Effects of Thermal Shocks on Integrity of Sealants under Unconfined and Confined Conditions for CCS Applications

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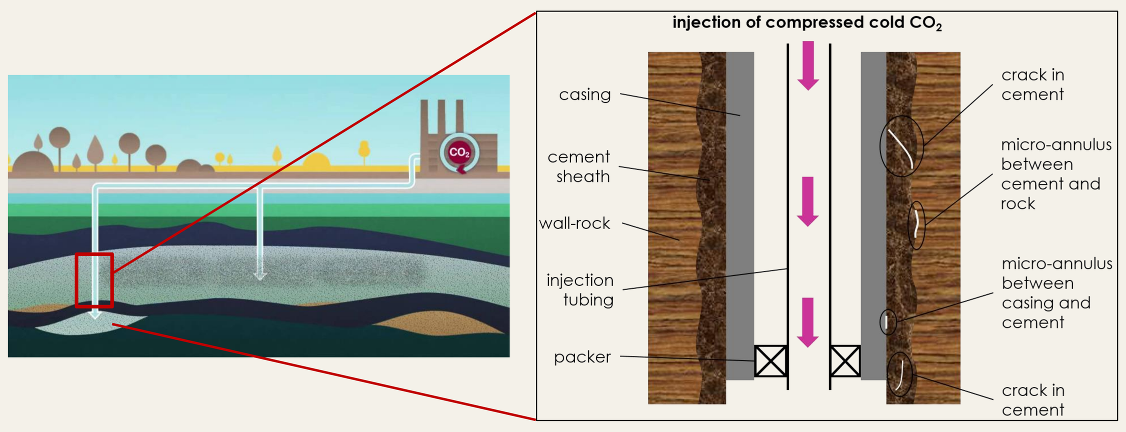
Introduction

Carbon capture and storage (CCS) has gained much attention as it fights climate change. However, during CCS, the periodic injection of pressurized cold CO_2 into warm reservoirs leads to thermal shocks and cycling. Under these temperature fluctuations, the wellbore and subsurface formations may undergo cyclic shrinkage upon cold CO_2 injection and subsequent expansion after injection when the system equilibrates back to reservoir temperature. As a result, micro-annuli between casing, sealant and wall-rock, and cracks in sealant may be induced. The leakage of CO_2 through these pathways has been identified as one of the main challenges to securing sustainable geological CO_2 storage. Therefore it is significant to understand how sealant integrity is affected by thermal shocks or cycling encountered in CCS..



Reservoirs 1-4 km deep.

In-situ temperature 80-120degC.

Potential leakage pathways due to thermal stresses.

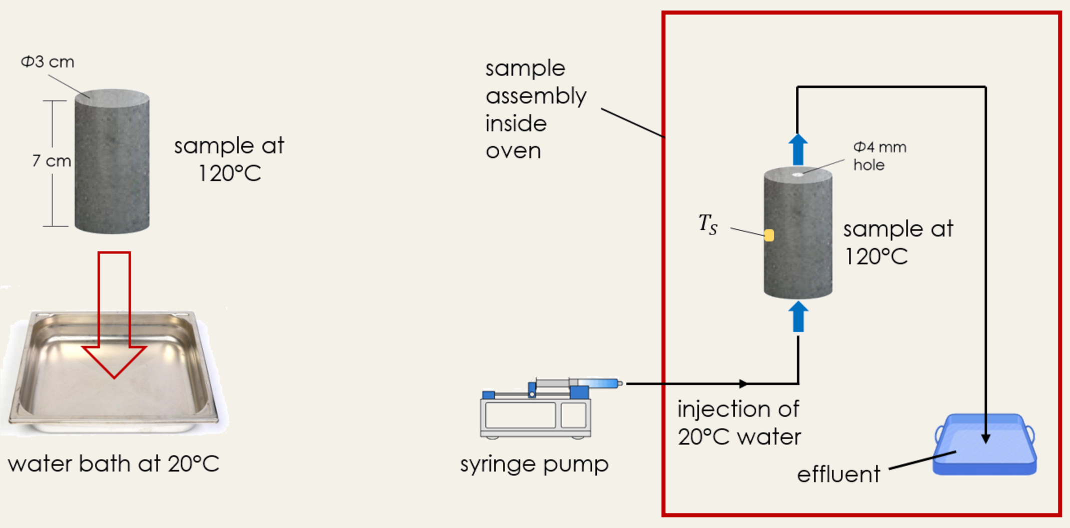
- ❑ **Seeking improved wellbore sealing materials and testing their suitability to maintain integrity are imperative.**
- ❑ **We investigate the efficacy of four sealants of different compositions under strong thermal shocks encountered in CCS, focused on thermally-induced cracks in sealants.**

