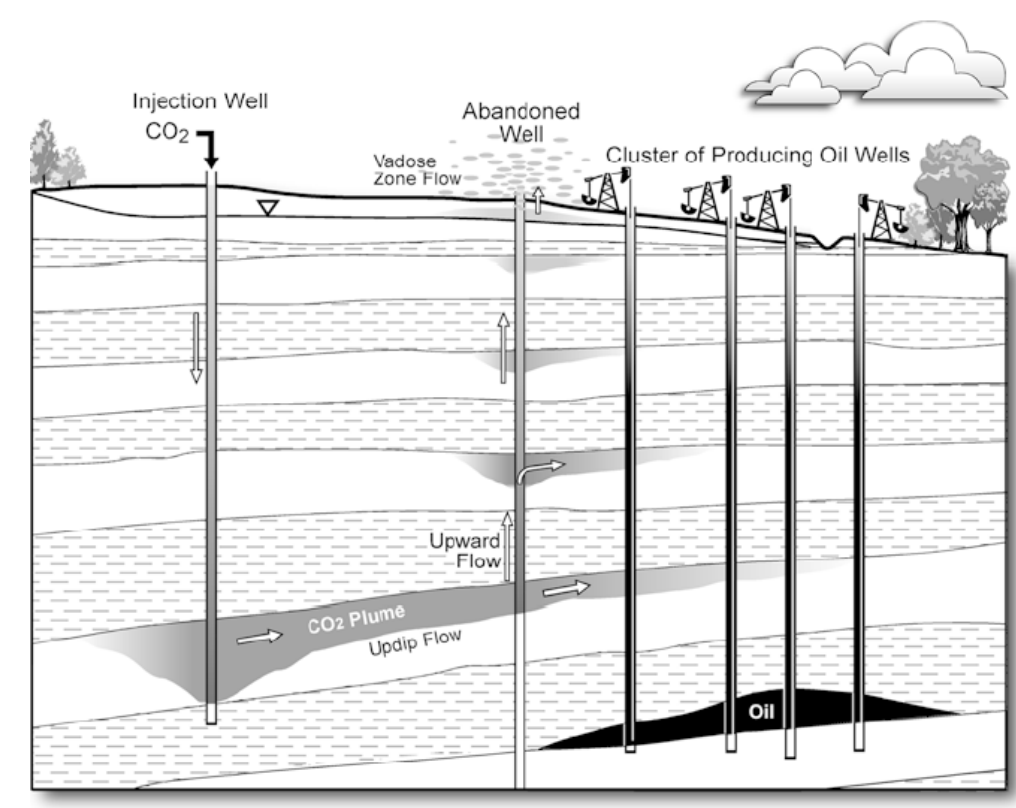
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1) Project Overview

This 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% CO₂ storage permanence.



Gasda, S. M. Celia, and S. Bachu, 2004. Spatial characterization of the location of potentially leaky wells penetrating a deep saline aquifer in a mature sedimentary basin. Environmental Geology. Vol. 46, 6-7, 707-720.

2) 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, **low permeability** and **high fracture toughness**.

-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.

Polymers	Nanomaterials			
	CNTs	Nanoclay	Nanosilica	NanoEG
Epoxy-Siloxane	C	C	U	P
Epoxy-Novolac	U	U	U	P
Phthalic Anhydride (PA) cured Epoxy	P	P	P	P
Epoxy-DPPETES				
Epoxy-Polyarylene esters				
Standard Repair Material (Microfine cement)			P (without nanomaterials)	
	C: Completed testing	U: Undergoing testing	P: Planned testing in coming quarter	

Figure 1. Matrix of nanocomposite materials to be used in this project. The matrix will test a suite of epoxy resins with varying loadings of carbon nanotubes (CNT's), nanoclay, nanosilica, and nano exfoliated graphene (NanoEG).

(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% CO₂ storage permanence.

-Success criteria: The degree to which system permeability to CO₂ is reduced after repair, cost, material availability and ease of use compared to conventional materials.

