Testing and developing improved wellbore sealants for CCS applications.

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ABSTRACT

The ACT-funded project Cementegrity aims to support the development of novel wellbore sealants, that can better maintain wellbore seal integrity, both during CCS-operations and afterwards, once injection is finished and wells are plugged. In order to do this, we have identified key damage mechanisms that can result in a loss in seal integrity during and after CCS, and are developing and applying laboratory methods for exposing sealant samples to these deleterious conditions, in order to assess how well different sealant materials can withstand them. Within Cementegrity, these tests are then used to compare five different sealant compositions relevant for CCS, taking into account storage in both depleted hydrocarbon reservoirs and saline aquifers. Here, we will highlight key findings obtained during the first half of the Cementegrity project.

Chemical attack during exposure to (impure) supercritical CO_2

WP's 1 and 2 are assessing the potential loss of sealant integrity resulting from exposure to CO_2 at temperature and pressure conditions beyond the supercritical point, and in the presence of selected impurities. In WP 1, a flow of either CO_2-saturated water or supercritical (sc.) CO_2 is forced through a confined cylindrical sealant sample, by applying a constant upstream pressure of 6.2 MPa (CO_2-saturated water) or 11.7 MPa (sc. CO_2) MPa, and keeping the downstream pressure constant at 1.4 or 8.3 MPa, respectively. This is equivalent to differential pressure gradients across the sample of approximately 60 and 43 MPa/m respectively. The samples are held at a temperature of 80°C, and exposed for up to 180 days. Water permeabilities are measured on selected samples before and after exposure, to determine changes in overall sample permeability. To assess the impact of CO_2-exposure on sealant (mechanical) properties, we use optical observation of the carbonation fronts, combined with fixed-force indentation mapping. Figure 1 shows indentation maps for two OPC-based reference sealant samples (composition S1) exposed to flows of sc. CO_2 (a) and CO_2-saturated water (b) for 180 days. Optical observations show that, after injection of sc. CO_2, a carbonation front penetrated about 20 mm into the sample from the injection point. This corresponds to shallower indentations (see Figure 1c), indicating that carbonation resulted in a mechanical toughening ("armouring") of the sealant. A similar carbonation front behind which shallower indentations were measured penetrated only about 9 mm into the sample exposed to CO_2-saturated water. This contrasts with the permeability measurements that showed a roughly 10x decrease in permeability for the sample exposed to

CO_2-saturated water compared to a roughly 3x decrease in permeability for the sample exposed to sc. CO_2.

Figure 2 presents a similar indentation map for a calcium-aluminate-based sealant sample (composition S4) exposed to CO_2-saturated water for 90 days, which shows armouring of the full sample compared to a reference sample not exposed to CO_2. In this case, the equivalent differential pressure gradient was 35 MPa/m. Further work is now ongoing to apply these testing methods to different sealant compositions, both to compare these different sealants in terms of resistance to carbonation, and to build a database correlating indentation depth to other mechanical properties. The methodology developed allows for a more accurate mapping of the impact of carbonation on sealant mechanical properties than obtained through sample-scale measurements, which in turn can be used to build better models for the extrapolation of carbonation effects on wellbore sealant integrity during CCS.

The work done in WP 1 will be supported by the activities in WP 2, where sealant samples are exposed to sc. CO_2 containing selected impurities (H_2S and others) in batch reactors, to identify mineralogical changes, and distinguish additional chemical reactions that may be induced by the presence of these impurities.

Integrity of the sealant and sealant-wellbore interfaces

WP5 is tasked with studying the integrity of selected sealants, focusing especially on the interface between sealant and wellbore (particularly the sealant/steel-casing). In addition to exploring the mechanical bond strength along the cement-steel interface, WP5 is developing the use of electrical properties measurements (i.e. frequency-dependent impedance/admittance) to monitor the sealant-steel interface condition, and the evolving sealant material bulk properties. As a sealant hardens its microstructure evolves, resulting in changes to the mechanical properties, but also in the underlying physical properties such as porosity, pore size distribution, and permeability. As these are known to be directly related to the electrical conductivity and polarizability of sealant materials, impedance measurements can be used to track sealant maturation, and to characterize different sealant types. Changes in seal integrity, either through the seal body, or along a seal-wellbore interface, may result in measurable, frequency-dependent alterations in system impedance, thereby potentially allowing the monitoring and detection of seal integrity compromise.

