Effect of temperature on equilibrium swelling pressure of bentonites

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1. Introduction

Bentonite was selected as the candidate buffer material in deep geological disposal project for dealing with high level radioactive waste (HLW) from nuclear power industry. High self-healing capacity is very important characteristics for avoiding the leakage of nuclide waste in such a long-term operation period. Swelling pressures, especially equilibrium swelling pressure (p_{eq}, see Ruan *et al.* 2022a, swelling pressure in saturated state) was viewed as important parameter to evaluate the self-healing capacity of bentonite.

Before HLW decays totally, a great amount of heat would be emitted from nuclide waste, thereby inducing the temperature increase in buffer material. The temperatures insider and outside the buffer material during the long-term operation period were reported varying from approxi. 45 °C to approxi. 95 °C NUMO by simulation (NUMO 1999). Therefore, it is necessary to investigate the temperature effect on equilibrium swellings of bentonites.

2. Material and Testing Methodology

This study used five bentonites: 1) Kunigel-V1, a sodium type bentonite from Tsukinuno Mine, Yamagata, Japan; 2) Volclay, a sodium type bentonite from Wyoming, USA; 3) Kunibond, a calcium type bentonite from Dobuyama Mine, Miyagi, Japan; 4) MX-80, a sodium type bentonite from Wyoming, USA; and 5) Kunigel-GX, a sodium type bentonite from Tsukinuno Mine, Yamagata, Japan. Physical properties and their values of these three bentonites can be seen in Table 1 from Ruan *et al.* (2022a)

Table 1 Physical properties of bentonites and their values (from Ruan *et al.* 2022a)

		Kunigel-V1	Volclay	Kunibond	MX-80	Kunigel-GX
Bentonite type		Na	Na	Ca	Na	Na
Grain size		Powder	Powder	Powder	Granular	Granular
Soil particle density (g/cm^3)		2.76	2.84	2.63	2.88	2.64
Liquid limit (%)		468.1	565.4	128.7	437.3	345.9
Plastic limit (%)		29.1	47.2	58.4	28.7	33.4
Plasticity index (%)		439	518.2	70.3	408.6	312.5
Montmorillonite content (%)		50	72	78	61	45
CEC, Total cation exchangeable capacity (meq/100 g); EXC, amount of extractable cations (meq/100 g)	CEC	88.4	103.2	120.3	79.3	85.6
	EXC_{Na}	53.3	57.2	40.8	41.3	61.8
	EXC_{Ca}	33.7	32.8	69.3	29.6	8.3
	EXC_{Mg}	1.3	12.8	9.1	8	15.3
	EXC_{K}	0.1	0.4	1.1	0.4	0.2

At the beginning, bentonites were dried in oven at 110 °C for approx. 48 h. Subsequently, oven dried bentonite samples were put into 10 mm-height and 28-mm inner diameter rings and were compressed in a static load device. Then, the surfaces of the specimens were trimmed. After that, specimens were installed in the swelling pressure apparatus (Fig. 1, details for swelling pressure can be seen in Ruan *et al*. 2022b). For controlling the testing temperatures, the whole testing system, including the water supply container and the swelling pressure apparatus with specimen, was put into oven with setting temperature (Fig. 1). Before the water was supplied, the whole testing system was placed in the oven for approx. 4 h in order to let specimen and distilled water reach setting temperatures. In this study, 25, 50, and 80 °C were selected as the temperatures for swelling pressure tests. The temperature inside buffer material varies from approx. 45 °C to approx. 95 °C as introduced above. Thus, 50 and 80 °C were chosen as the experimental temperatures. Besides that, 25 °C was adopted as the room temperature case.

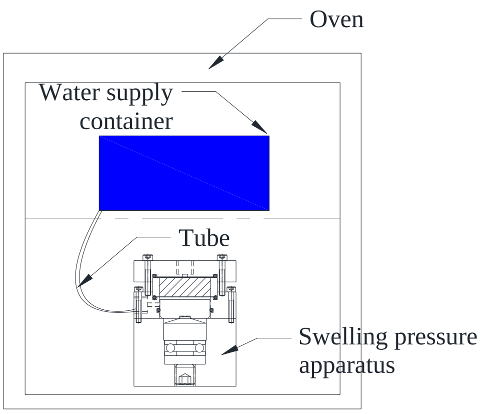

Fig. 1 Schematic showing swelling pressure tests at different temperatures.

Bentonites Temperature Equilibrium swelling pressure
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3. Results

