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Effects of Thermal Shocks on Cement for CCS under Confined and Unconfined Conditions

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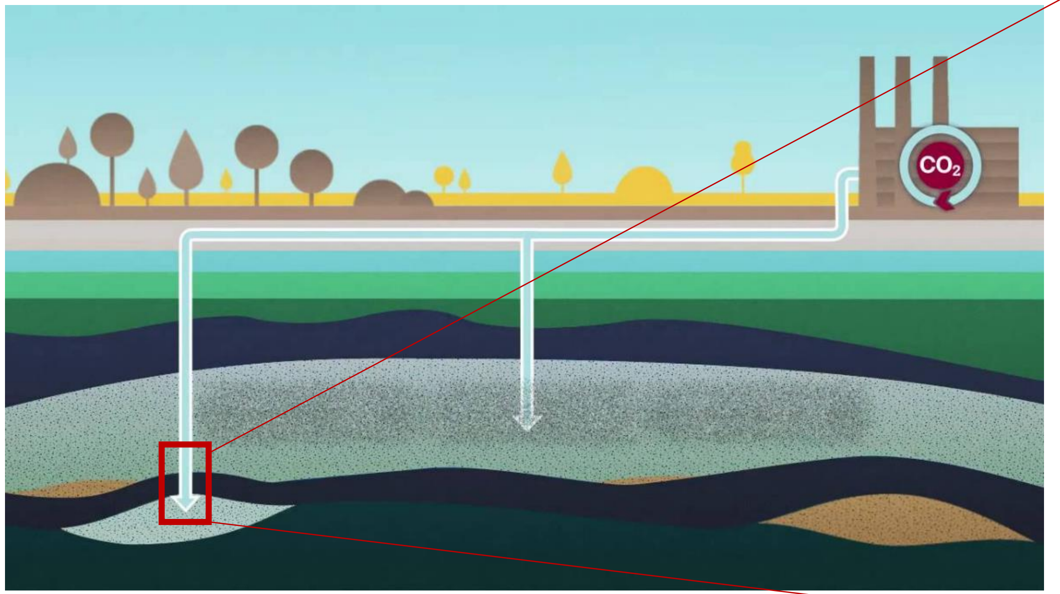
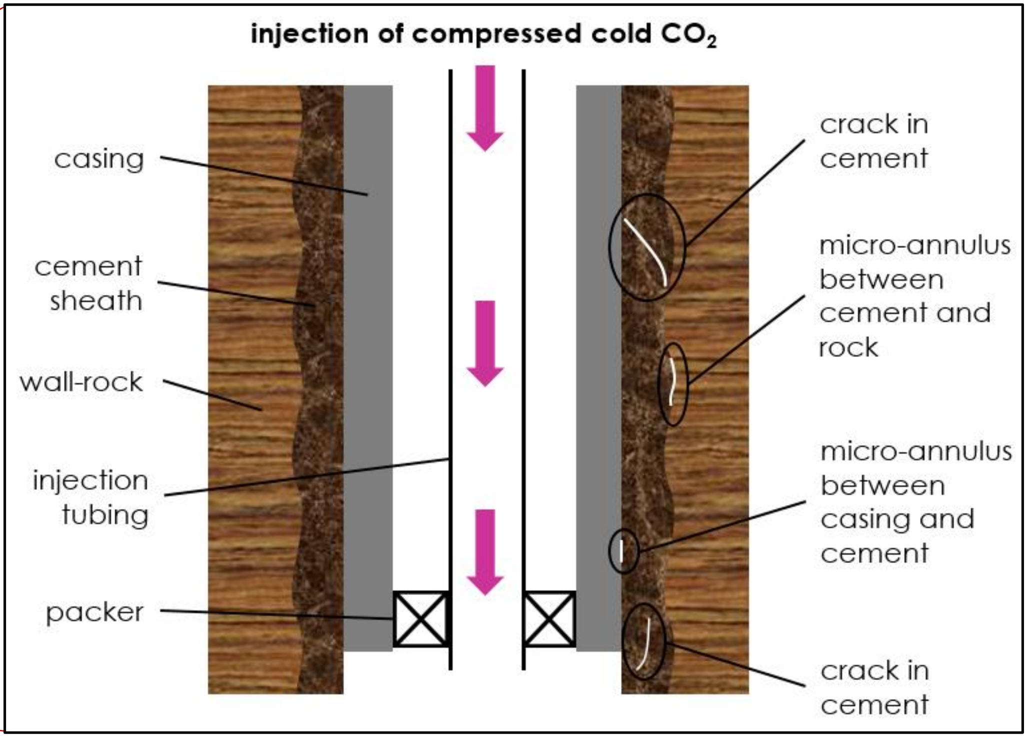
CEMENTEGRITY

