Non-isothermal behavior of excavation damaged zone around deep radioactive waste disposal

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Indurated argillaceous rocks are being investigated as suitable hosts for high-level nuclear waste storage. An important aspect in evaluating the efficiency of waste disposal is the examination of the thermal impact's potential effects on the excavation damaged zone (EDZ) near the field. Increased temperatures could alter the EDZ's crack network, potentially leading to hydraulic failure through thermal pressurization. To accurately understand and model the EDZ surrounding repository cells at higher temperatures, it is essential to account for the coupled influence of thermal-hydraulic-mechanical (THM) phenomena in the constitutive model. Recent studies [1] underline two crucial behaviors in the thermomechanical response of argillaceous rocks: a gradual change in mechanical properties, such as strength and stiffness, with temperature that leads to a more ductile state at higher temperatures; and the occurrence of reversible expansive strains due to temperature increase, which, upon exceeding a specific threshold, turn into irreversible contractive strains.

These experimental findings led to the idea of developing a thermomechanical constitutive model. The core of the mechanical part of the reference model is taken from the Mohr-Coulomb yield criterion generalized to depend explicitly on temperature and suitably modified to reproduce the main thermal features of argillaceous rocks. The proposed model is then applied to the THM modelling of an in-situ heating test carried out in Callovo-Oxfordian (COx) claystone in the Meuse/Haute-Marne underground research laboratory [2], [3], [4]. The model comprises two main deformation mechanisms: an *instantaneous response* related to stress and temperature change and a *time-dependent response* occurring under constant stress. The instantaneous response is described within the framework of elastoplasticity so that under low deviatoric stresses, the response is linear elastic but characterized through a transverse isotropic form of Hooke's law. For higher deviatoric stresses, plastic deformations can take place. An initial, a peak and a residual yield limit are considered. Further details on developing the constitutive model are provided in [5], [6].

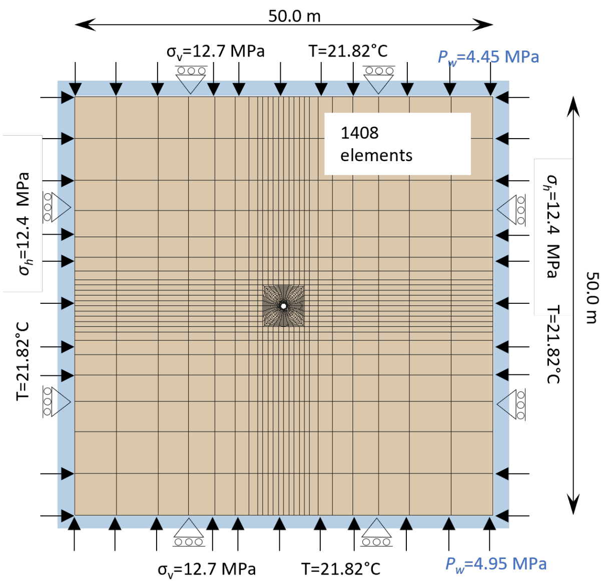

Figure 1. Domain, finite element mesh and boundary conditions.

In order to illustrate the applicability of the proposed model, a THM 2D finite-element (FE) analysis of the in situ heating tests was performed assuming plane-strain conditions. Details of the adopted coupled THM numerical formulation and description of the FE model are given in [5], [7] (Fig. 1).

The cumulative value of the plastic multiplier along a horizontal line from the tunnel wall is depicted in Fig. 2a for simulations conducted using both isothermal and non-isothermal models. The simulation that employs the non-isothermal model exhibits a larger size of the fractured zone. This phenomenon can be attributed to the reduction in material strength and stiffness as temperature rises, which in turn causes more damage and leads to the accumulation of plastic deformations.

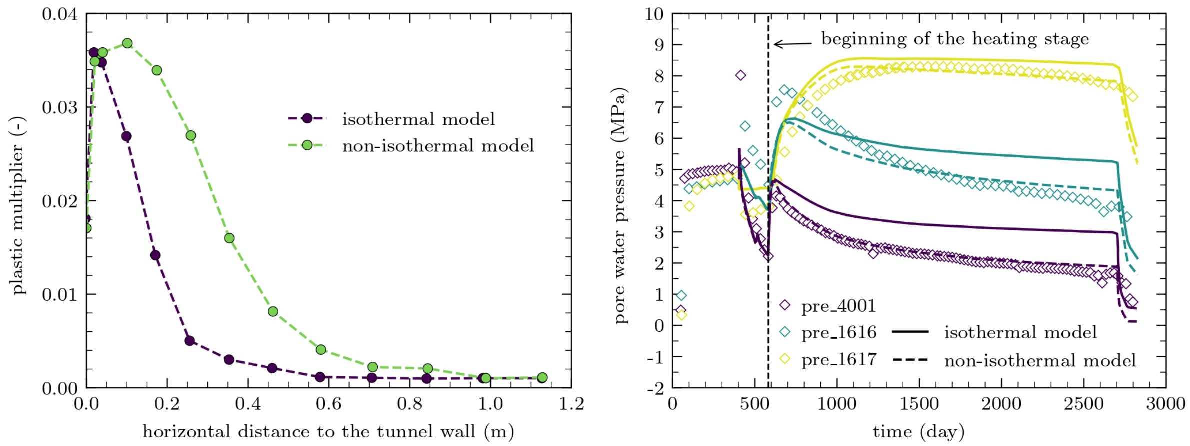

Figure 2. Computed plastic multiplier increment distributions at the end of heating in horizontal distance to the tunnel wall (left), Evolution of pore pressure increments at various points in the COx claystone: observed and computed results (right).

Fig. 2b compares simulation outcomes with pore pressure measurements, including results from an isothermal model. Results with the non-isothermal model are significantly closer to field values when consolidation dominates the pore-water pressure behavior. The latter is the result of a larger extension of the fractured zone, causing the permeability increase with damage to occur further into the claystone, resulting in lower pressures that are more consistent with field values. These observations suggest that the evolution of mechanical parameters with temperature might result in some limited enlargement of the fractured zone during heating.

References

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