Comparison of unconfined compressive strength on heated bentonite-sand mixture by chemical exposure

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ABSTRACT

The construction design of deep geological repositories for high-level radioactive waste (HLW) consist of the construction of a barrier system around the waste containers produced by a sealing hard stiffness material. In this paper, thermal-hydraulic-mechanical-chemical properties of bentonite-sand were presented for geological and engineered barrier through Na-type bentonite. Unconfined compressive strengths were measured, and compared under unsaturated/saturated condition, with/without heating effect and/or chemical exposure due to salt components. Saturated specimens were swelled both distilled water and salt water with salt component of 3.5 %. Also, heating effort leaded decreasing of unconfined compressive strength for saturated bentonite-sand samples.

Keywords: bentonite, heating, salt water, unconfined compressive strength

1 INTRODUCTION

The construction design of deep geological repositories for high-level radioactive waste consist of the construction of a barrier system around the waste containers produced by a sealing hard stiffness material (Delage et al., 2010). The barrier system used bentonite, which is extremely low permeability, high swelling capacity, high soil water retention and strong strength. The safety concept of engineered barrier system is determined by the characteristics of unsaturated/saturated bentonite including Chemo-thermo-hydro-mechanical properties (Gens et al., 2007). These causes are radioactive decay that heating generated from waste and seepages from host rock surrounding barrier. For the evaluation of the long period to behavior of engineered barrier system it is very important that understanding hydraulic process from host rock, thermal effect due to heating supply produced by canister and chemical solution by salt component. These causes were recognized as Chemo-thermo-hydro-mechanical (CTHM) loadings to bentonite-sand, and CTHM behavior was widely studied, conducted out on previous works. In the laboratory, several studies on the hydraulic-mechanical behavior and thermal-hydraulic-mechanical behavior was performed (Wersin et al., 2007 and Chen et al., 2017).

In this paper, some advances on the chemo-thermo-hydro-mechanical properties of bentonite-sand were presented for geological and engineered barrier through bentonite. Unconfined compression strength was focued on instead of shear strength obtained triaxial compression test. Unconfined compressive strength was compared under unsaturated/saturated condition, with/without heating effect and/or chemical exposure due to salt components. Some different bentonite-sand samples were prepared as following: Unsaturated specimen, saturated specimen due to swelling both distilled water and salt water having chemical component of 3.5 %, heated samples subjected to remaining of temperature of 20 and 80 degrees Celsius. All specimens had a dry density of 1.600 g/cm^3 with water content of 17.0 %. Unconfined compression tests were conducted at various compression speeds using a newly-developed thermal triaxial compression apparatus. Saturated bentonite-sand with/without chemical exposure provided the decreasing of unconfined compressive strength at a temperature of 80 degrees Celsius.

2 TEST PROCEDURE

2.1 Soil materials

Kunigel V1 was used in this testing program which was sodium bentonite. Kunigel V1 was used to measure hydro-mechanical properties at previous works. With its high content of montmorillonite, a bentonite had fines content larger than 95 %. Measured density of soil particles was 2.733 g/cm^3. Also, SiO_2 occupied 62 % as chemical components. For mixture, silica sand, named Iitoyo No.4, was used, which had highly unique grain size distribution obtained from grain seize analysis test. Maximum size was evaluated as 2.0 mm with sieve controlling. The mixture ratio of sand and bentonite, was 7:3 in dry weight.

After the bentonite-sand equilibrium to required

https://doi.org/10.3208/jgssp.v09.cpeg002

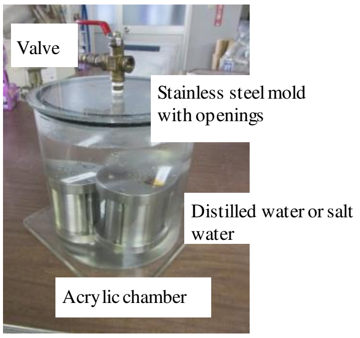
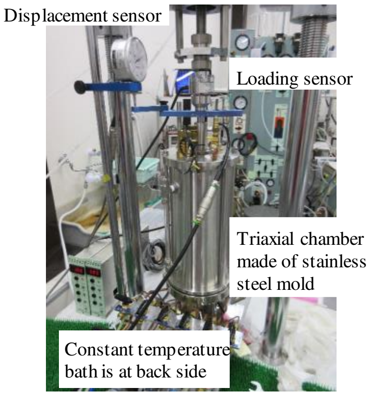


Photo 1. Swelling process in steel mold.