Objectives of Our Study





- Reservoirs 1-4 km deep
- In-situ temperature 80-120°C

- 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.**

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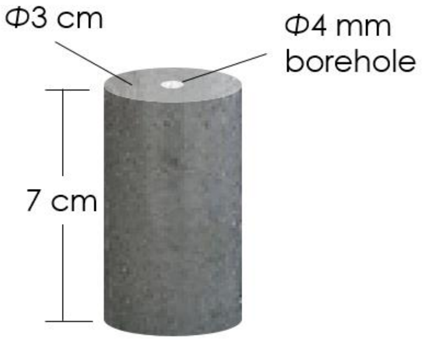
Sealants of Four Compositions

- All samples prepared by Halliburton AS Norway, following API specification 10B-2.
  - water/cement ratio 0.4.
  - cured at 150℃ and 30 MPa, for 28 days.

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 silica fume and expansion agent in form of dead-burnt MgO	7: proven technology
S3	1.90 SG class G cement with 35% BWOC silica flour, with silica fume, 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

↑ sealant compositions

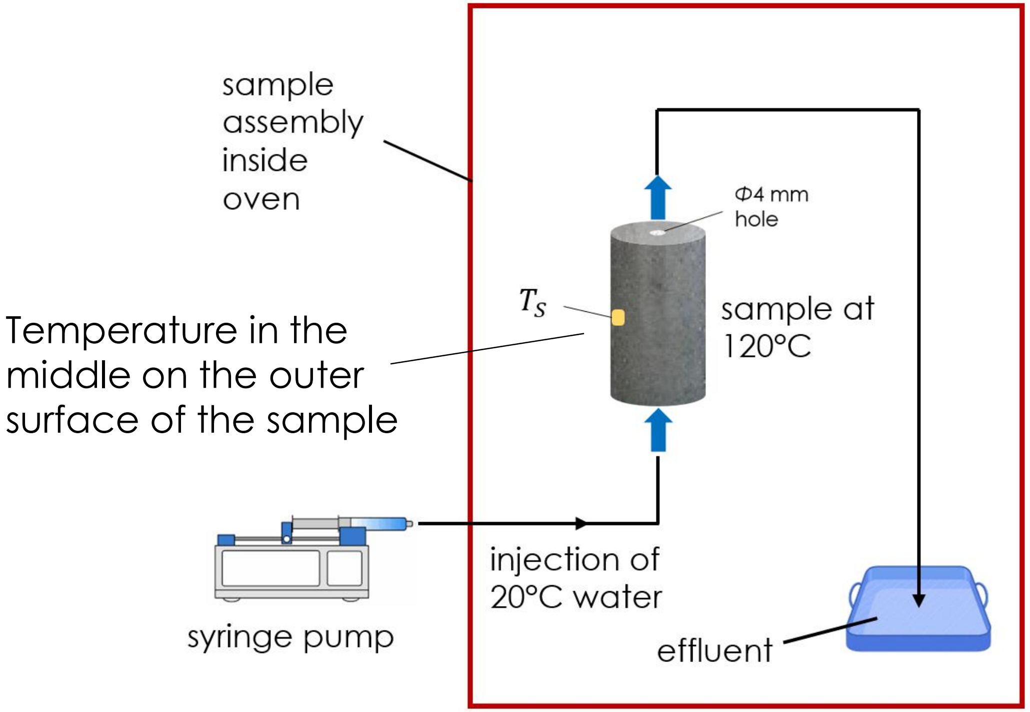


sample

before use:

- submerged in fresh water and stored at room temperature.
- dry the sample at 80℃ for 2 days for use.