Preliminary results from low frequency conductivity measurements on two sealants subject to an enhanced curing regime, at elevated temperature and pressure (28 days at up to 150°C and 30 MPa), have shown that the curing/maturation process can be tracked using such a scheme (see Figure 3). Further, the results suggest that differences between the sealants can be characterized. Subsequent preliminary post-curing measurements of complex impedance, up to MHz frequencies, have shown that more detailed exploration of the electrical/physical properties is feasible.

Further activities in Cementegrity

In addition to the results highlighted above, other WP's within Cementegrity address the impact of thermal cycling on the integrity of the sealant material, and the seal-wellbore interface (WP 3), the development of a rock-based geopolymer sealant tailored to CO2-storage applications (WP 6), and the development of a microstructural model of such a rock-based geopolymer (WP 4).

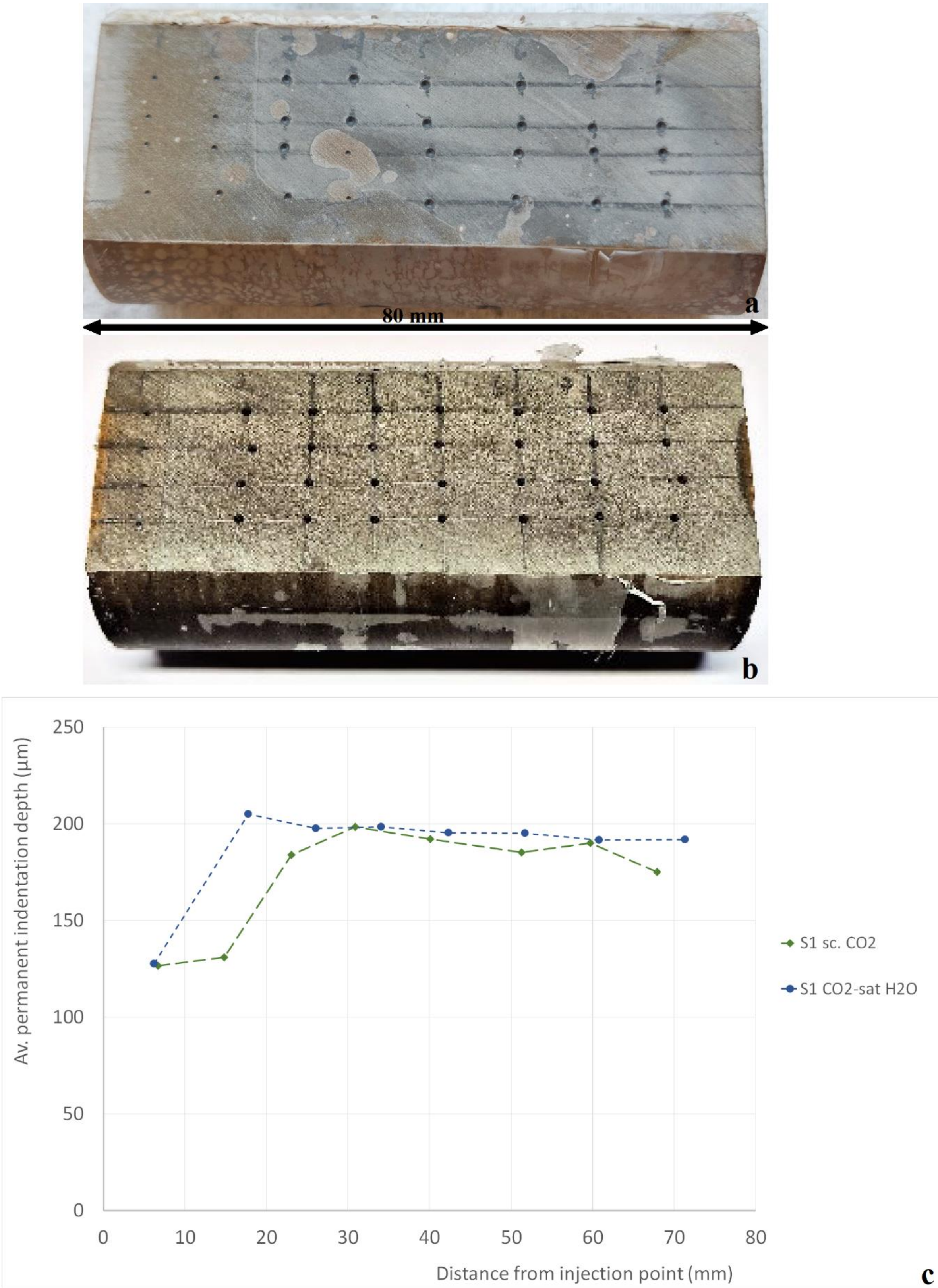

Figure 1. Samples of sealant S1 (Class G cement with 35% BWOC silica flour) exposed to a flow of (a) sc. CO_2, or (b) CO_2-saturated water. Graph (c) plots average permanent indentations depths against distance from the injection point for these samples.