Phot. 2. Thermal triaxial apparatus.

water content of 17.0 %, specimens were compacted statically in the stiffness steel mold, and size of specimens were a diameter of 3.8 cm and a height of 7.6 cm. Initial specimens had a dry density of 1.600 g/cm^3, void ratio of 0.710 and degree of saturation of 65.61 % as physical variables. Also, when unsaturated specimen apply to saturation in swelling process, the stiffness mold was used as shown in Phot. 1. The specimen was saturated in acrylic chamber under constant initial volume that vacuum of supply remained at least one month. Degree of saturation using obtained water content at end of test realized saturation condition. Distilled water and salt water with concentration of 3.5 % were permeated through specimens.

2.2 Thermal triaxial apparatus

A newly-developed thermal triaxial apparatus was used for measurement of unconfined compressive strength of compacted bentonite subjected to thermal impact. The apparatus was indicated as shown in Phot. 2 which can controlled temperature for isotropic thermal phase. The specimen was placed on the pedestal in the inner cell made of acrylic material. The inner cell was covered the heating water tube, which was made of stainless steel with a spiral in sharp. The outer chamber was made of stiffness steel material and, had high resistance to heating impact. The measurement of compression stresses were performed using a load cell installed in the chamber, which had a resistance to high temperature, and the capacity of maximum temperature

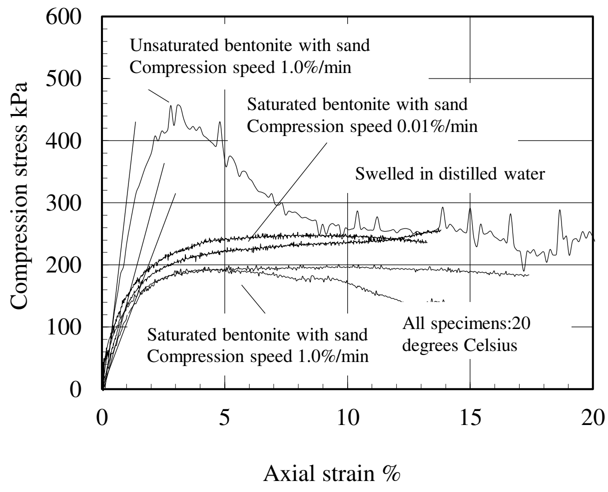


Fig. 1. Comparison between unsaturated/saturated specimens.

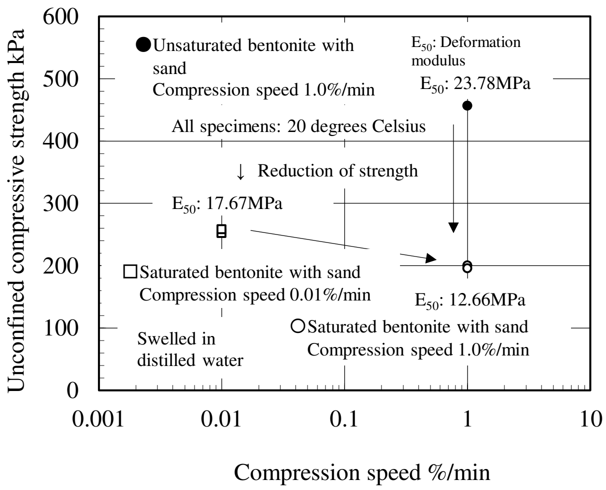


Fig. 2. Influence of compression speed on strength for saturated specimen at 20 degrees Celsius.

was 120 degrees Celsius. Axial deformation was measured using the dial gauge installed outside of the outer cell. A membrane with a thickness of 0.5 mm covered the whole specimen at both pedestal and cap. The temperature probe surrounding specimen measured the temperature of heating water supplied in the cell. The heating water tube was connected to constant temperature control bath placed at outside cell. 20 and 80 degrees Celsius were controlled in the constant temperature controlling water bath.