Procedures of Unconfined Test

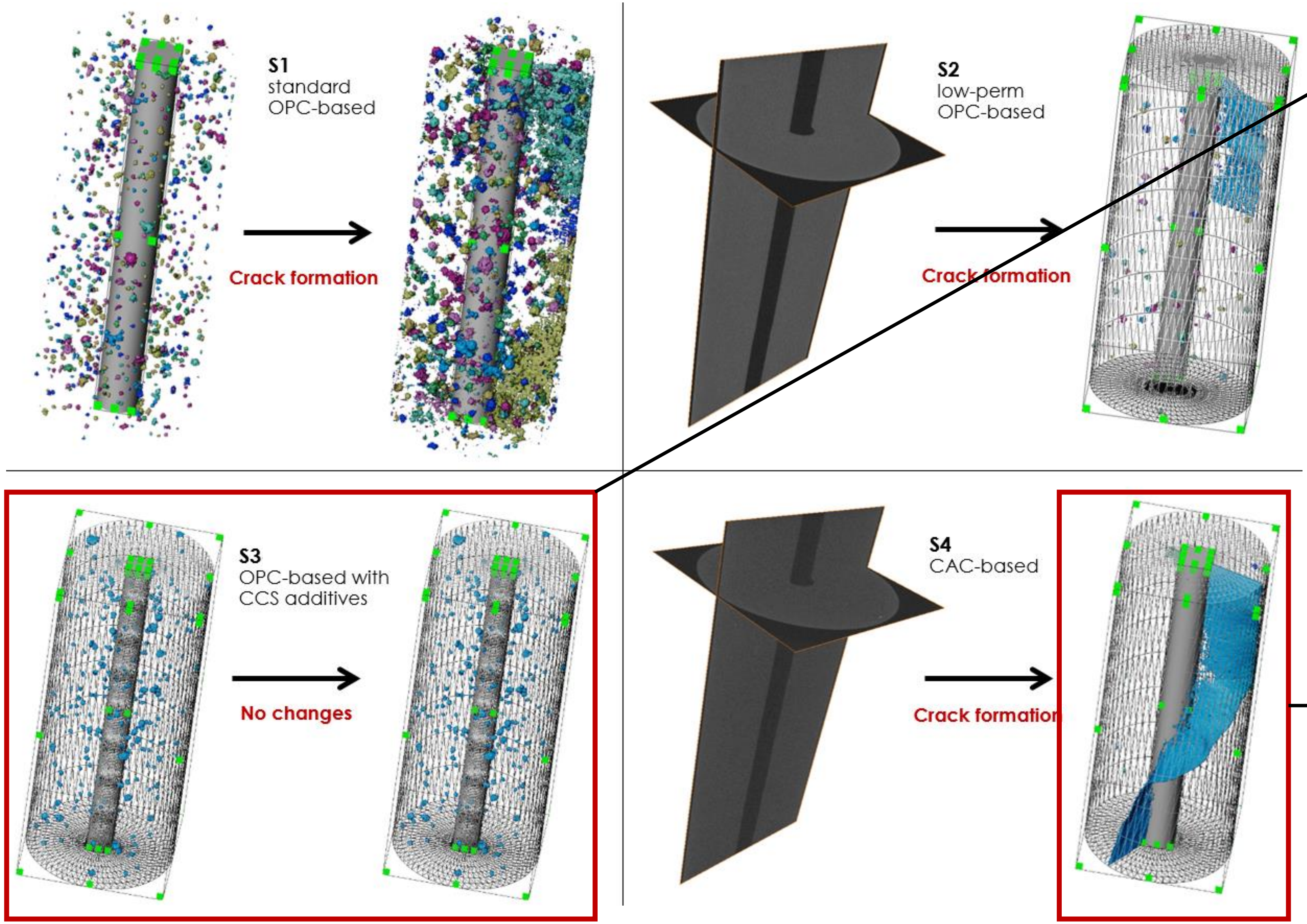


- **Without confining pressure.**
- Pre-heat the sample to and maintain at 120℃ for 0.5h in the oven.
- 160 mL 20℃ water flows through the sample in 2 mins, halt for 12 mins to reheat.
- Eight cycles of thermal shock.

Experimental scheme:

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

Unconfined Results



- S3 sample still intact after thermal shock by flow-through.
- Experiments induced cracks and new voids in S1, S2, and S4 samples.
    - only limited radial cracks were created.
- Flow-through created cracks all through sample S4.