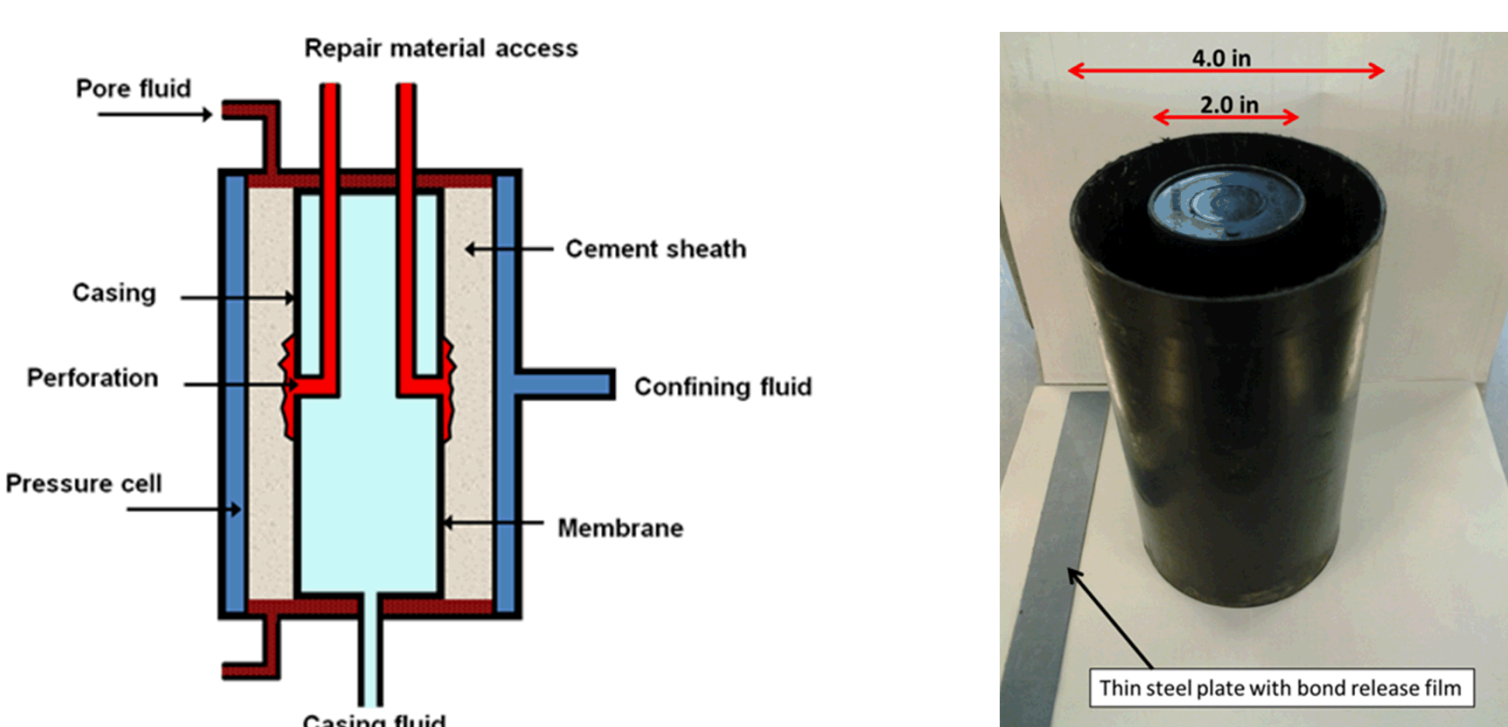


Figure 2. Lab-scale seal system testing. From all candidate nanocomposites, those with the most promising material properties will be chosen for bench-scale testing in a wellbore mock-up.

3) Nanocomposite Synthesis

Dispersion of nanomaterial within the epoxy matrix is crucial. Processing methods are aimed at uniformly distributing nanomaterial in the nanocomposite. Uniformity of the composite mixture is critical to ensuring that nanocomposites are homogeneous, and is often a challenge in developing processing protocols.

Carbon Nanotubes (CNT's)

