Hydro-mechanical-damage behaviour of the Callovo-Oxfordian argillites upon drying

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ABSTRACT

Deep clayey sediments, thanks to their low permeability and strong retention properties, have been largely considered as potential host formation for geological radioactive waste disposal, such as the Callovo-Oxfordian (COx) argillites, a thick layer of c.a. 160 m deposited at about 500 m depth in France. During operational phases, the geological host formation immediate to the tunnel, being initially fully saturated, is dried due to gallery ventilation, thus inducing microcracks which may alter its confining and isolating functions. This issue is tackled in the present study with a simplified coupled hydro-mechanical-damage (HMDs) model and a drying tests campaign on COx argillites.

Water retention curve, water relative permeability and deformations were monitored with imposed decreasing relative humidity by supersaturated saline solutions. The main assumption in the HMDs model consists in supposing that the gaseous phase is constituted only of water vapour, which allows combining the mass balance equations of the fluid phases (i.e. liquid and vapour water) into a single one. The extended Biot theory is used for formulating the skeleton constitutive equations. Damage is introduced in the model by tension-induced microcracks, characterised by a scalar damage density variable.

Damage-induced alterations of elastic moduli, Biot coefficient and permeabilities are estimated by micromechanical approach. For this purpose, COx argillites are preliminarily represented as a two-scale matrix-inclusions type composite. Indeed, the first (micro-)scale, corresponding to the intact state, describes clay minerals with "inert and occluded" nano-porosity as a homogeneous matrix in which are randomly distributed spheroidal inclusions representing micro- and macro-porosities, quartz and calcite. At the second (meso-)scale, the damaged COx argillites are composed of the previously homogenised intact argillites matrix in which are embedded randomly oriented penny-shaped microcracks. Different analytical upscaling schemes by averaged medium approximation (dilute, Mori-Tanaka, self-consistent and IDD - interaction direct derivative) are used to estimate COx macroscopic poroelastic properties. Parametric investigations with these schemes reveal that quartz and calcite inclusions form has negligible effect on COx poroelastic properties, while porosity, pore aspect ratio and damage variable show significant repercussions. Damage variable evolution is ruled, based on microscopic experimental observations in the literature, by a Mazars-like equivalent strain calculated from the averaged clay matrix strain, the latter being computed from the macroscopic strain and the analytical averaged strain localisation tensor.

The model is then implemented in the in-house finite element code Cast3M and used to simulate two drying tests on COx argillites with correspondingly mass loss and strain measurements under isothermal stepwise relative humidity decrease. Comparisons between experimental and simulated results in terms of mass loss and strains evolutions show satisfactory agreements and justify the simplifying assumption on the gaseous phase, which leads to much lower computation costs. Furthermore, the simulation provides also damage state evolutions as function of relative humidity and time, which are qualitatively consistent with experimental unaided-eye observations.