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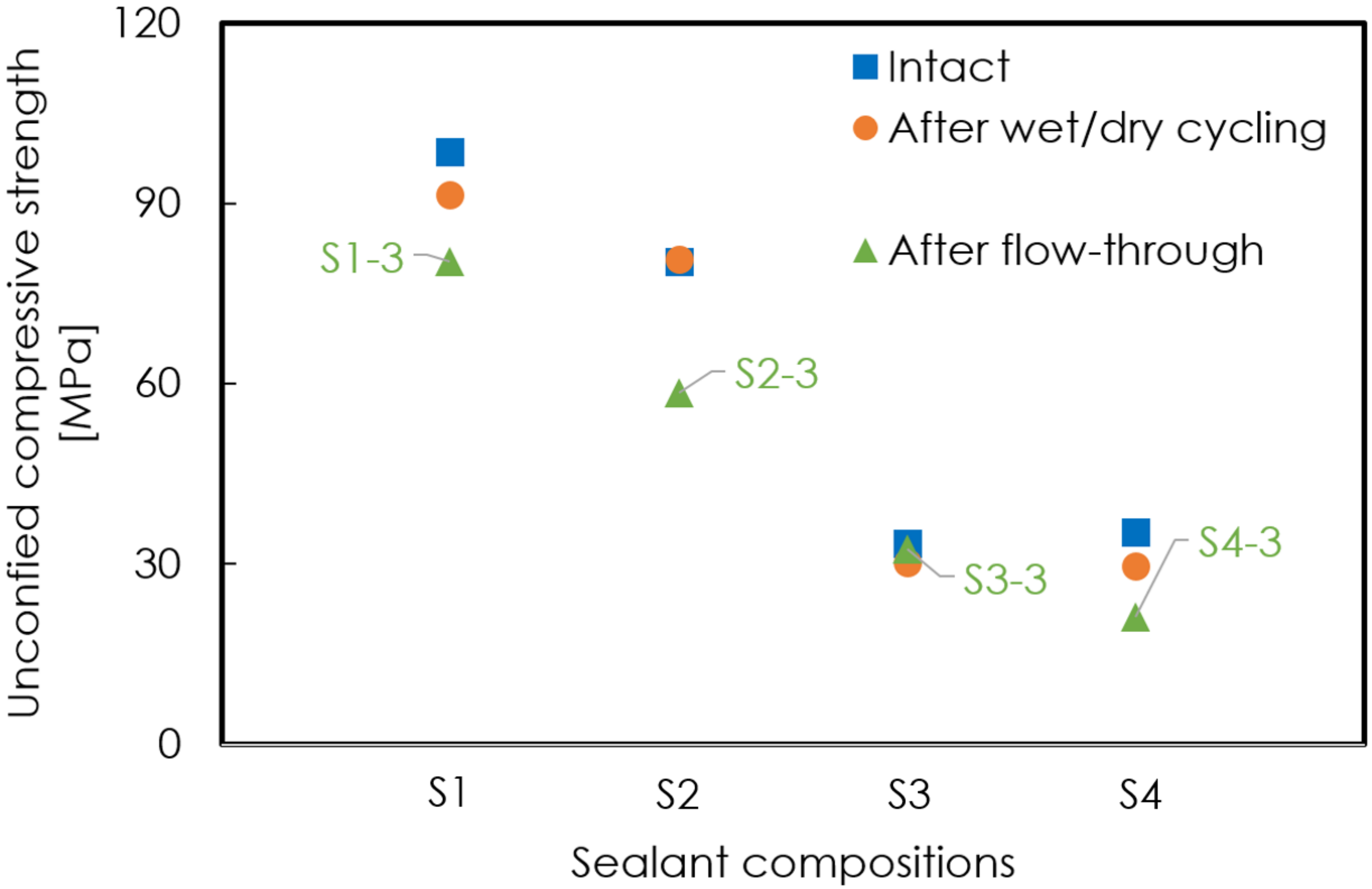
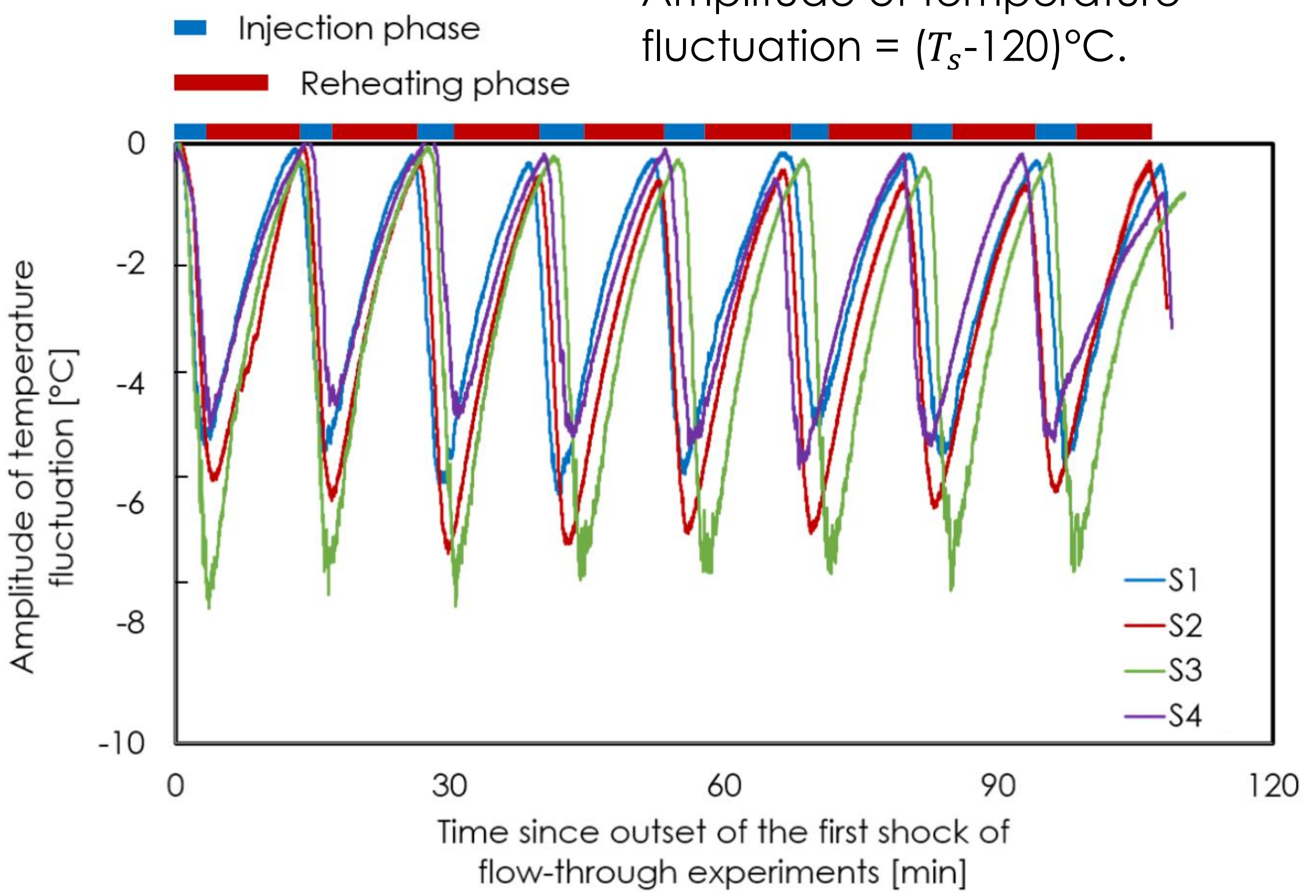
Unconfined: Effects of thermal shocks on UCS for all samples