Experimental Materials, Setups and Methods

Sealant compositions, provided by Halliburton AS. Norway:

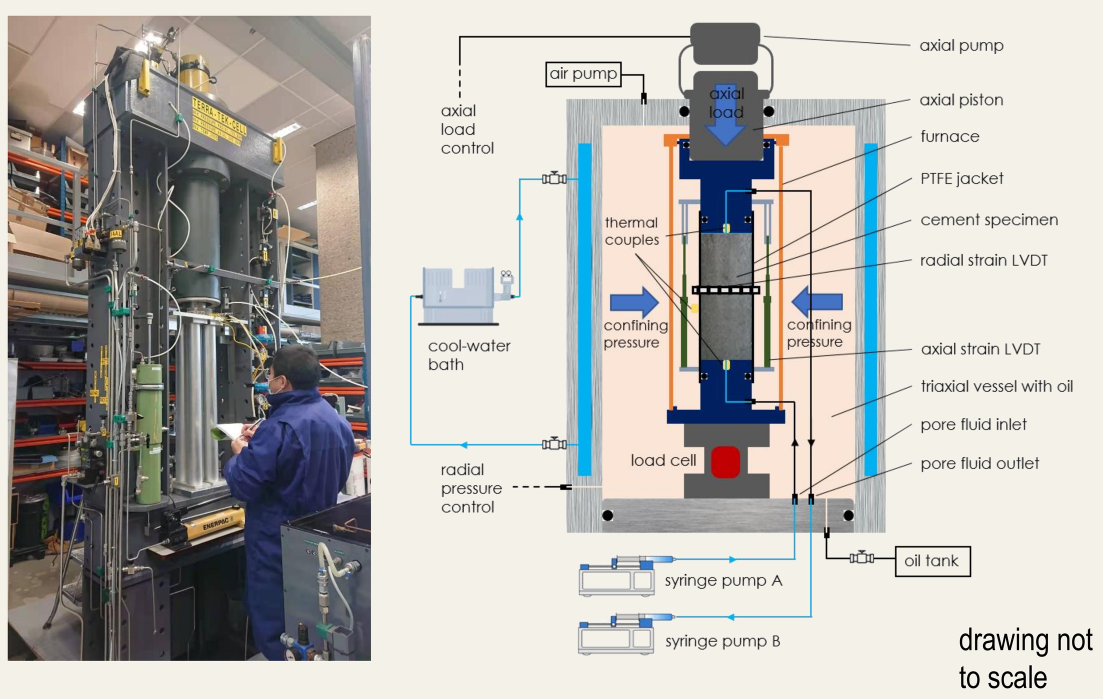
Sealant	Composition	TRL
S1	1.90 SG class G cement with 35% BWOC silica flour	7: proven technology
S2	1.90 SG ultra-low permeability class G cement with 35% BWOC silica flour, with expansion agent in form of dead-burnt MgO	7: proven technology
S3	1.90 SG class G cement with 35% BWOC silica flour, with expansion agent in form of dead-burnt MgO, and CO_2-sequestering additives	3: prototype tested
S4	1.80 SG calcium aluminate cement-based blend	7: proven technology

Unconfined - quenching and flow-through experiments:



- Type 1: quench into 6 L 20°C cold water bath.
- Type 2: 160 mL 20°C water flows through the sample in 2 mins, halt for 12 mins to reheat.
- Both are eight cycles of thermal shock.