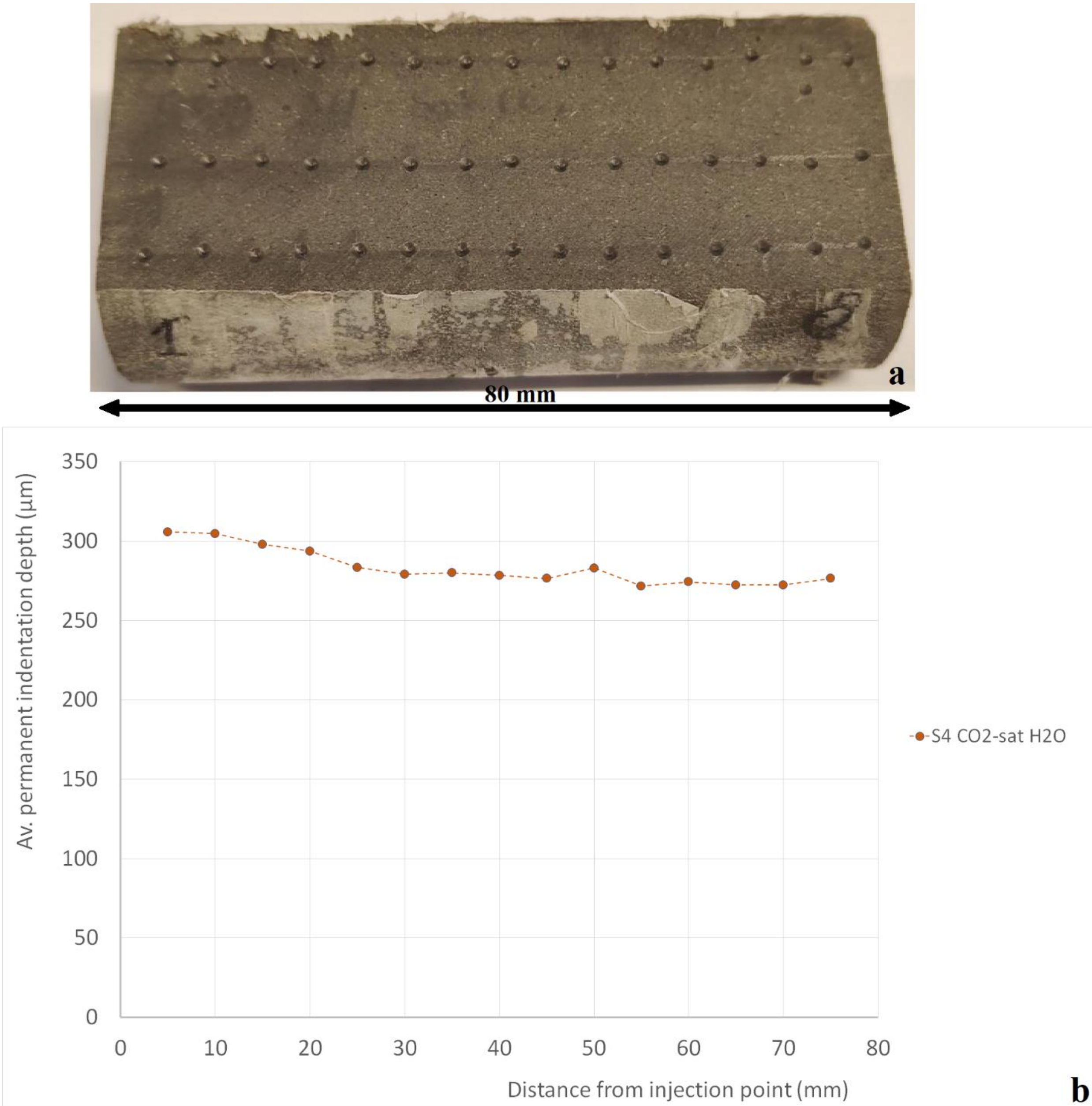

Figure 2. A sample of sealant S4 (calcium aluminate based blend) exposed to a flow of CO_2-saturated water. Graph (b) plots average permanent indentation depths against distance from the injection point for this sample.

