NUMERICAL ANALYSIS STUDY ON SWELLING CHARACTERISTICS OF COMPACTED BENTONITE BLOCKS CONSIDERING THERMAL EXPANSION OF OEDOMETER EQUIPMENT UNDER HIGH TEMPERATURE CONDITIONS

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Introduction

- A geological repository system includes a disposal canister containing spent nuclear fuel, along with buffer material, backfill, and the surrounding intact rock (Fig.1). Among these components, the bentonite buffer plays a crucial role in ensuring the safe disposal of high-level radioactive waste (HLW).
- Compressed bentonite, which is used as a buffer material in a high-level radioactive waste disposal site, has the characteristic of swelling due to groundwater infiltration in the initial disposal stage. At this time, if the swelling pressure is excessively low or high, there is a possibility that the movement of radionuclides may increase or the long-term stability of the disposal system may be impaired. Therefore, it is essential to precisely design the properties of compressed bentonite so that an appropriate swelling pressure can be maintained.
- In this study, a numerical analysis model is proposed to evaluate the swelling behavior of compressed bentonite blocks in an environment similar to field conditions. In particular, the swelling characteristics of bentonite blocks were analyzed by considering the thermal expansion effect of the oedometer equipment in a high-temperature environment.

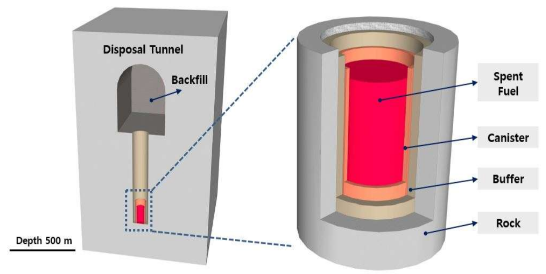


Fig 1. Schematic view of the engineered barrier system (EBS).

Methodology

- The sample used in this experiment was KJ-II bentonite, and various specimens with initial dry densities ranging from 1.28 to 1.85 g/cm³ were prepared.
- The test sample was molded to a diameter of 5 cm and a thickness of 1 cm, and was mounted on a dedicated Oedometer cell to measure the swelling pressure under vertical restraint.
- In addition, water was slowly injected from the bottom through a porous disc to induce the sample to swell.
- The swelling pressure generated during the test was precisely measured through a load cell, and the test data was automatically recorded through a control pad.

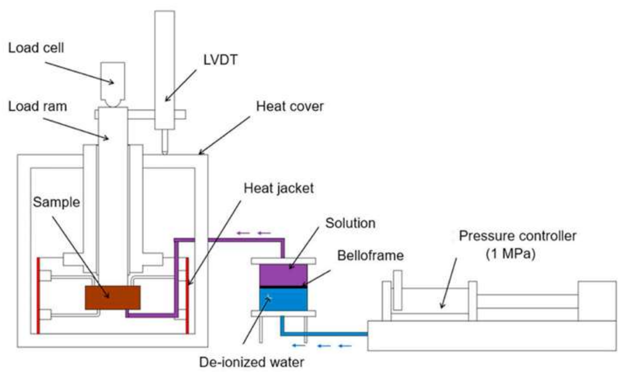


Fig 2. Schematic view of the oedometer and pump controllers (Kim et al., 2021).

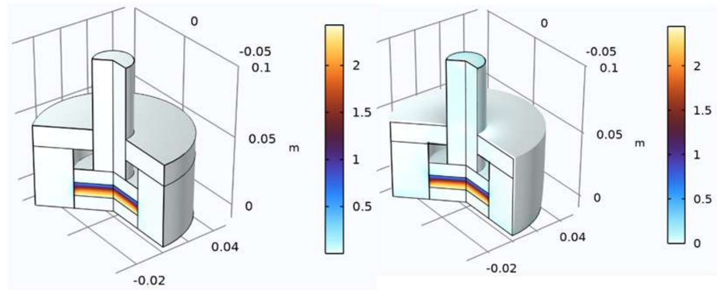
- In the numerical study, the swelling behavior of bentonite was assessed by incorporating it into an elastic constitutive model based on the generalized Hooke's law (Narkuniene et al., 2022).

$$\rho_w \cdot \left(\frac{C_m}{\rho_w g} + S_e \cdot S \right) \frac{\partial p_l}{\partial t} + \nabla \rho_w \left(-\frac{k_s}{\mu} \cdot k_r \cdot (\nabla p_l + \rho_w \cdot g \cdot \nabla z) \right) = Q_m \quad (1)$$

$$\sigma_{ij} = C^e_{ijkl} \cdot (\varepsilon_{kl} - \varepsilon^{sw}_{kl}) \qquad \varepsilon^{sw}_{ij} = \beta^{sw} n \Delta S_e \delta_{ij} \quad (2)$$

where σ_{ij} represents the stress tensor, C_{eijkl} is the material stiffness tensor, ε_{kl} is the total strain tensor, and ε_{klsw} signifies the strain tensor owing to wetting-induced swelling. β_{sw} represents the swelling coefficient for isotropic materials, ΔS_e is the change in effective saturation, and δ is the Kronecker delta.

Results and Conclusions



(b) 30 ℃ (b) 90 ℃

Fig 3. Comparisons of von Mises stress between different temperature conditions

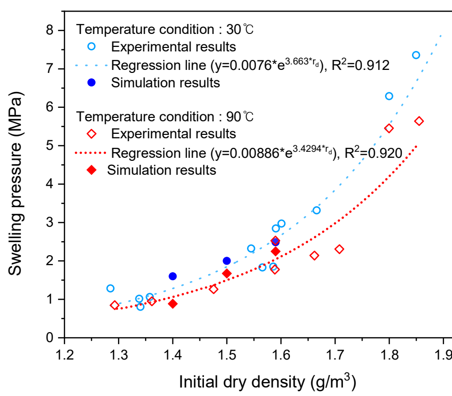


Fig. 4. Comparisons of swelling pressures between experiments and simulations

- Based on the experiment results, at a temperature of 30 ○C, initial dry density change had a more significant influence on swelling pressure variations.
- The effect of temperature on the swelling of KJ bentonite showed a negative correlation overall. However, for conditions with very low initial dry density, the effect of temperature was relatively minimal.
- The thermal expansion of the oedometer equipment occurring in high-temperature conditions significantly affects the swelling behavior of compressed bentonite blocks.

Acknowledgements

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Reference

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