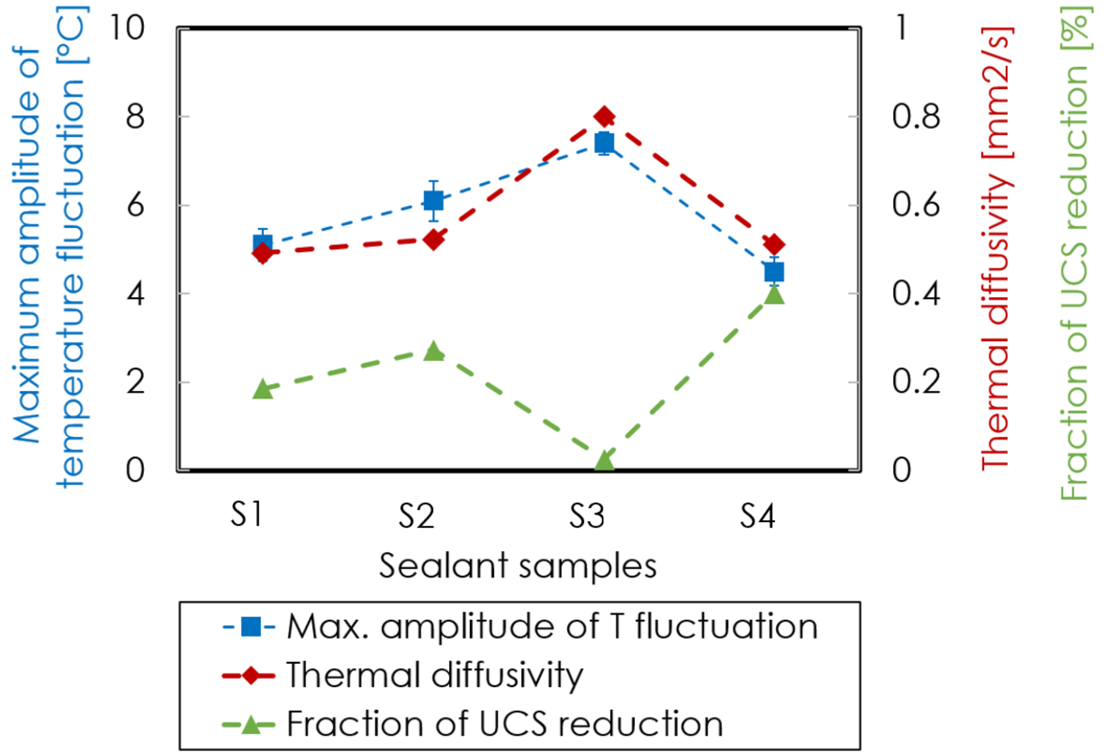


- UCS of S1, S2, and S4 samples decreases after flow-through experiments.
- No jeopardizing effects on UCS of S3 sample after flow-through.
- **Larger increase in the volume of thermal-induced cracks: greater reduction in strength.**

Unconfined: Temperature profile

Amplitude of temperature fluctuation = (T_s-120)°C.