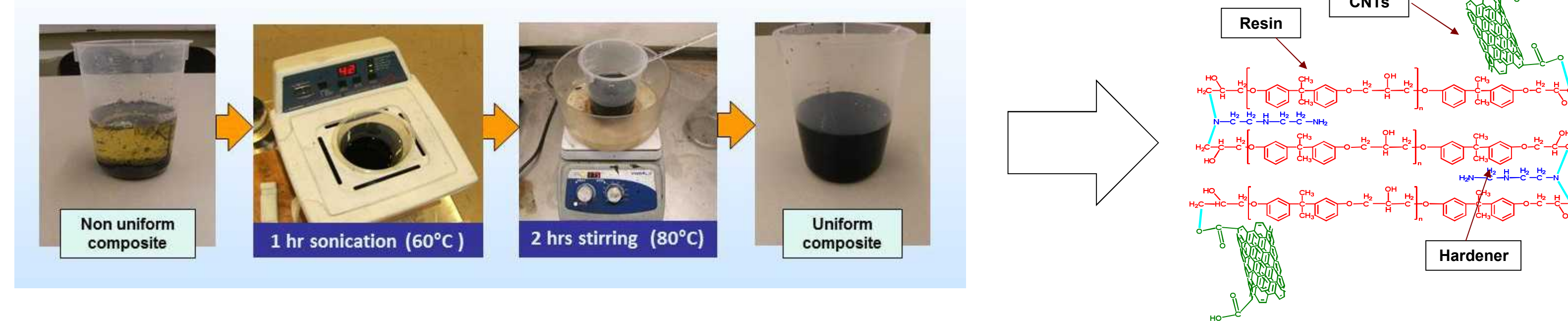


Figure 3. Carbon nanotubes (CNT's) need multiple processing steps in order to achieve a uniform composite. Heating and mechanical agitation provide sufficient energy to disperse the CNT's, as illustrated in this figure. Prior to heating, sonication, and stirring, the epoxy-CNT mixture is clearly non-uniform and unsuitable for use as a seal material. The treated mixture, however, is visibly well-mixed as the CNT's are disaggregated in the composite mix. Similar processing is used to intercalate nanoclay.

Nanoclay

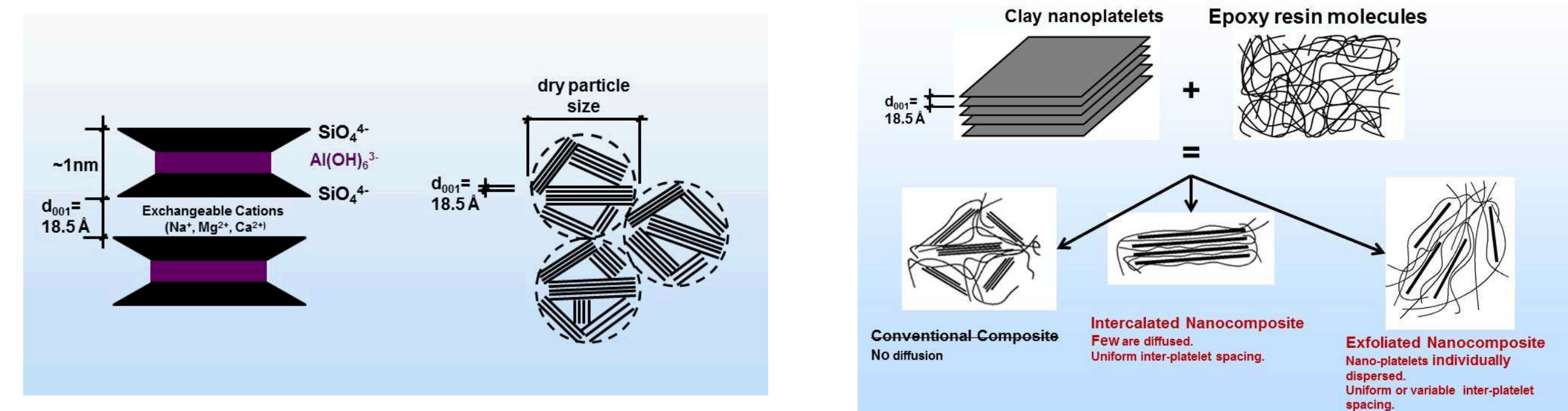


Figure 4. Sheet structure of 2:1 Smectite clay mineral. (left) and aggregated structure of clay particles (right).

Figure 5. Intercalation regimes for clay nanoplatelet/epoxy mixtures

4) Optimizing Material Properties

Flowability and **bond strength** are key material properties that are essential to correctly tune to make an effective seal repair. Material selection will take these properties, as well as fracture toughness and yield stress, into account to optimize for the best combination of material attributes. Wellbore modeling will be used to aid in the optimization process.

Flowability is key for effective delivery seal repair material



Figure 6. Flowability test performed according to ASTM C1437 and ASTM C1611 standards.