Confined - triaxial deformation apparatus:



- Confining pressure up to 70 Mpa + axial stress up to 424 Mpa.
- Eight cycles of thermal shock by 20°C cold water flow-through pre-heated 120 °C sample.

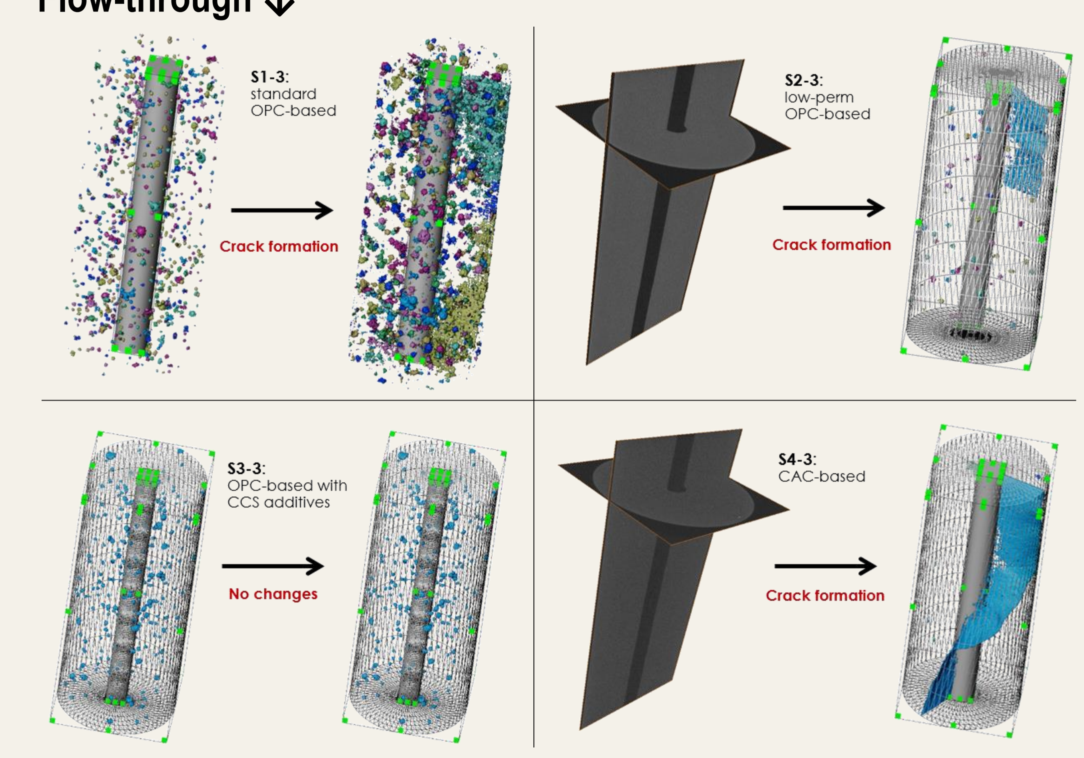
Experimental scheme:

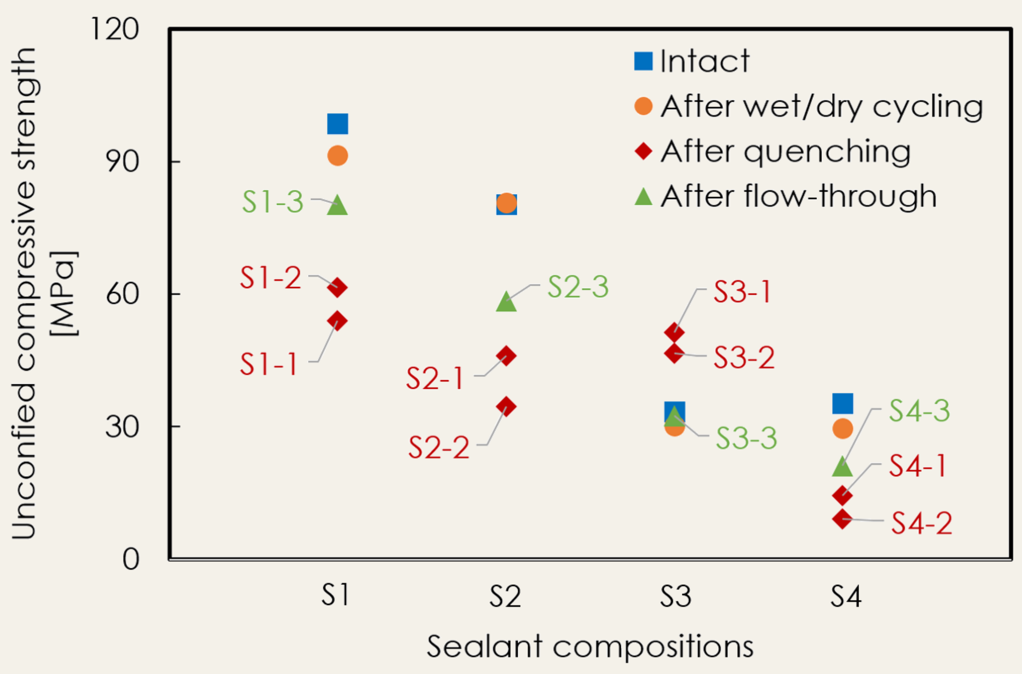
micro-CT → **Thermal treatment** → micro-CT → UCS test

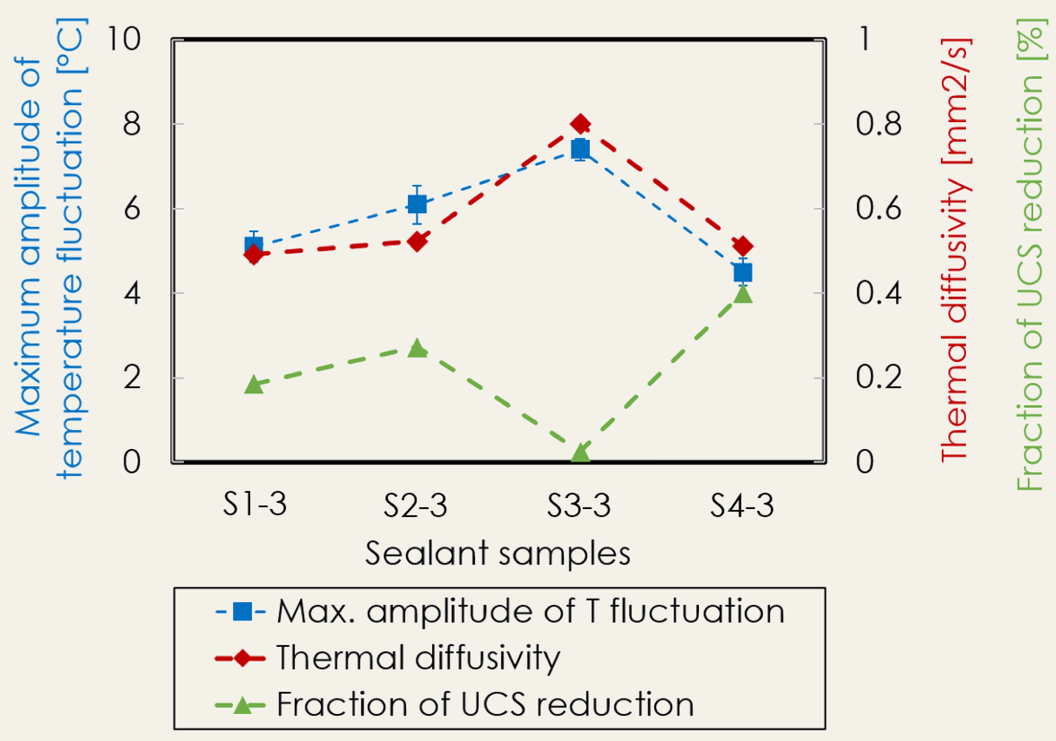
Unconfined quenching and flow-through tests

