Application of Thermo-Hydro-Mechanical Damage Model on Triaxial Test of Granite

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1. Introduction

In a repository for radioactive waste disposal, the coupled thermo-hydro-mechanical (THM) behavior in porous media is one of the important issues from the perspective of a long-term safety concerns. Formation of microcracks, which is primarily caused from damage evolution in a repository are essential consideration in the evaluation of the long-term performance of waste disposal system. The accumulation of damage induces changes in the mechanical, hydraulic, and thermal properties of the rock.

The objective of this study is to propose the coupled thermo-hydro-mechanical damage (THMD) model to investigate the time-dependent deformation and failure process of rock.

2. Approach

In the model development, Young's modulus, permeability and thermal conductivity of rock are changed in accordance to damage evolution. The THMD model development is primarily performed by COMSOL Multiphysics ver. 5.3. Two-phase Darcy's law, solid mechanics and heat transfer in porous media modules are used in this study. The model includes the accumulation of damage applied to individual elements, which modifies the modulus, permeability and thermal conductivity. With regard to the damage model application to THMD development, Mazars damage model is used in the structural mechanics module and it is incorporated into COMSOL as an external material in this study (www.comsol.com/blogs).

3. Model setup

The mode geometry is presented in Fig. 1 below. A cylindrical apparatus with a 10 cm diameter and a 20 cm height, presses the rock sample from the top by a prescribed pressure (50 MPa). The sample is radially constrained by a pressure of 10 MPa.

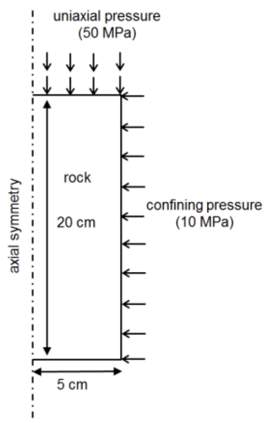


Fig. 1. Dimensions and loading condition for triaxial test.

Governing equations for water and gas phases used in the model development are as follows:

$$\rho_w S \frac{\partial p^w}{\partial t} + \nabla \rho_w \left\{ -\frac{k k^{rw}}{\mu^w} \cdot (\nabla p^w) \right\} = Q_m \quad (1)$$

$$\rho_g S \frac{\partial p^g}{\partial t} + \nabla \rho_g \left\{ -\frac{k k^{rg}}{\mu^g} \cdot (\nabla p^g) \right\} = Q_m \quad (2)$$

where S is a storage coefficient, which can be interpreted as weighted compressibility of the bulk aquifer material and the fluid in the pores. Q_m is a mass source term.

Damage is described by two different evolution laws under tension and compression in Mazars' damage model.

$$D = \alpha_t * D_t + \alpha_c * D_c \quad (3)$$

$$D_t(k) = 1 - \frac{k_0(1-A_t)}{k} - A_t e^{B_t(k-k_0)} \quad (4)$$

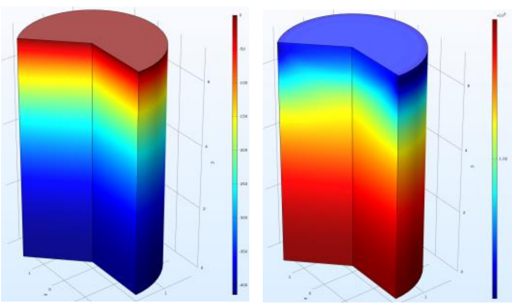
$$D_c(k) = 1 - \frac{k_0(1-A_c)}{k} - A_c e^{B_c(k-k_0)} \quad (5)$$

where D is total damage, D_t and D_c indicate tensile and compressive damage. A_t, B_t, κ_0, A_c, and B_c are material parameters which can be determined by experiments.

4. Main Results

4.1 Variation of thermal and hydraulic properties

Fig. 2 shows the changes of porewater pressure and corresponding gas pressure with time.



(a) porewater pressure (b) gas pressure

Fig. 2. Pressure variation at 100d under THM triaxial test.

4.2 Damage evolution under THM triaxial test

Damage evolution of rock is presented in Fig. 3. Deviatoric stress of 40 MPa causes the maximum degree of damage of 0.12 in the THM triaxial test. The additional displacement of a specimen has been produced due to the temperature rise. This is attributed to the fact that thermal expansion term is additionally taken into account in contrary to HM test condition.

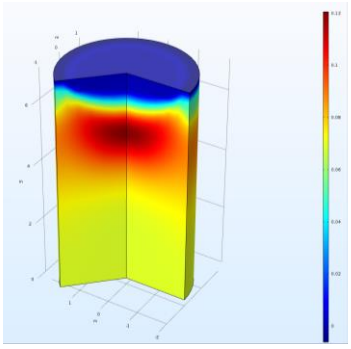


Fig. 3. Damage evolution at 1000d under THM triaxial test.

5. Conclusion

The THM model development in which damage evolution is taken into account can contribute to the better prediction of THM behaviors in a nuclear waste repository.

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