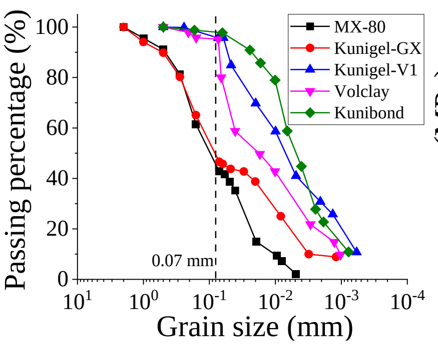

Fig. 2 Grain size distributions of bentonites

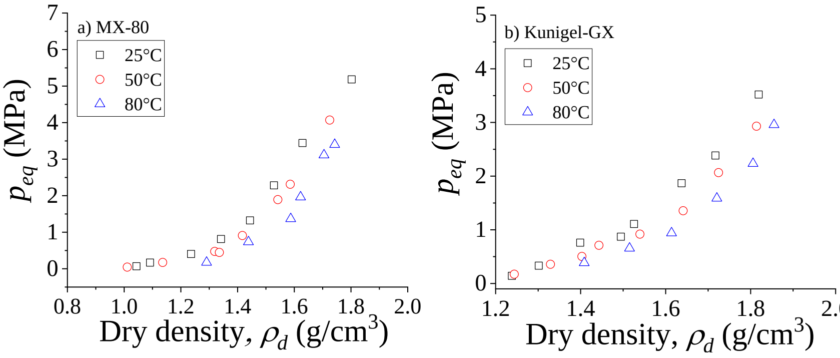

Fig. 3 Equilibrium swelling pressure of granular bentonites

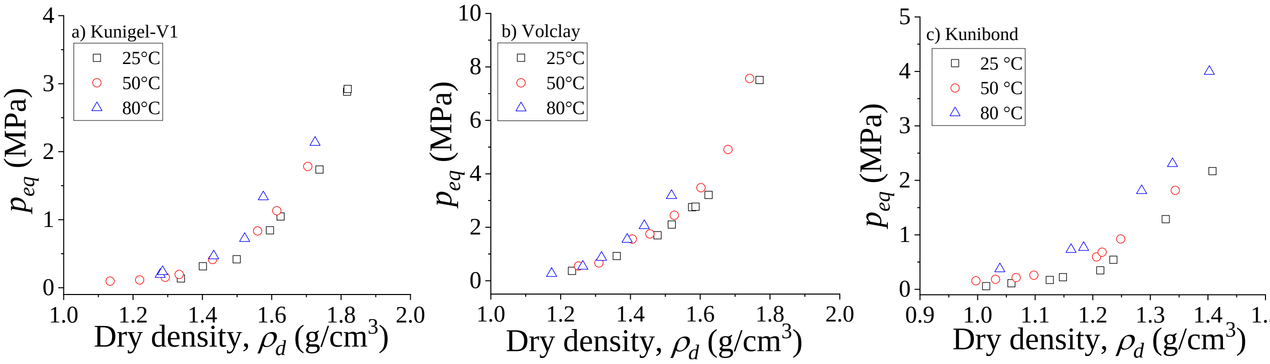

Fig. 4 Equilibrium swelling pressure of powder bentonites

Grain size distributions of bentonites are presented in Fig. 2. More details for the grain size distribution test can be seen in Ruan *et al.* (2022a). It is apparent from Fig. 2 that grains larger than 0.07 mm of MX-80 and Kunigel-GX are both over 50%, which shows that granular soils dominate the contents of MX-80 and Kunigel-GX bentonites. For this study, MX-80 and FEBEX were designated as granular bentonites. For Kunigel-V1, Volclay, and Kunibond bentonites, 95% of grains were smaller than 0.07 mm, reflecting that powder soils account for most of the composition. Thus, Kunigel-V1, Volclay, and Kunibond are designated as powder bentonites.

Figure 3 shows equilibrium swelling pressure of granular bentonites (MX-80 and Kunigel-GX) at different temperatures. The MX-80 equilibrium swelling pressures at different temperature conditions are presented in Fig. 3(a). The conclusion for MX-80 can be found easily from Fig. 3(a): p_{eq} decreases with rising temperature. Figure 3(b) exhibits p_{eq} of Kunigel-GX at 25, 50 and 80 °C. It is apparent from Fig. 3(b) that p_{eq} of Kunigel-GX decreases as temperature increases. Two granular bentonites used for this study both have smaller p_{eq} in higher temperatures.

Figure 4 reveals the values of p_{eq} obtained for powder bentonites (Kunigel-V1, Volclay and Kunibond) at different temperatures. Kunigel-V1 equilibrium swelling pressures at 25, 50 and 80 °C are presented in Fig. 4(a). As Fig. 4(a) shows, p_{eq} of Kunigel-V1 increases with increasing temperature. Figure 4(b) exhibits p_{eq} of Volclay at different temperatures. It can be clarified from Fig. 4(b) that, for Volclay, p_{eq} rises with the increase of temperature. Equilibrium swelling pressures at 25, 50, and 80 °C of Kunibond are shown in Fig. 4(c). Unlike the two sodium powder bentonites described above, the Kunibond bentonite examined for this study is a calcium type bentonite. The trend implies readily for Kunibond from Fig. 4(c) that p_{eq} increases as temperature rises. A summary of temperature effects on p_{eq} of these three powder bentonites indicates a clear general tendency: p_{eq} increases with rising temperature.

4. Conclusions

For Kunigel-V1, Volclay and Kunibond (powder bentonite in this study), equilibrium swelling pressure increased as temperature increases. In the cases of MX-80 and Kunigel-GX (Granular bentonite in this study), equilibrium swelling pressure decreased with increasing temperature.

Reference: (1) JNC 1999. Technical reliability of the geological disposal for high level radioactive waste in Japan geological disposal research and development. Second compiled General report. Japan Nuclear Cycle Development Institute, JNC TN1400 99–020, IV-80. (In Japanese). (2) Ruan, K., Wang, H., Komine, H., and Ito, D., 2022a. Experimental study for temperature effect on swelling pressures during saturation of bentonites, Soils and Foundations, 62 (6): 101245. https://doi.org/10.1016/j.sandf.2022.101245. (3) Ruan, K., Komine, H., Wang, H., and Ito, D., 2022b. Experimental study of initial water content and specimen preparation method effects on Kunigel-V1 bentonite swelling pressures, Canadian Geotechnical Journal, Ahead of Print, https://doi.org/10.1139/cgj-2021-0532