Quenching ↓

Flow-through ↓







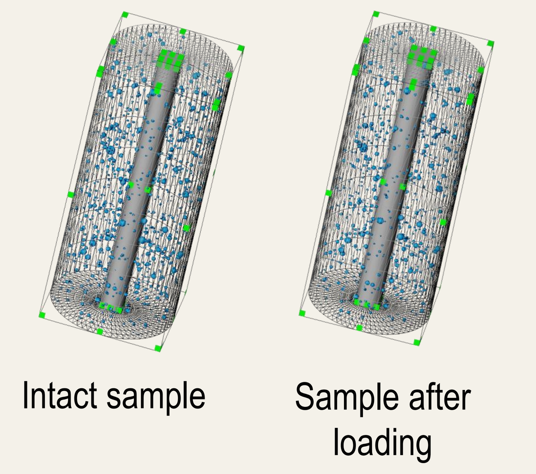
Without confinement:

- ➢ S3 resists thermal shocks the best! Good candidate that tolerates T fluctuation in CCS.
  - higher thermal diffusivity → transfer heat more efficiently → lower thermal stresses that are insufficient to damage the integrity.
- ➢ S1 and S2 (Existing OPC-based) and S4 (CAC-based) lost integrity after thermal-shocking experiments: may not be optimal for CCS.
  - Quenching caused 2x greater UCS reduction than flow-through experiments.
- ➢ S4 (CAC-based) experienced greatest adverse impact from thermal shocks.
  - S4 has low strength (UCS) → not strong enough to withstand the created thermal stresses due to shocks.

Confined flow-through tests

Effects of confinement without thermal shocks (sealant S1 shown below):

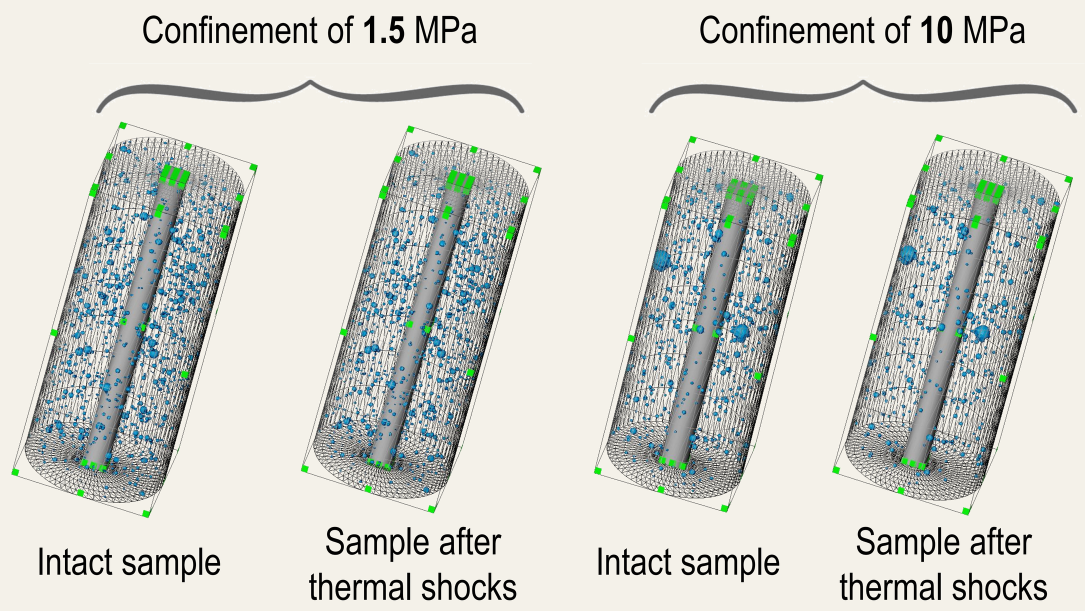
- Hydrostatic stress state: 10 MPa.
- Without thermal shocks.