- S3-experiences the largest drop, and S4 the smallest.
- **S3 has higher thermal diffusivity → transfers heat most efficiently → causing the less thermal stresses → no damage from thermal shocks → insignificant change in UCS.**

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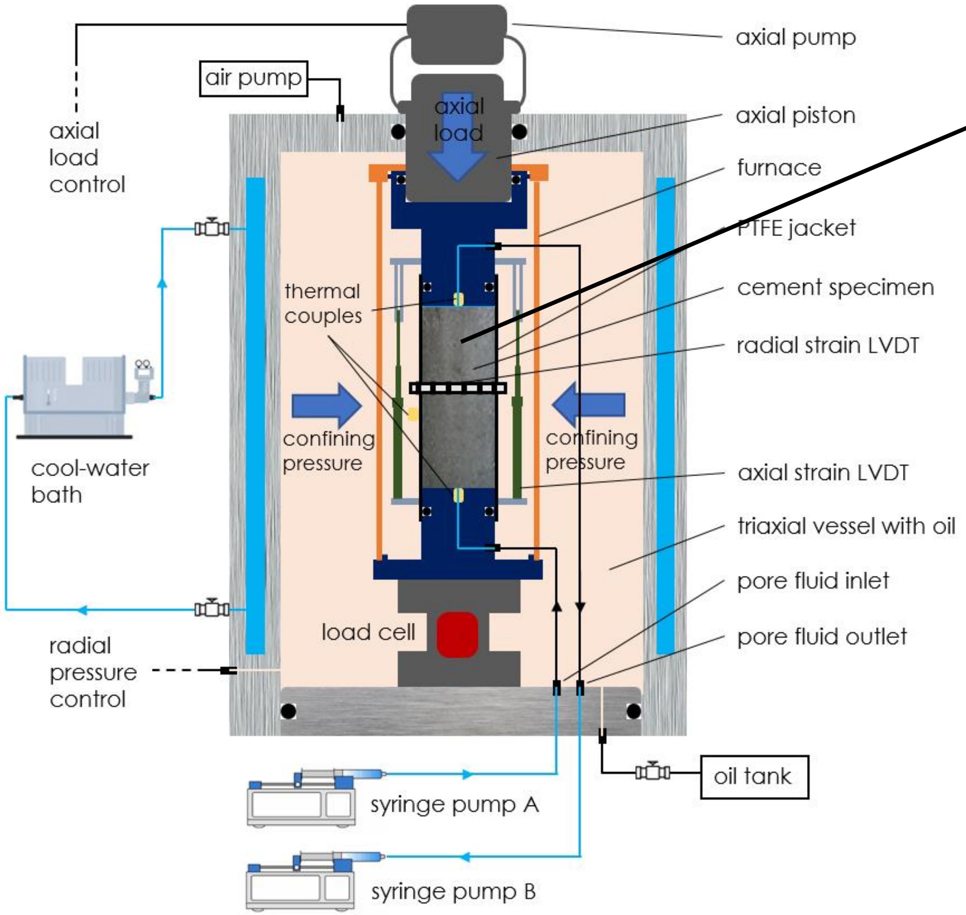
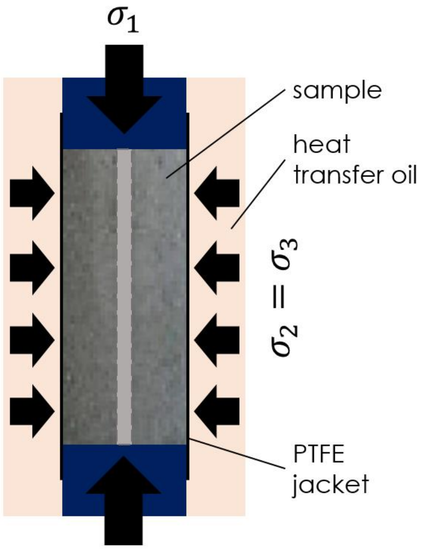
Setup and Procedures of Confined Tests





- **Confinement of 1.5 and 10 MPa.**
- Heat the sample to and maintain at 120℃ for 0.5h in the vessel.
- 160 mL 20℃ water flows through the sample in 2 mins, halt for 12 mins to reheat.
- Eight cycles of thermal shock.

