Influence of different ion on the infiltration behavior of salt solution into compacted K_V1 bentonite

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1. Introduction

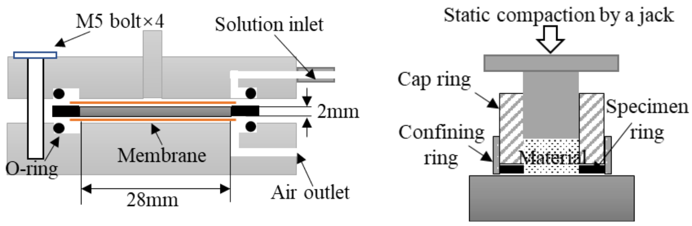
Deep geological disposal is the preferred option for the final storage of high-level radioactive waste (HLW) in many countries. Compacted bentonite is a potential candidate in the deep geological disposal owing to its high swelling behavior and low hydraulic conductivity. However, the infiltration of surrounding groundwater containing variety of chemical components could significantly affect the properties of buffer/backfill materials. The infiltration of the salt solutions into bentonite which enhances the concentration of ions inside the pore fluid and therefore inhibit the swelling behabvior of compacted bentonite (Karnland *et al*. 2007; Komine *et al*. 2009). Therefore, it is needed to investigate the infiltration behavior of salt solution into compacted bentonite. In this study, infiltration tests were conducted on compacted 2mm thickness K_V1 bentonite specimens with different solutions (NaCl and KCl) ranging from 0-2 mol/L. After the infiltration test, the leached ion of the specimen was measured using the benzyltrimethylammonium chloride (BTM) method (Shirakawabe *et al*. 2022), and the ion concentration of the infiltration solution was calculated.

2. Materials, Equipments and Procedures

A commercial bentonite, Kunigel V1 (K_V1) was used for this study. Fundamental properties and their values of K_V1 bentonite can be seen in Table 1. Two test programmes, iucluding the infiltration test and leached cation measurement test, were conducted in this study. The schematic illustration of the apparatus proposed by Wang *et al*.(2022) for infiltration test is shown in Fig. 1(a). The specimen is confined in a mold ring with an inner diameter of 28 mm and the height of 2 mm. A stainless-steel base plate fastened by four M5 bolts with top plate is used to confine specimen deformation. Solution is supplied to a specimen passing a solution inlet and spread through a membrane filter which can also prevent significant deformation itself due to swelling of specimen. As illustrated in Fig. 1(b), specimens were prepared through static compaction using an oil jack, and the details are provided in the eariler report (Wang *et al*. 2022). Table 2 provides general informations regarding the infiltration test. When the infiltration test was finished, the specimen was taken out and wet mass was measured. After that, the specimen was dried in the oven at 110°C for 24 hours and then the dried mass of specimen was measured to calculate the final water content of specimen. In leached cation measurement test, every specimen after dried was grinded to a powder state. About 0.5g powder sample was mixed with 50 mL of a 6% BTM solution. For ensuring the completation of cation exchange between the specimen and the solution, the mixture was subjected to 24 hours shaking and then sent to 20 minutes of ultrasonic dispersion. After centrifuging at 3000rpm for 5min, the leached ion concentration of the mixture supernatant was measured with ICP-OES.

Table 1 Fundamental properties of K_V1 bentonite

Soil properties	Values
Soil particle density (g/cm^3)	2.776
Liquid Limit (%)	504.8
Plastic Limit (%)	44.8
Plasticity Index	460
Montmorillonite content (%)	54.3
CEC [cmol(+)/kg]	78.4
LC (Na^+) [cmol(+)/kg]	62.2
LC (Ca^+) [cmol(+)/kg]	44.5
LC (Mg^+) [cmol(+)/kg]	1.8
LC (K^+) [cmol(+)/kg]	0.2



(a)Layout apparatus
(b) Schematic illustration of specimen compaction

Fig. 1 Test apparatuses and specimen preparation method

Table 2 Infiltration test plan in this study

Specimens	Initial dry density range (g/cm^3)	Initial water content range (%)	Infiltration time (h)	Ion concentration (mol/L)
No.1-5 No.6-10	1.497-1.506	8.59-9.40	24	0/0.1/0.5/1/2 M NaCl 0/0.1/0.5/1/2 M KCl

3. Test results and discussion

Table 3 shows the final water contents of specimens infiltrated by different solutions. The results of leached ion of specimens were showed in Fig. 2. It can be observed from Fig.2 (a) that as the ion concentration of the supplied NaCl solution increases, the leached sodium ions of the specimen significantly increase. For the case of the supplied

