SWELLING PRESSURE AND WATER DIFFUSIVITY OF SODIUM-BENTONITE SATURATED BY DIFFERENT SOLUTIONS UNDER CONFINED WETTING

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1. Introduction

Compacted bentonites were selected by different countries as buffer material in deep geological disposal method for handling high level radioactive waste. Swelling pressure and water diffusivity, which are two important ingredients for compacted bentonites, were greatly reached by numerous scholars using distilled water. In Japanese program, a disposal facility will be constructed in coastal area for the feasibility of waste transportation (Komine et al. 2009). Therefore, subterranean water chemistry effect on mechanical characteristics of compacted bentonite should be further assessed.

2. Material, testing apparatus and testing mythology

MX80 bentonite with 78% montmorillonite content was used in this study. This bentonite is a sodium type bentonite from sodium bentonite from Wyoming, USA..

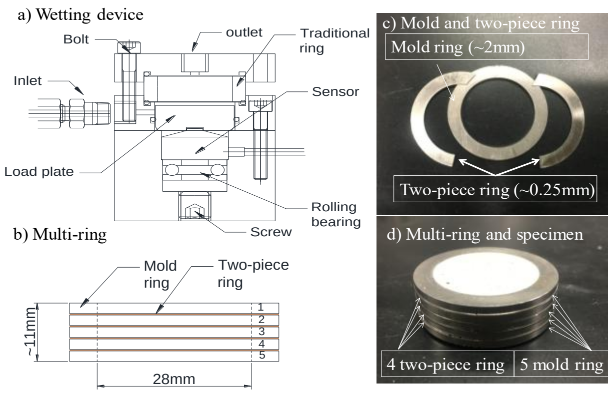

Fig. 1 Wetting device and multi-ring mold

The apparatus used for swelling pressure is portrayed in Fig. 1(a). This newly developed swelling pressure apparatus has a mold ring of 10 mm height and 28 mm diameter sandwiched by a top cap and load plate to restrict lateral and vertical displacement. Stress from the specimen is transferred to the load plate, by which it is measured by a sensor and recorded with a data logger. Under the sensor is a screw. By rotating it, one can ensure that no distance remains between the load plate and specimen. For this study, the mold ring was changed to a multi-ring mold (Fig. 1(b)). The multi-ring mold comprises five mold rings (2 mm thickness) and four two-piece rings (0.25–0.30 mm thickness) installed between mold rings (Fig. 1(c)). All experimental devices mentioned above were made by an anti-erosion metal in Japan (SUS316L). After air dried powders were putted into the multi-ring mold, they were compressed in a static load device to achieve 11 mm height, 28 mm diameter (Fig. 1(d))., and 1.40 g/cm^3 target dry density. Distilled water (DIW), 0.5M NaCl and 0.5M $CaCl_2$ were used as saturation liquids. In each condition, 7 specimens were prepared for dismantling times of 2 h-240 h. The specimen details are presented in Table 1. After wetting different durations, multi-ring molds were taken out and vertical deformation of the multi-ring mold was constrained by clip immediately. Later, two-piece rings were removed. The specimen was sliced carefully into five slices using a thin saw. Later, moisture of each slice was measured.

Table. 1 Test conditions

Material	Montmorillonite content (%)	Dry density (g/cm^3)	Uncovered Time (h)	Solutions
MX80	78	1.4	2, 4, 8, 24, 48, 120 and 240	DIW, 0.5M NaCl and $CaCl_2$

3. Test results

Water diffusivity

The distributions of gravimetric water contents in specimens after water absorption are presented in Fig. 2. It is a general truth from Fig. 2, gravimetric water content increases as the position close to the water supply end and as time increases.

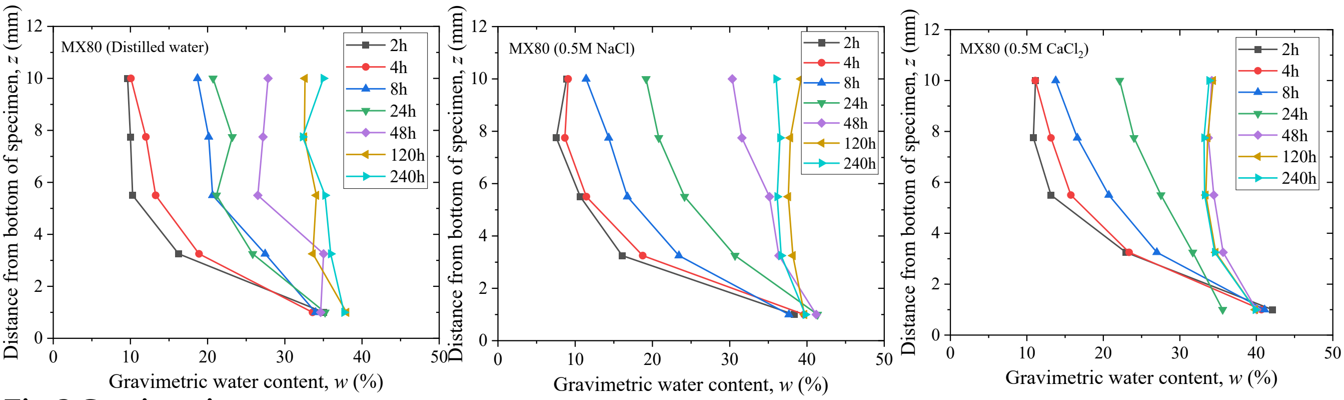

Fig. 2 Gravimetric water contents

Darcy equation related the diffusivity of water in soil (D) and volumetric water content (θ) as:

(1) $\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(D(\theta)\frac{\partial \theta}{\partial z}\right)$

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However, it is very hard to achieve water diffusivity from equation (1). Klute and Dirksen (1986) took $\chi = z/\sqrt{t}$ into equation (1), and used Boltzmann transformation change partial differential equation into ordinary differential one as:

(2) $D(\theta) = -\frac{1}{2}\left(\frac{d\chi(\theta)}{d\theta}\right)\int_{\theta_0}^{\theta_s}\chi(\theta)\,d\theta$

where θ_0 signifies the initial volumetric water content (%) and θ_s stands for the saturated volumetric water content (%). In this study, specimens were cut into slices of equal height to measure water diffusivity. However, this method has a certain dispersion, which is caused by the discrete type of water content distribution in each slice after the experiment is stopped at different times. Wang et al. (2020) tried to use mathematical methods to fit the relation between χ and θ in this method. As Wang et al. (2020) reported, relation between χ and θ can be expressed as:

(3) $\chi(\theta) = A - B\ln(\theta - C)$

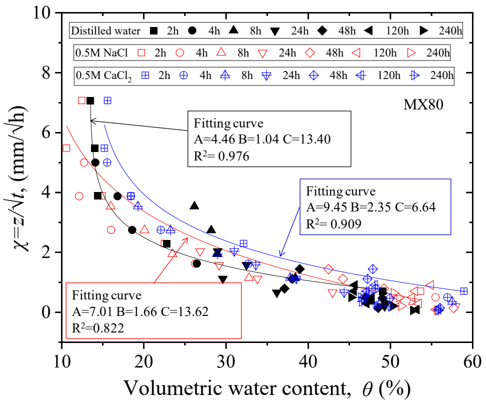

Fig. 3 Relation between θ and χ

where A, B and C are fitting parameters with testing data. By bringing equation (3) into equation (2), the equation for calculating water diffusivity can be formed as:

(4) $D(\theta) = \frac{AB}{2} - \frac{B^2}{2}(ln(\theta - C) - 1)$

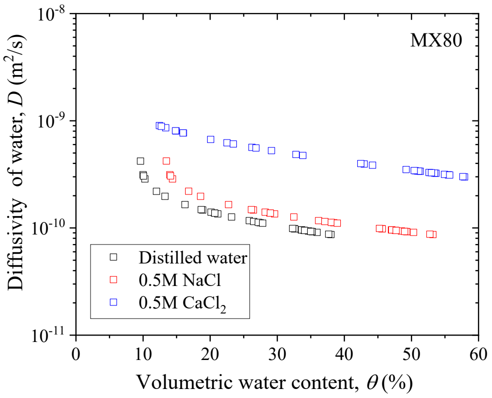

Fig.4 Water diffusivity of MX80

Figure 3 presents the relation between θ and χ for bentonite saturated by different solutions. It is apparent from Fig. 3 that experimental data follows good with equation (3). Thus, the calculation for water diffusivity in this study can follow equation (4). Figure 4 depicts water diffusivity changes with the volumetric water content. A ready conclusion can be drawn from Fig. 4 that water diffusivity decreases concomitantly with increasing volumetric water content. Same phenomenon could be found from Wang et al. 2020. Another conclusion can be made from Fig. 4 that, MX80 saturated by $CaCl_2$ has bigger diffusivities than NaCl. Distilled water has smaller water diffusivity than salt solutions.

Swelling pressure

Figure 5 presents the change of swelling pressure with time. As mentioned in numerous studies (Wang et al., 2020), the development of swelling pressure for low dry densities compacted bentonites can be divided into four stages in chronological order: 1) initial quick increase stage, 2) drop stage, 3) re-increase stage, and 4) long-term stable stage. It is apparently from Fig. 5, swelling pressures increase quickly during the first approx. 5h. Swelling pressures subsequently drop at approx. 25 h. Later, stable rising of swelling pressures occurs. Finally, swelling pressure remains a constant value for long time. Fig. 5 also show that final swelling pressure (from 240h) saturated by $CaCl_2$ is bigger than that saturated by NaCl. Distilled water has bigger final swelling pressure than salt solutions.

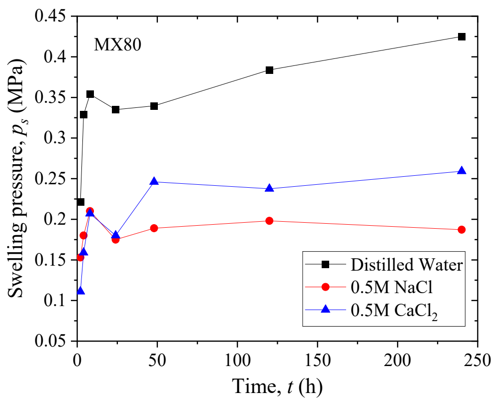

Fig.5 Change of swelling pressure with time.

4. Conclusion

1) Water diffusivity decreases with the increase of water content. MX80 bentonite saturated by $CaCl_2$ has bigger water diffusivities than NaCl, when their concentrations are the same. Distilled water has smaller water diffusivity than salt $CaCl_2$ and NaCl solutions.

2) Final swelling pressure saturated by $CaCl_2$ is bigger than that saturated by NaCl. Distilled water has bigger final swelling pressure than salt solutions.

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