New materials and innovative monitoring for safe sealing structures in underground repositories

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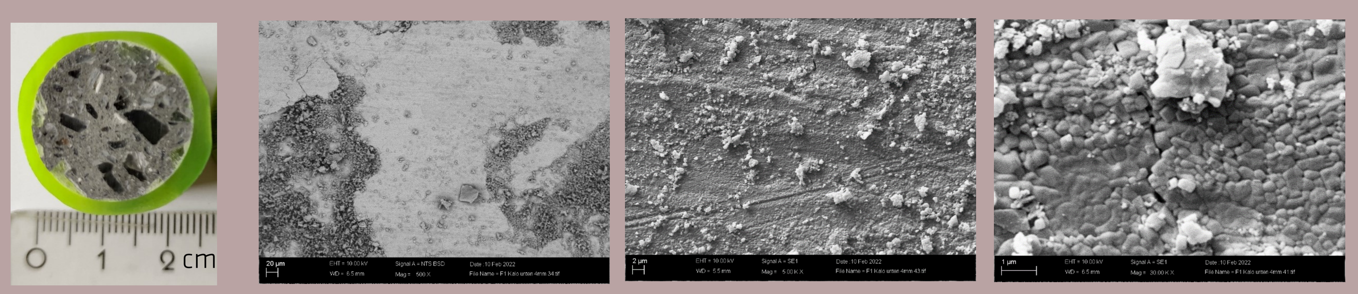
Abstract
Within salt as a host rock, engineered barrier systems are a crucial part to seal nuclear waste. To meet the high demands concerning integrity, an innovative alkali-activated material (AAM) is advanced in the project SealWasteSafe. After detailed laboratory analysis, test specimens (150-340 l) were manufactured and equipped with a multi-sensory monitoring system to understand and investigate the new AAM in comparison to the existing salt concrete. Additional quality assurance methods are applied at the surface and from within boreholes of test specimens and an in-situ sealing structure.

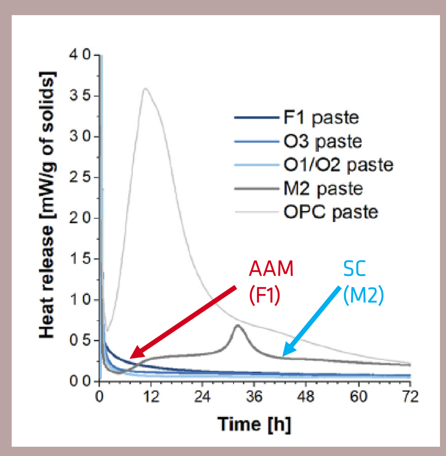
Overall, the project SealWasteSafe aims at optimising the construction material, multi-sensory monitoring concepts and ultrasonics for quality assurance applied at sealing structures.

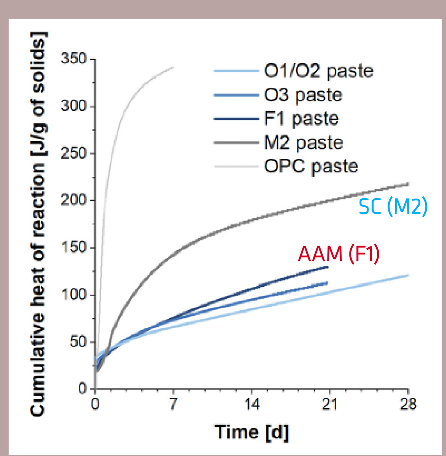
Concept of an engineered barrier system (source: BfS, 2015)

Materials: alkali-activated material (AAM) [1] & salt concrete (M2 receipt [2])



