Wellbore Seal Repair Using Nanocomposite Materials

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Presentation Outline

- Introduction and overview
- Materials synthesis
- Materials testing and characterization
- Annular seal system testing
- Numerical simulation
- Summary
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% CO₂ storage permanence.
(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.
(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 Task Flow

1. Synthesize nanocomposites (Task 2)
2. Macro- and micro-characterization of materials (Task 3 and 4)
3. 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

<table>
<thead>
<tr>
<th>Polymers</th>
<th>Nanomaterials</th>
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<tbody>
<tr>
<td></td>
<td>CNTs</td>
</tr>
<tr>
<td>Epoxy – Siloxane</td>
<td>C</td>
</tr>
<tr>
<td>Epoxy-Novolac</td>
<td>U</td>
</tr>
<tr>
<td>PA cured Epoxy</td>
<td>P</td>
</tr>
<tr>
<td>Epoxy-DPPETES</td>
<td></td>
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<tr>
<td>Epoxy-Polyarylene esters</td>
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</tbody>
</table>

### 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

Conventional Composite

Intercalated Nanocomposite

Exfoliated Nanocomposite
Flowability
related to ability to inject nanocomposite into flaws.
Flowability results

C1611

Flowability %

<table>
<thead>
<tr>
<th></th>
<th>Neat epoxy</th>
<th>0.5% CNT</th>
<th>1.0% CNT</th>
<th>1.5% CNT</th>
<th>4% nanoclay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>-7%</td>
<td>-8%</td>
<td>-9.3%</td>
<td>-17%</td>
</tr>
</tbody>
</table>
Bond strength characterization

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

Bond Strength (lb/in²)

- Neat
- 0.5% CNTs
- 1.0% CNTs
- 1.5% CNTs
- 4% nanoclay

-58%
Slant shear test results
Fatigue test

[Diagram showing a load test with dimensions and labels such as L = 66.6 mm, 3L = 200 mm, and overlay beam 25 mm width.]

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
Results show importance of material properties on wellbore conditions

- High yield stress
  - Cement/rock interface (orange curve)
  - Cement/casing interface (light blue curve)

- Low yield stress
  - 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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Organization Chart

Stormont (UNM) PD/PI

Taha (UNM) PI
Materials synthesis and testing

Graduate student 1

Graduate student 2

Student intern 1

Student intern 2

Matteo/Dewers (Sandia) Co-investigators
Materials evaluation and numerical simulations
Gantt Chart

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
Publications generated from project
