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Upscaling rocks mechanical properties to study Underground Hydrogen Storage feasibility

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Underground Hydrogen Storage (UHS) is a feasible option for large-scale energy storage considering the advancements of the large-scale production of green hydrogen. One of the main engineering objective is to ensure the continuous safety of the storage, such that subsurface operations can be carried under safe stress regimes. Despite obvious similarities to Carbon Capture and Storage, a few differences make the task a new research challenge.

The first one relates to the cyclic nature of UHS, which is expected to be carried at variable frequency and injection/production loads. Current models are not adequate for the lower frequency range considered in this application. In that case, the visco-plastic nature of rocks becomes non-negligible and needs to be taken into account.

As a second observation, UHS revolves around a new gas, much lighter than CH4 and super critical CO2. Hydrogen's atoms are so small they can diffuse even inside rock and this absorption causes rock matrix mechanical properties to weaken. This process is know as Hydrogen Embrittlement. When unaccounted for, such physical phenomenon could lead to catastrophic failure of the caprock, which is supposed to maintain stability to ensure safe storage. The caprock being responsible for the confinement of the hydrogen in the reservoir, development of cracks would enhance greatly permeability of an otherwise impermeable medium, resulting in an environmental disaster as the hydrogen suddenly leaks towards the subsurface and through groundwater aquifers.

No empirical model is able to capture those two behaviours at the macro-scale since they are both phenomena principally related to grain-scale physics. As such, this contribution presents a Digital Rock Physics framework to upscale rock mechanical properties from the grain-scale. Rocks of interest are microCT-scanned to extract the digitized microstructure. Direct numerical simulations of elasto-plasticity are performed for different stress paths in order to compute the full yield surface (see Figure 1) instead of just the Uniaxial Compressive Strength. While most studies use Discrete Element Modelling to consider grain contacts explicitly, our simulator uses Finite Element Modelling which allows more flexibility in the approach to model multiphysics processes present during UHS. The contacts are modelled instead as an upscaled plastic law. Details of the numerical algorithms are presented in [1].

As a first case study for this framework, we present a comprehensive parametric study on the impact of cementation on rock strength for real microstructures of granular materials. The framework is then coupled with a numerical erosion algorithm that simulates homogeneous precipitation of mineral matter to represent cementation. New results on the influence of cement property namely Young's modulus, friction and cohesion on the rock's yield surface are explored. This study contributes to preliminary results on Hydrogen Embrittlement which directly influences those same mechanical properties. However more work is needed to model realistically the Hydrogen Embrittlement, which is the aim of our new PhD project OCEAN. The process will be observed experimentally at the micro-scale in order to calibrate the simulator. MicroCT-scan images will determine the spatial distribution of the phenomenon. Visco-plasticity will be implemented from [2] to go one step further and determine the effect of Hydrogen Embrittlement during cyclic injection/production of hydrogen.

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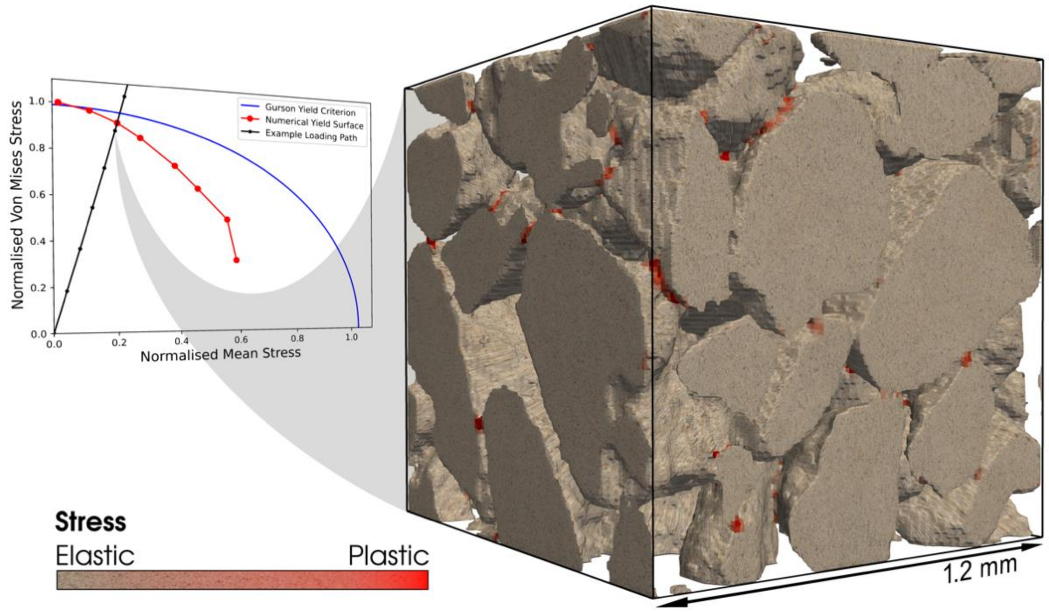

Figure 1: Plasticity distribution of digital rock from one point of the yield envelope, taken from [3].

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