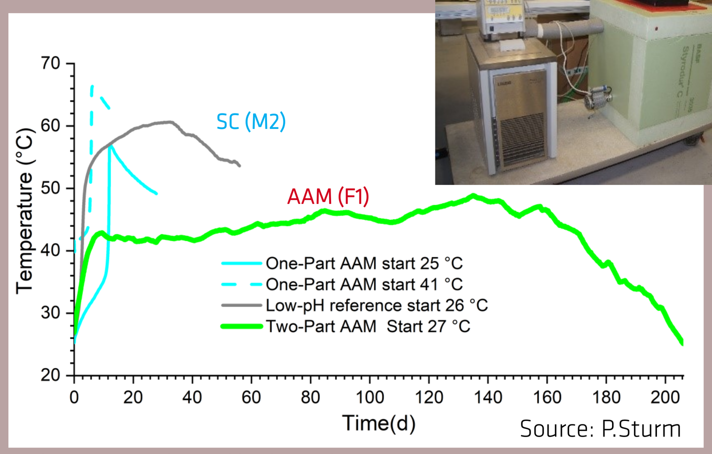
Photography and scanning electron microscopy images of AAM F1 (from left to right becoming more detailed)





Concreting

Heat release and cumulative heat of reaction showing less heat of reaction for AAM (F1) in comparison to salt concrete [1]. Thus, AAM has a potential for less cracking during hydration.



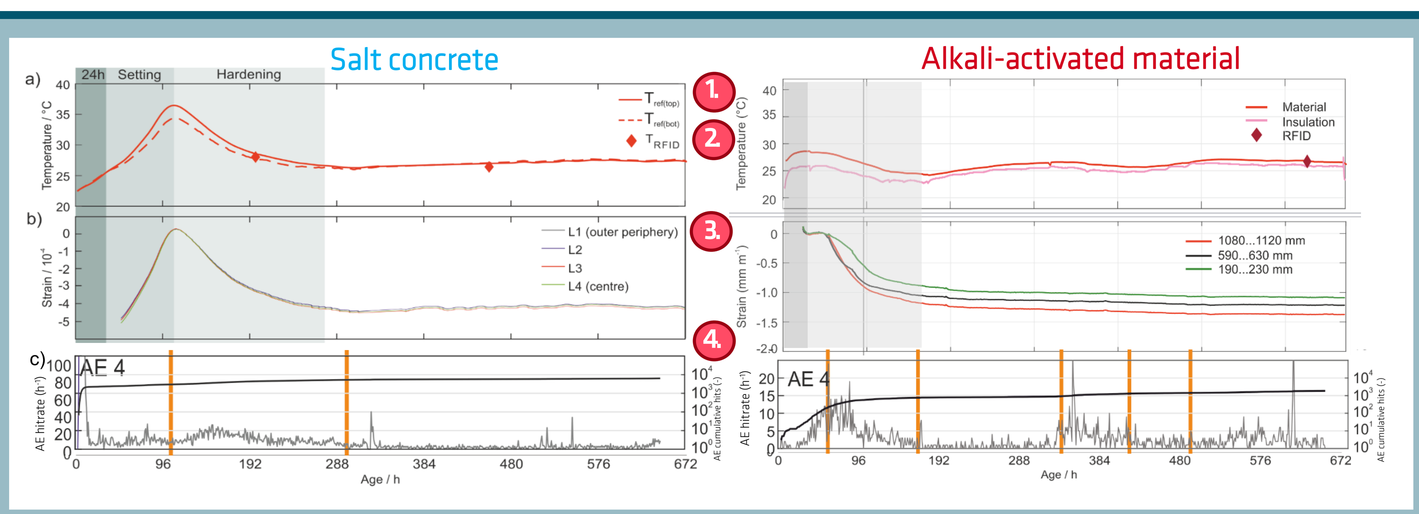
The semi-adiabatic temperature measured in a concrete calorimeter (photo, simulating in-situ conditions) shows significantly lower temperatures for the AAM in comparison to the SC.