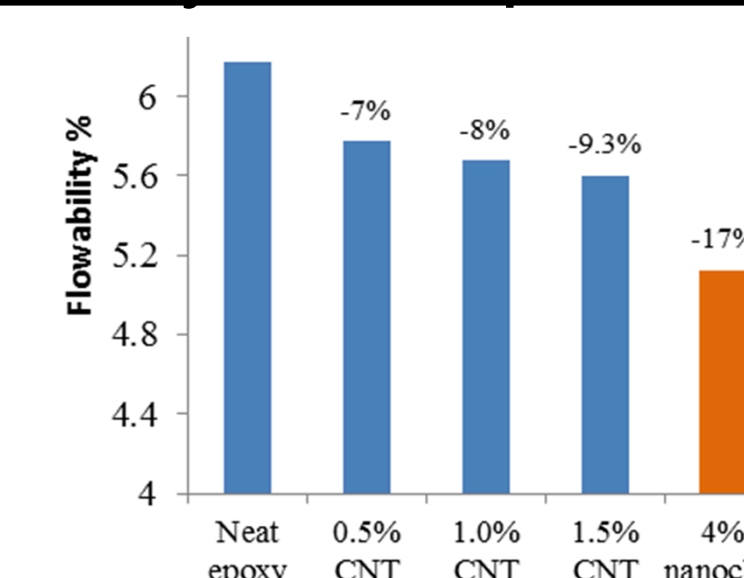


Figure 7. Flowability test results show the negative impact of CNT's and nanoclay additions.

Bond strength is key to restoring seal integrity

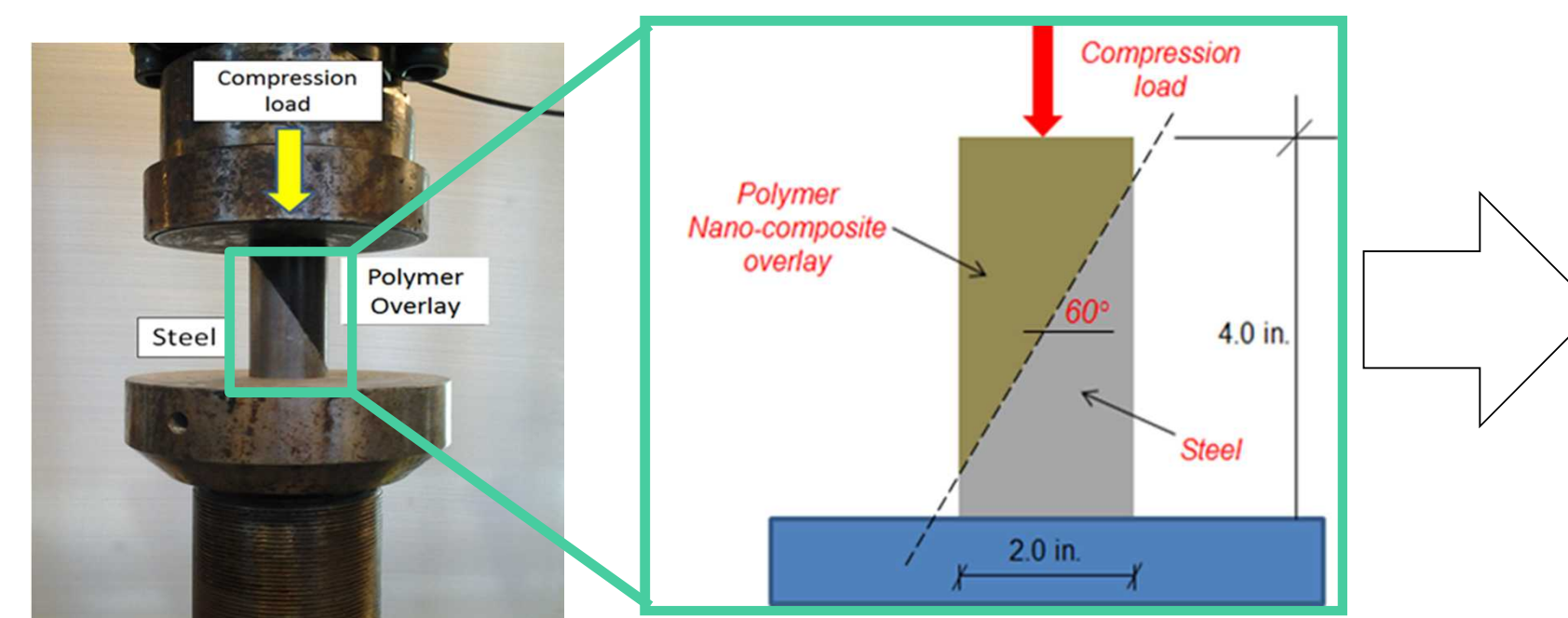


Figure 8. Slant shear test performed according to ASTM C882 standards. The lower steel portion of the test cylinder is cut and sandblasted, and then overlaid with the epoxy in a mold for the test.