Experimental scheme:

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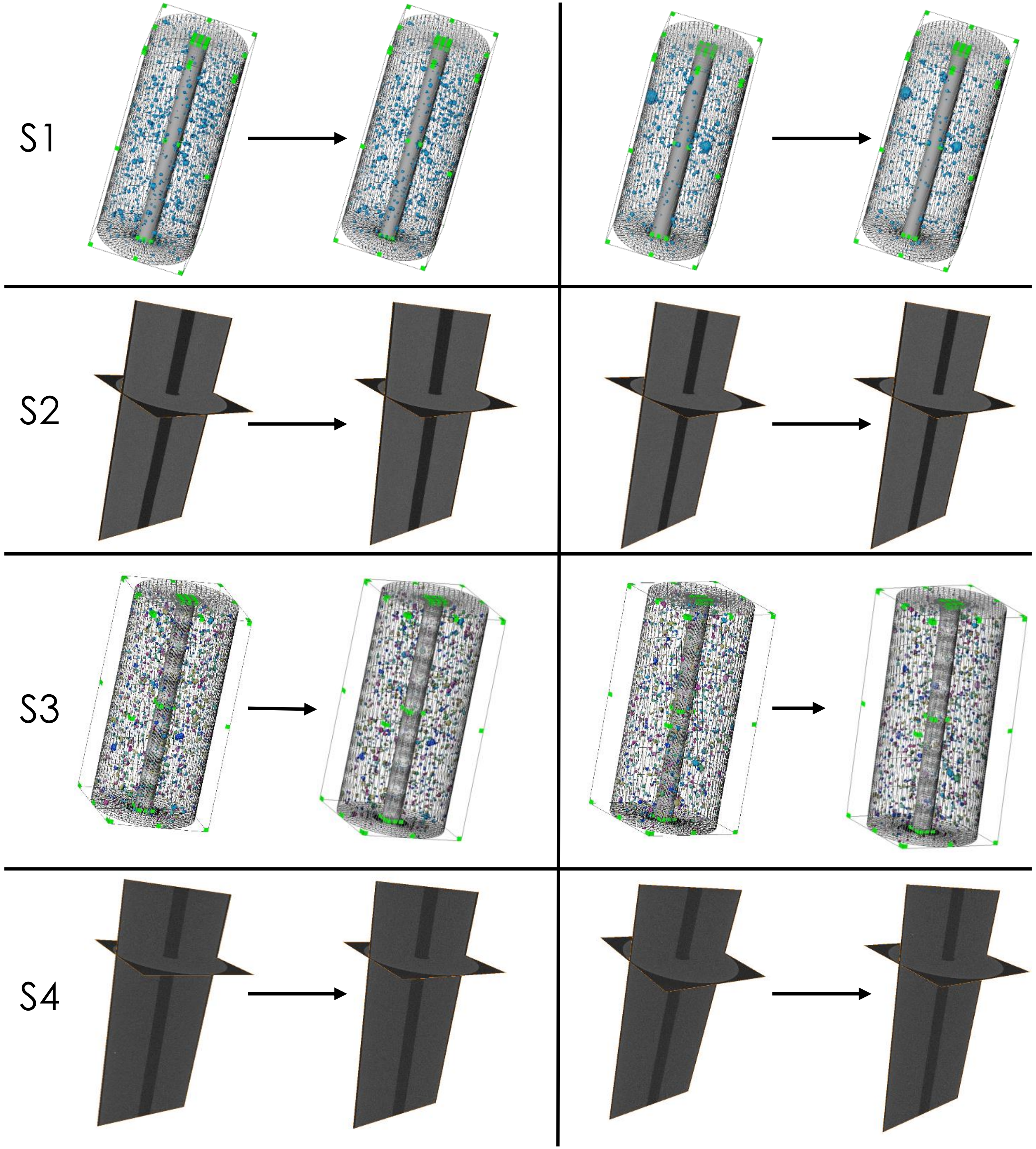
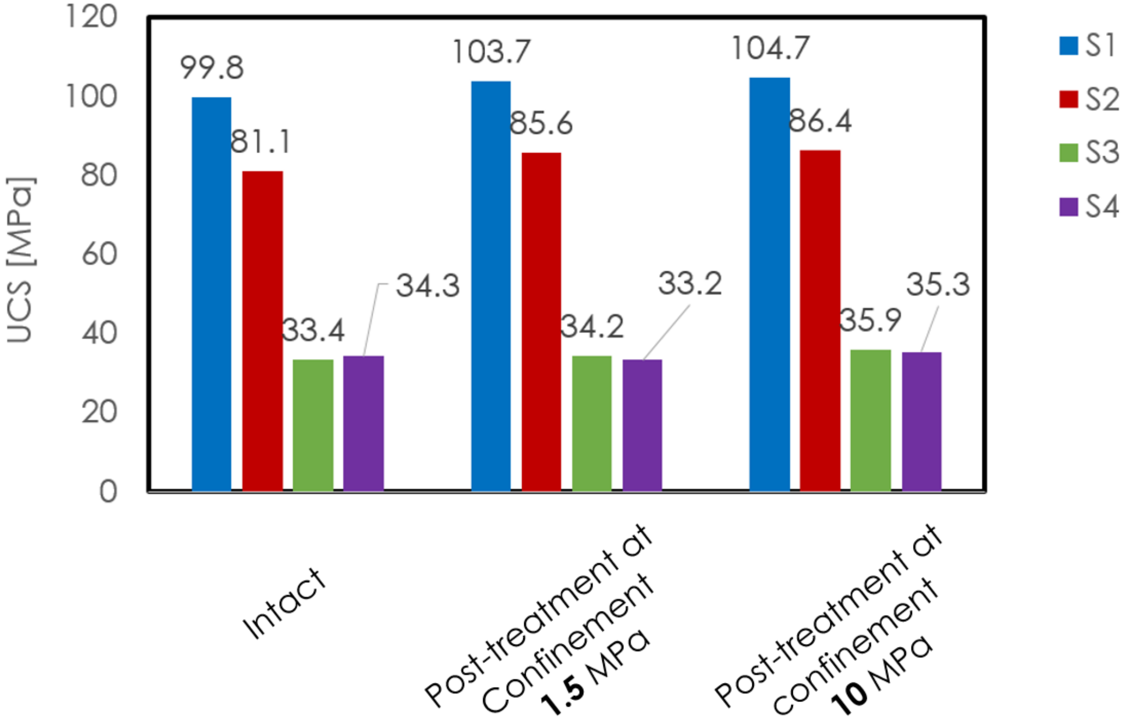


