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3D microscale investigation of active deformation mechanisms of halite under conditions representative of underground hydrogen storage

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To tackle the challenges raised by climate change, we need to rapidly switch our energy sources to low-carbon ones for all economic sectors. As renewable energies are intermittent, efficient energy carriers, such as hydrogen, will be needed to meet the energy demand. Green hydrogen is considered to be a promising energy vector for the future. However, in addition to problematics related to its production, safe and large scale storage solutions still need to be developed. The geological formations including saline aquifers and former depleted gas fields offer the largest storage capacities but are more adapted to seasonal or mid-to-long term storage. Conversely, underground salt caverns are well suited for storage/withdrawal cycles as short as daily cycling. These artificial structures, offering exceptional tightness, have already been used for decades for hydrocarbons storage but at seasonal storage/with-drawal cycles. The adaptation to short-term hydrogen storage still requires further studies to ensure the stability of the caverns under such loading conditions. Indeed, rapid cyclic loading conditions may impact the tightness and the integrity of the cavern [1, 6].

Rock salt is polycrystalline material with an essentially viscoplastic behaviour, involving different micro-mechanisms such as crystal slip plasticity and grain boundary sliding. At mechanical loading conditions representative of those operated in storage caverns, the rock salt is characterized by non-linear viscous flow. The activation of grain boundary sliding is necessary to accom-modate local plastic incompatibilities between neighbouring grains. It has been shown in uniaxial loading conditions but has not been verified in triaxial conditions yet [2, 4]. The presence of brine also affects the micro-mechanisms involved, with for example phenomena like dissolution-precipitation or diffusional mass transfer along grain boundaries, and can modify the mechanical be-haviour [5].

In our studies, we investigate the active micro-mechanisms in synthetic halite through *in situ* X-ray microcomputed tomography (XR-µCT) analysis and digital volume correlation (DVC) and damage quantification. To reproduce loading conditions representa-tive of those in real salt caverns, we apply different confining pressures with a triaxial cell. This triaxial device, developed recently [3], is adapted to *in situ* XR-µCT tests. We study the development of damage networks and the evolution of pores during the deformation of rock salt under different confining pressures. Samples of halite are prepared by compaction of pure NaCl powder in dry and humid conditions. It gives samples with different brine contents and allows us to study the effect of brine on the deformation mechanims.

An effect of brine is visible, as the cracks seem to appear earlier in the dry samples. On the µCT scans, cracks start to be visible for a lower strain in the case of dry samples compared to the case of wet samples. For a dry sample in uniaxial loading conditions, the cracks were already clearly visible and well formed in most of the sample at 1.3% axial strain. For a wet sample, very few cracks only start to become slightly visible in some areas at 1.45% axial strain. This could be due to the activity of mechanisms involving brine, such as dissolution-precipitation allowing for crack healing.

The effect of the confining pressure is also noticeable. After unloading the wet sample and removing the confining pressure, we observed that the few cracks formed during the deformation of the sample opened up, indicating that the healing process was not

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complete. Dissolution and precipitation are kinetically slaw processes, which are mostly active at low strain rates. Therefore, further deformation experiments must also explore the effect of strain rate.

Natural salt always contains some humidity. Therefore, the effect of brine in deformation and damage formation/healing mechanisms is important to understand, especially in the context of gas storage in salt caverns.

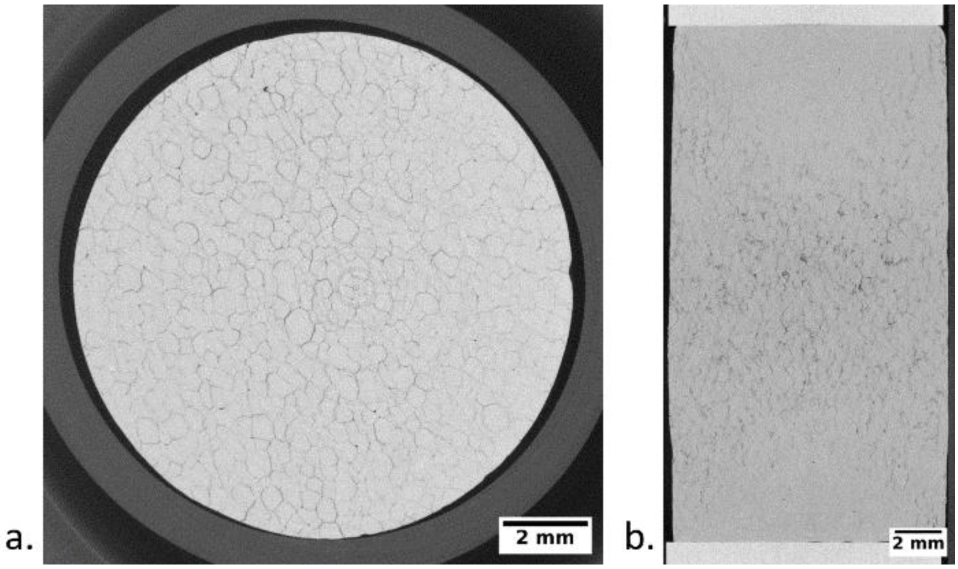

Figure 1: X-Ray Computed Tomography images of a dry synthetic rock salt sample (12mm in diameter, 24mm in height) deformed (3.7% axial strain) under uniaxial conditions, horizontal slice (a) and vertical slice (b).

Contributor statement

Conceptualization - Methodology: Alexandre Dimanov, Michel Bornert; Investigation: Alexandre Dimanov, Michel Bornerrt, Nina Du; Project administration: Alexandre Dimanov; Ressources: Patrick Aimedieu, Vincent de Greef; Writing - Original Draft: Nina Du; Writing – Review & Editing: Alexandre Dimanov, Michel Bornert

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