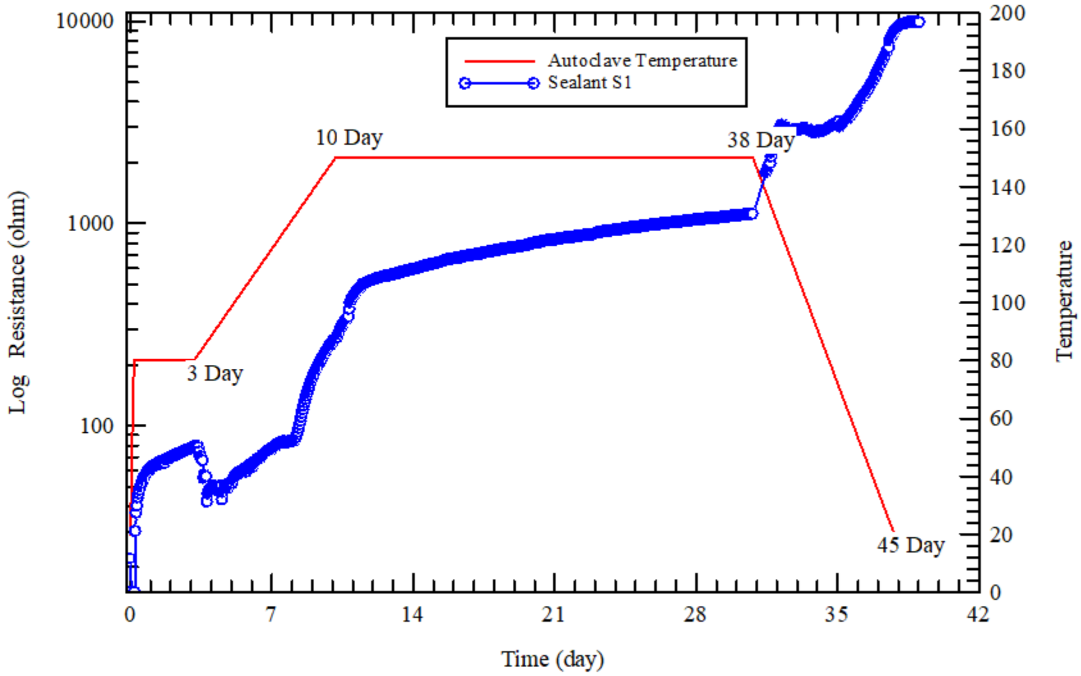

Figure 3. A plot showing the evolution of resistance vs. time for a sample of Sealant 1 during curing. The red line shows the temperature path of the autoclave in which the sample was cured.