Bentonite; infiltration behavior; ion concentration

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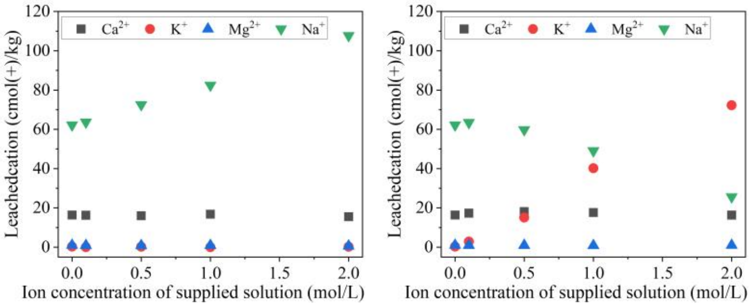
KCl solutions, the leached potassium ions from the specimens increased substantially with the increase of solution concentration, however the leached sodium ions from the specimens decreased significantly. Explanations to this phenomenon could be that according to the cation exchanging capacity of Na+ is smaller than that of K+ (Mitchell and Soga 2005). K_V1 bentonite is a kind of sodium bentonite; some Na+ were replaced by K+ with the infiltration of KCl solution, resulting in the decrease of the leached sodium ions from the specimens which infiltrated by the supplied KCl solution.

Table 3 Results of final water content (%)

Solution	0mol/L	0.1mol/L	0.5mol/L	1mol/L	2mol/L
NaCl	34.12	32.88	37.05	36.80	35.75
KCl	34.12	34.52	34.22	33.92	30.75



(a) NaCl solutions (b) KCl solutions

Fig. 2 Leached cations of specimen under different solutions

In the infiltration test, ion infiltrated into the compacted K_V1 bentonite with water together, leading to the increase of leached ions of the soil. Therefore, the increase of leached ions and final water content of the specimen can be used to calculate the ion concentration of the infiltration solution with the following formula (1):

$$C_{Inf} = \frac{LC_i(x^+) - LC_0(x^+)}{w_{fi} - w_{fi0}} \cdot \frac{1}{100\rho_w} \quad (1)$$

Here, C_{inf} is the ion concentration of the solution infiltrating into specimen (mol/L); $LC_i(x^+)$ and $LC_0(x^+)$ are the leached x ions of specimen under i and 0 mol/L x solution (cmol(+)/kg), respectively; w_{fi} and w_{fi0} is the final water content of specimen before and after being infiltrated by the i mol/L x solution (%), respectively; and ρ_w is the free water density (=1.0kg/L).

The relationship between supplied solution concentration and the ion concentration of the solution infiltrating into compacted K_V1 bentonite is shown in Fig. 3. It can be observed that the concentration of sodium ion of the solution infiltrating into the compacted K_V1 bentonite is lower than that of the supplied solution. For the supplied KCl solution with a concentration of 0.1mol/L, the concentration of potassium ion of the solution infiltrating into the compacted K_V1 bentonite is lower than that of the supplied solution. As the concentration of the supplied solution increases, the ion concentration of the solution infiltrating into the compacted K_V1 bentonite is greater than the ion concentration of the supplied solution. Higher concentration of the infiltration means more K^+ ion infiltrate into the compacted K_V1 bentonite. The replacement of Na^+ ions with K^+ ions may contribute the higher potassium ion concentration of the infiltration solution. And the potassium has an ionic diameter 2.66 Å, which is almost the same as the diameter of the cavity in the oxygen layer of smectite. Due to the lower hydration energy of potassium ions and steric reasons, the potassium ions can fit into the cavity which is a hexagonal oxygen ring (Kaufhold and Dohrmann, 2010). The K^+ fixation may also be one of the reasons for the higher potassium ion concentration of the infiltration solution.

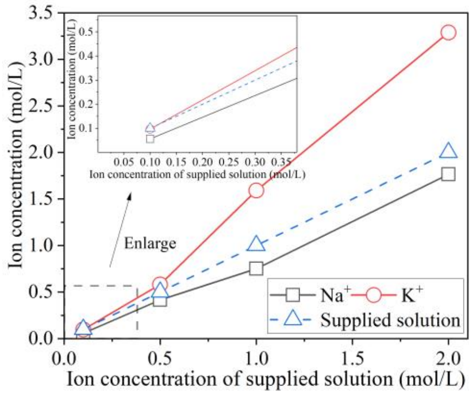


Fig. 3 Relationship between supplied solution concentration and infiltration solution concentration

4. Conclusions

1) The Na^+ concentration of the solution infiltrating into the compacted K_V1 bentonite is lower than that of the supplied NaCl solution. 2) The K^+ concentration of the solution infiltrating into the compacted K_V1 bentonite is greater than that of the higher supplied KCl solution. 3) The replacement of Na^+ ions with K^+ ions and the K^+ fixation may be the cause of higher potassium ion concentration of the infiltration solution.

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