2.3 Unconfined compression test

Unconfined compression tests were conducted to evaluate the stress-strain curves with various compression speeds that range from 0.01 %/min to 1.0 %/min. While the compression proceeded without lateral confining pressure, the temperature was controlled in either 20 or 80 degrees Celsius. The influence of membrane used in specimen on shear resistance was assumed to be negligible. Summary of this testing program associated to THMC behavior was described in Table 1.

Table. 1. Summary of this test program.

Performance	Contents
Thermal	20 and 80 degrees
Hydration	Translation to saturation
Mechanical	Unconfined compression at a range from 0.01 %/min to 1.0 %/min
Chemical	Comparison salt water to distilled water

3 TEST RESULTS

3.1 Reduction of strength due to swelling

Stress and strain curves were indicated in Fig. 1 for unsaturated specimen and saturated specimen under various compression speed at constant 20 degrees Celsius. Unsaturated specimen produced a larger increment of compression stress at beginning. It was clear that large reduction was observed beyond a peak compression stress.

Saturated specimens approached maximum compression stresses at axial strain of about 5.0 %. It was found that resistance reduction was slight after unconfined compressive strength was evaluated. Relationship between compression speed and unconfined compressive strength (after this: strength) was descried in Fig. 2. Unsaturated test data was only one (symbol: ●) that exhibited the largest strength as compared to saturated test data sets. According to swell bentonite, it was essentially to delete suction due to both increment of soil moisture and reduction resistance of micro-macro structure. Also, the influence of increment of compression speed induced reduction of strength. Evaluated deformation modulus was provided in Fig. 2 that high strength had large deformation modulus.

3.2 Decrement induced by heating

Heating effort was applied that changing of temperature was from 20 degrees Celsius to 80 degrees Celsius for saturated specimen in distilled water. Compression stresses against axial strain were plotted in Fig. 3 for which the compression speed was constant at 1.0 %/min. While unconfined compression test, temperature was maintained either 20 or 80 degrees Celsius. Two stress and strain curves at 20 degrees Celsius had a fit well. Axial strain at peak compression stress value for specimen subjected to 80 degrees Celsius was smaller than that of 20 degrees Celsius condition. Increment of temperature produced reduction of strength as shown in Fig. 4. Stiffness showed about 50 % reduction to that of 20 degrees Celsius.

3.3 Influence of salt water

Saturated specimens were prepared that swelled in salt water with concentration of 3.5 %. Two difference compression speeds were applied at unconfined compression test that strengths were determined with evaluation of deformation modulus. Figure 5 showed

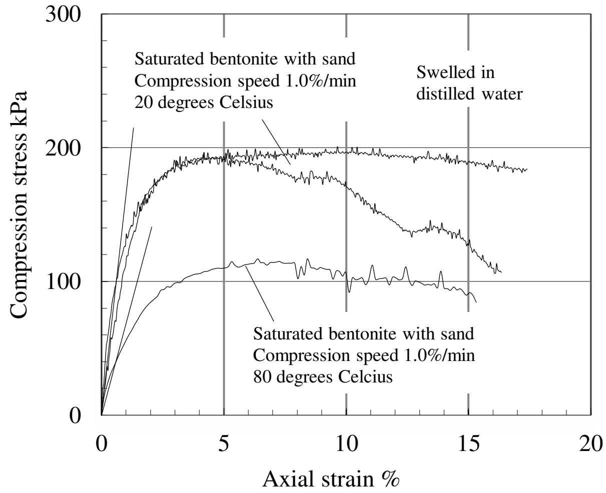


Fig. 3. Influence of heating effort on strength of saturated specimen.