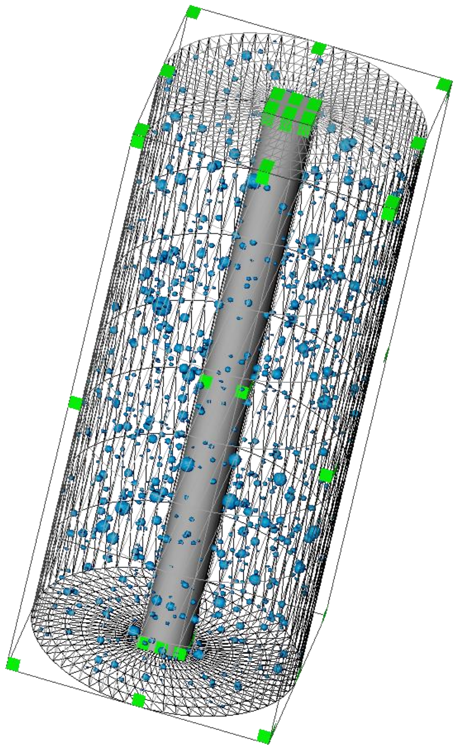
Confinement of 1.5 (left) and 10 (right) MPa



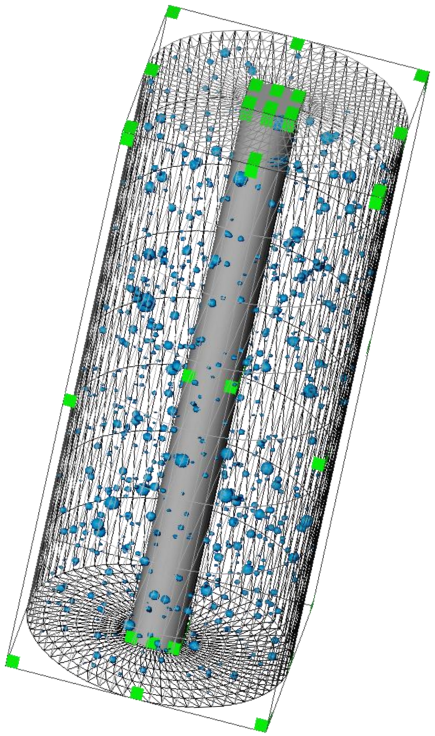
- For all sealants, no cracks after thermal shocks with **confinement**, even at 1.5 MPa.
- Higher confining pressure causes more compression to the sample, resulting in greater strength.

Confined: Effects of Confinement in Triaxial Apparatus

- S1 sample.
- Hydrostatic stress state: 10 MPa.
- Without thermal shocks.



Intact sample



Sample through confinement

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.

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Without confinement:

- **S3 (OPC with CO_2-sequestering additives)** resists thermal shocks the best! 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.
- **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.

With confinement:

- **For all four sealants**, no cracks after thermal shocks with confinement, even at 1.5 MPa.
- Confining pressure 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.

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