① Construction material

② Multi-sensory monitoring

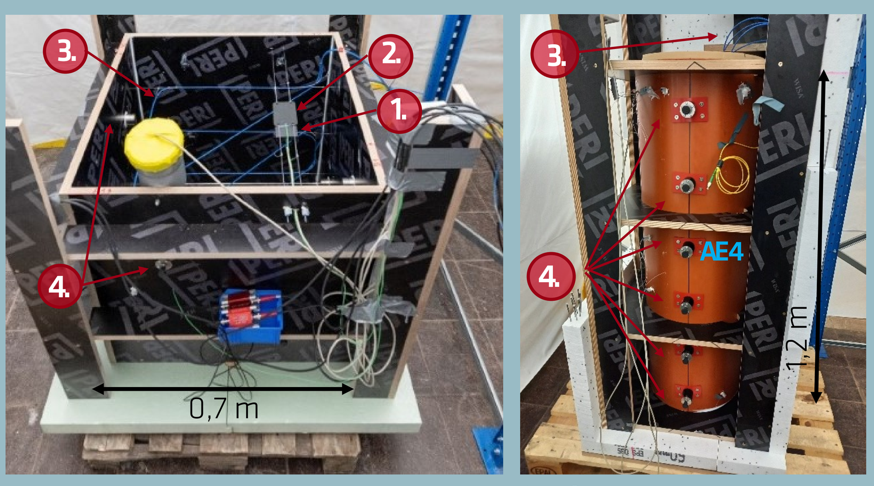
③ Quality assurance with ultrasonics

Seal Waste Safe



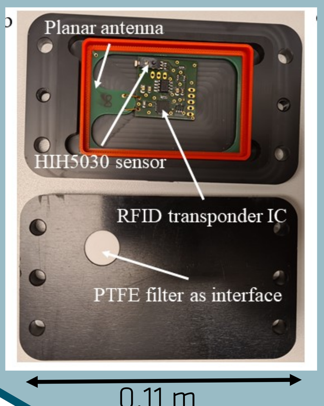
Multi-sensory hydration monitoring (28 days, cylindrical specimens) for salt concrete (left) and AAM F1 (right). a) temperature, b) strain from fibreoptic sensing, c) acoustic emission hitrate at sensor AE4. Strain and temperature indicate slower reaction kinetics for AAM, AE hits imply less cracking for AAM [3].

Sensory System
1. Temperature and humidity as reference (T,H)
2. Radiofrequency identification (RFID) based sensors (T,H)
3. Fibreoptic sensing (FOS) (strain)
4. Acoustic emission (AE) sensing (crack activity)



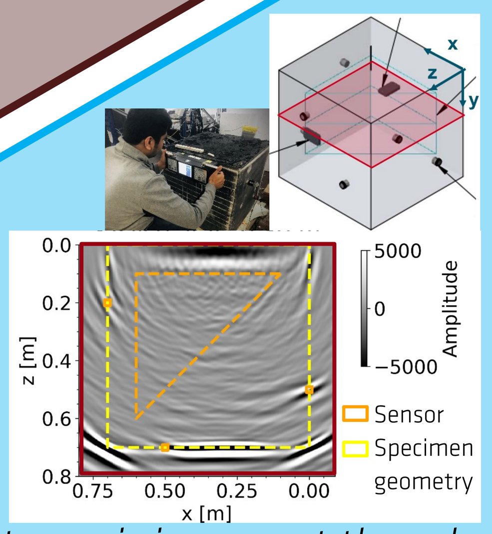
Test specimens with sensors before concreting

RFID-based sensor [3,4]

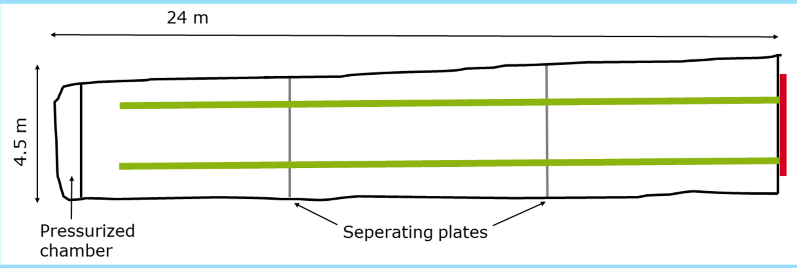


Left: Large aperture ultrasonic system LAUS measuring at the front of a test sealing structure in Morsleben [6].

