Influence Of Temperature On The Short- And Long-Term Behaviour Of Callovo-Oxfordian Claystone

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Abstract

The French National Agency for Radioactive Waste Management (Andra) is sspearheading the Cigéo project, whose objective is to optimise the engineering design and enhance the safety features of a deep geological repository intended for the disposal of intermediate- and high-level long-lived radioactive waste within the Callovo-Oxfordian (COx) claystone formation. Owing to their favourable properties—such as low permeability and self-sealing capacity—three clay formations have been identified as suitable host rocks for radioactive waste disposal in Europe: Boom Clay, Opalinus Clay (OPA), and COx claystone.

Since 2000, Andra has conducted extensive in-situ and laboratory Thermo-Hydro-Mechanical (THM) experiments to better understand the behaviour of these clays under repository conditions. Advanced numerical models have been developed to simulate these coupled processes, incorporating complex behaviours such as anisotropic elastoplasticity, creep, and damage. The model proposed by Souley et al. (2024) fits in this framework, integrating all relevant strain mechanisms. The pre-peak response is governed by plastic strain hardening with a non-associated flow rule, without any degradation of the effective moduli. In contrast, the post-peak behaviour is primarily characterized by strain softening driven by material damage, followed by a perfectly plastic residual phase corresponding to the residual strength observed on triaxial tests.

Despite numerous laboratory investigations, the effects of temperature on both short- and long-term behaviour remain insufficiently understood. The EURAD HITEC program addresses this knowledge gap through targeted experiments and modelling efforts (Villar et al. 2025). Based on these data, temperature-induced changes in several mechanical properties and thresholds have been quantified—often approximated using piecewise linear functions—and implemented in COMSOL Multiphysics. These include uniaxial compressive strength, anisotropic elastic moduli, plasticity threshold, peak strength, volumetric plastic strain rate, and viscosity.

For short-term behaviour, triaxial THM compression tests over a temperature range of 20-80 °C (Gbewade et al. 2024) were used to validate the extended model. Results show excellent agreement between experiences and model predictions. It is important to note that all short-term mechanical parameters at ambient temperature were derived from values in Andra's database, with no additional parameter identification beyond temperature effects. This serves as a valuable independent validation of the model and its parameters.

The THM tests also revealed challenges in controlling pore pressure within the sample, particularly during heating and under high-temperature conditions. These findings raise questions about the quasi-drained or pseudo-undrained nature of these tests. To address this, a numerical investigation was carried out by simulating various hydraulic boundary conditions applied to the sample's perimeter. These simulations provided deeper insight on the influence of drainage conditions on the thermo-mechanical response.

Regarding long-term behaviour, the influence of temperature on rock viscosity was introduced by applying Arrhenius' law within a time-dependent framework based on the Lemaitre creep model.

Next step will be the large-scale applications to evaluate its impact on the COx behaviour in the near- and far-fields of Radioactive Waste Repository.

Reference

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