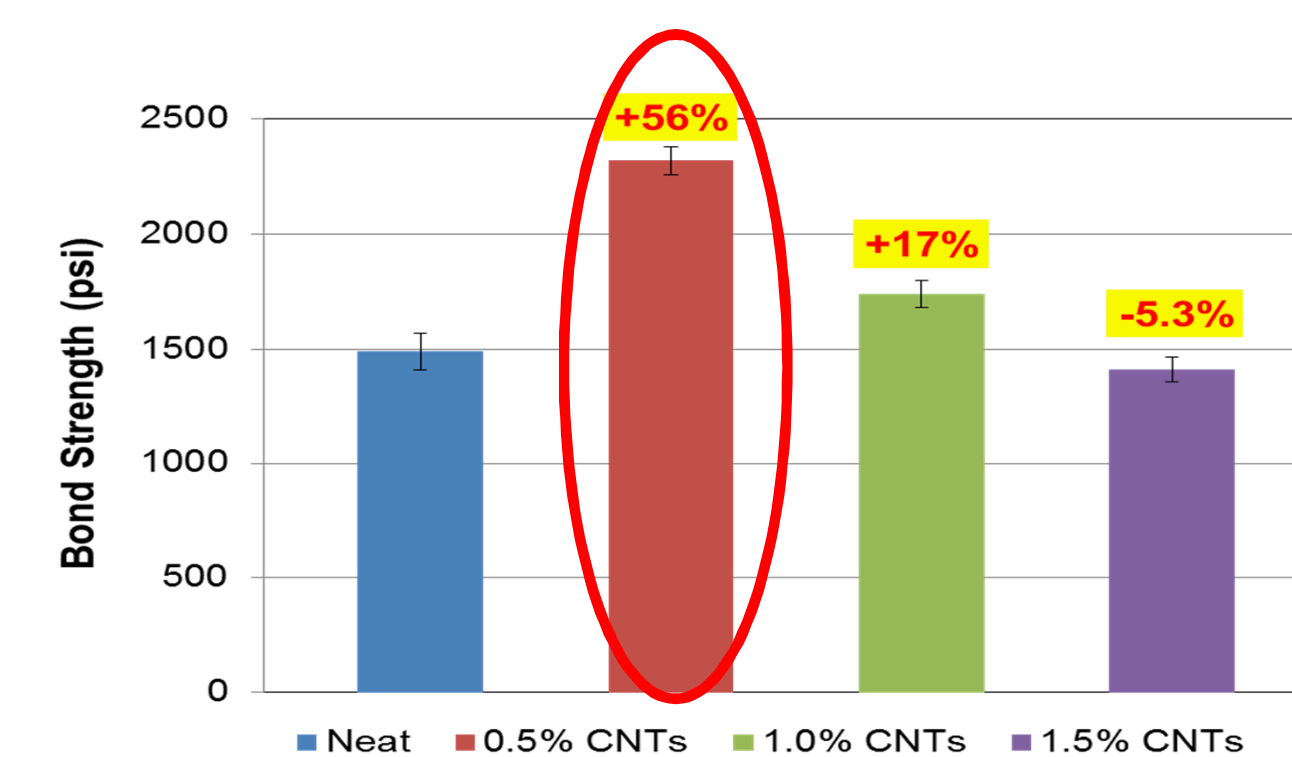


Figure 9. Slant shear test results show a remarkable improvement in bond strength for 0.5% CNT loading.

5) Predict In-Situ Wellbore Stresses and Materials Response

3D Geomechanical Wellbore Modeling

Wellbore modeling is being used to **quantify the stresses and strains** in that seal repair materials will face in the wellbore environment. Material properties of developed nanocomposites will also be used as input for the wellbore model to **predict the response of synthesized nanocomposites**.