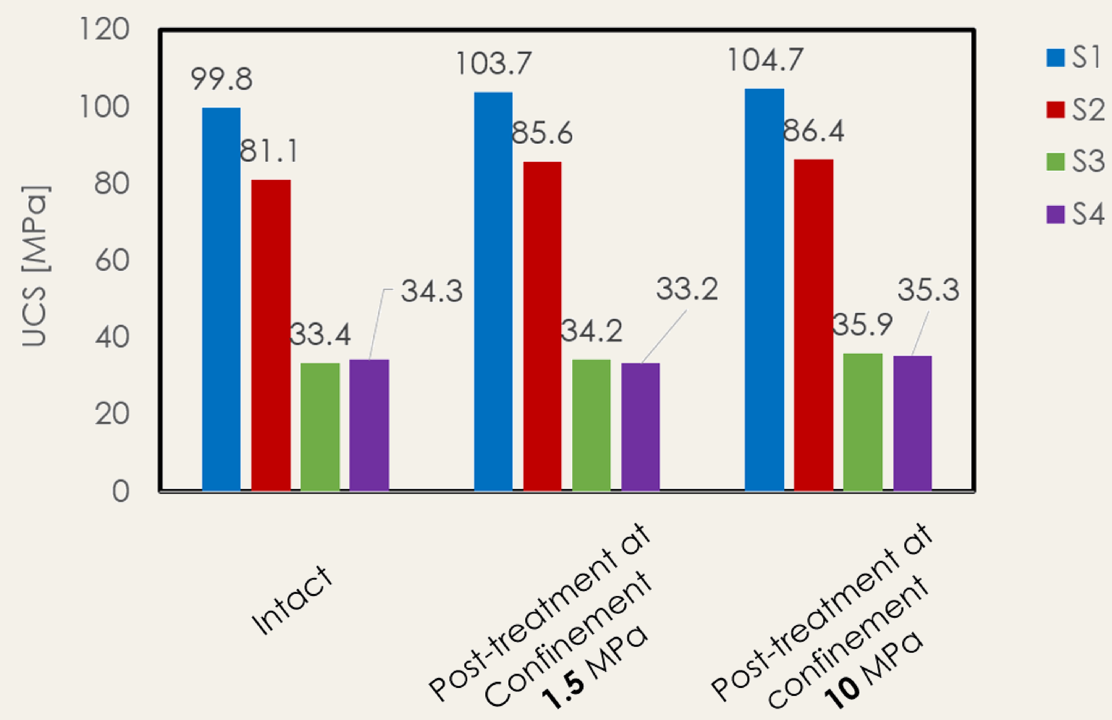


Samples	Intact	Through confinement
Unconfined Compressive strength [MPa]	99.8	102.9
Young's moduls [GPa]	13.44	13.69
Poisson's ratio	0.143	0.158
Volume of voids [mm^3]	147	127
Number of voids	1162	920

- ➢ Some pores are closed after confinement.
- ➢ Strength of sample increases slightly.

Effects of confined thermal shocks (sealant S1 shown below):



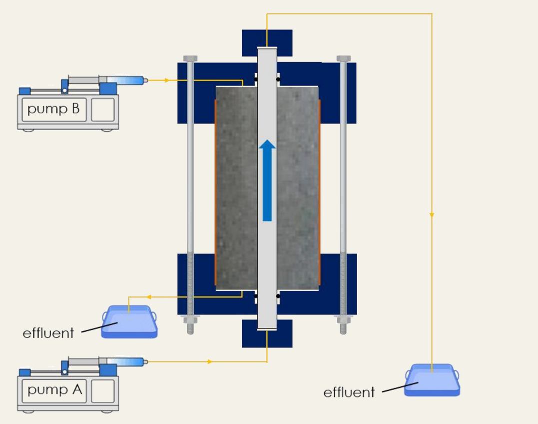


With confinement:

- ➢ No cracks after thermal shocks with confinement, even at 1.5 MPa.
- ➢ Confining pressure decreases the volume of voids, then strengthens the samples.
- ➢ For S1, S2 and S3, higher confinement causes more compression to the sample, resulting in greater strength.
  - confinement provides support to the sealant, increase its stiffness, hence reducing the potential for thermally-induced cracks in the cement.

Future Plans

1. Study integrity at the interface between casing and sealant – the bonding strength.



← newly-designed setup for unconfined tests.

✓ New piston sets have also been designed to conduct confined tests.

2. Study the efficacy of newly-designed rock-based geopolymer as a sealant in CCS applications when encountering strong thermal shocks.

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Consortium partners and funding agencies ↓

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