Inspection aim:
- Test integrity of structures
- Image defects (e.g. cracks, delamination) and sensor locations
- Parameter: acoustic impedance contrast (sound velocity, bulk density)

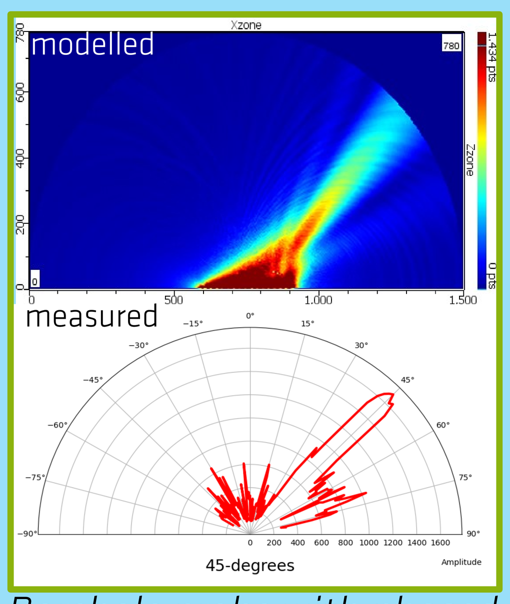


Ultrasonic images at the cuboid specimen (AAM) clearly identify sensor locations and specimen geometry. No major cracks are imaged, slightly less reflectivity for AAM than for SC.

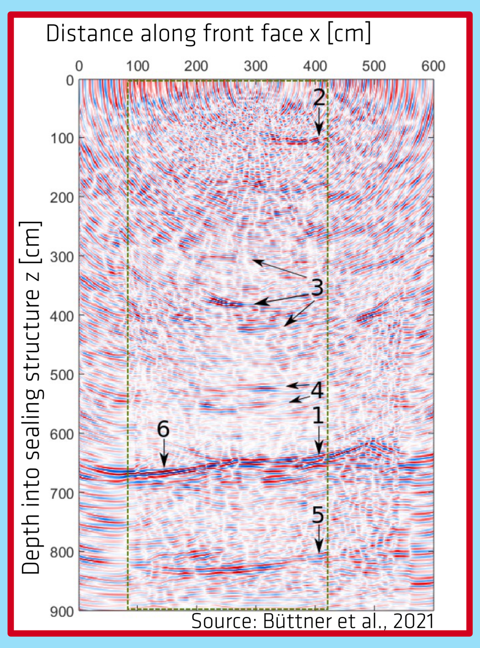


Sketch (side view) of an engineered barrier sealing a gallery with the location of ultrasonic echo inspection from with boreholes [5] and from the front [6,7].

Left: new borehole probe



Borehole probe with phased arrays focuses to specific angles as shown by modeling and laboratory analysis [5].



Left: Reconstructed image (using Reverse-Time-Migration) non-destructively reveals internal structures at an engineered barrier [7]. The identified features were verified by subsequent drilling and show built-in monitoring devices (2,4), the seperating plate (5) and air-filled cracks (3,6).

Key Findings – project SealWasteSafe

① Construction material
- Alkali-activated material (AAM) as alternative to salt concrete (SC)
- AAM shows promising material properties with slower reaction kinetics and lower temperatures

→ potential for less cracking

② Multi-sensory monitoring
- Sensors withstand harsh conditions in specimens
- Successful monitoring of hydration and long-term behaviour
- AAM shows less AE activity

→ hint for less cracking

③ Quality assurance with ultrasonics
- Inspection of structural integrity
- Non-destructive testing of internal structures (< 9 m depth) from the front
- New phased-array borehole probe with increased sound pressure and focusing

→ Imaging of cracks (less reflectivity for AAM)

Sicherheit in Technik und Chemie

References
- [1] Sturm et al., Open Ceramics, 2021
- [2] DBE, BfS, 2004
- [3] Baensch et al., SMIRT26 Proceedings, 2022
- [4] Johann et al., Materials Today: Proceedings, 2022
- [5] Prabhakara et al., NDT-CE: Proceedings, 2022
- [6] Effner et al., Materialwissenschaft und Werkstofftechnik, 2021
- [7] Büttner et al., Journal of Nondestructive Evaluation, 2021

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