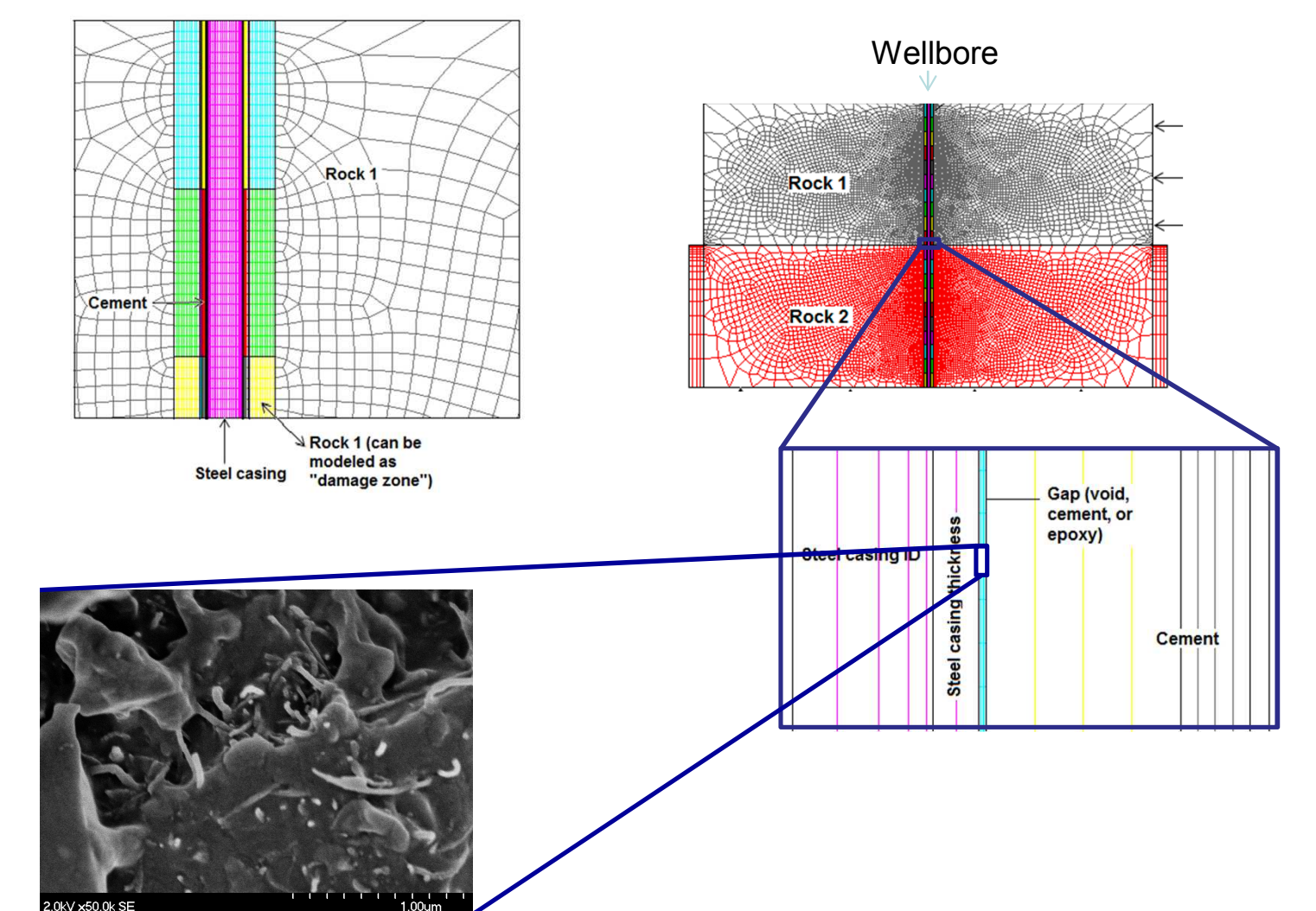


Figure 10. Simplified mesh (top right) was used to develop and test simulation code. The mesh includes well casing, cement sheath, void region, and rock formation (bottom right, top left). The void region or "Gap" can represent a flaw (annular gap), intact cement, or epoxy (bottom left image of epoxy).

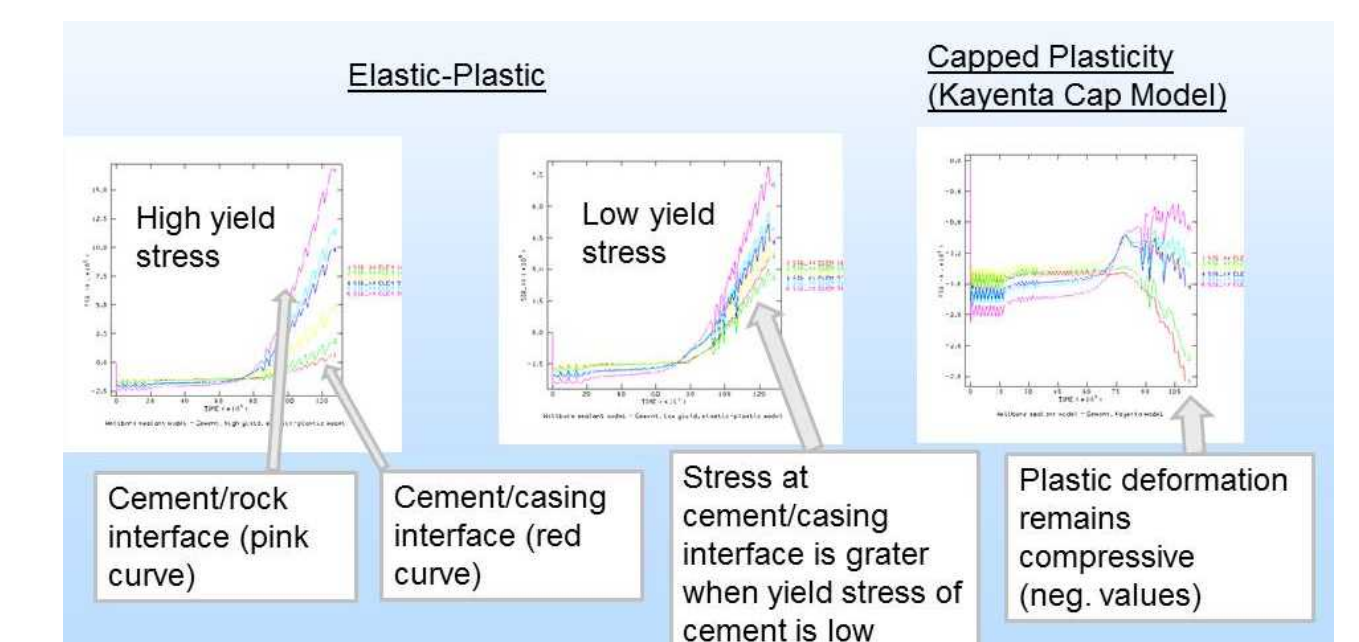


Figure 11. Preliminary modeling results indicate the importance of both the yield stress and plasticity model employed

6) Summary

Candidate nanocomposite materials are being synthesized and will be selected for further testing on the basis of materials characterization. The ideal seal material repair material will have optimal rheological and strength properties. Selected materials will be tested in a lab-scale integrated seal system that will evaluate performance under wellbore conditions of temperature and pressure.

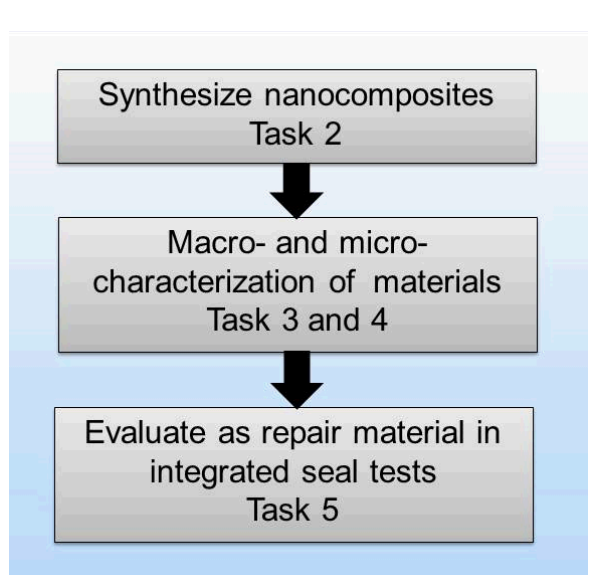


Figure 12. Broad summary of project tasks

Acknowledgements

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