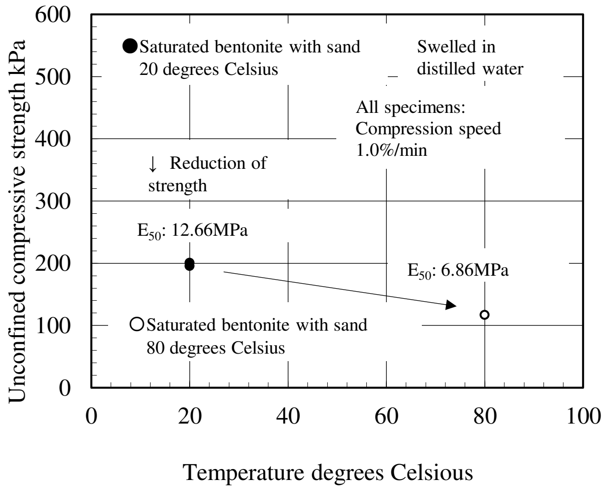


Fig. 4. Decreasing of strength according to temperature increment for saturated specimen in distilled water.

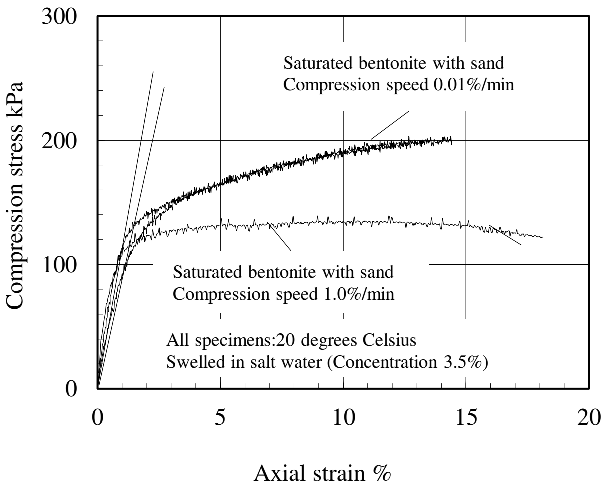


Fig. 5. Stress-strain curves of saturated specimen (salt water).

that stress and strain curves of series of 0.01 %/min had certainly repeatable. Two curves concerned, indicated a remaining of stresses with axial strain. Other hands, quite difference form was observed in series of

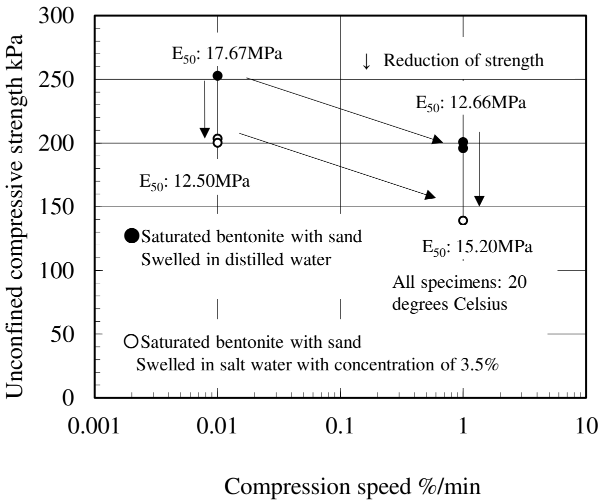


Fig. 6. Influence of salt water on strength at 20 degrees Celsius.

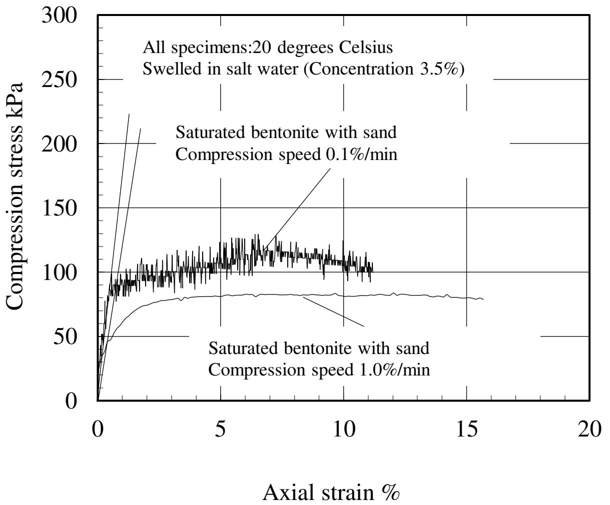


Fig. 7. Stress-strain curves with two difference compression speeds at 20 degrees Celsius.

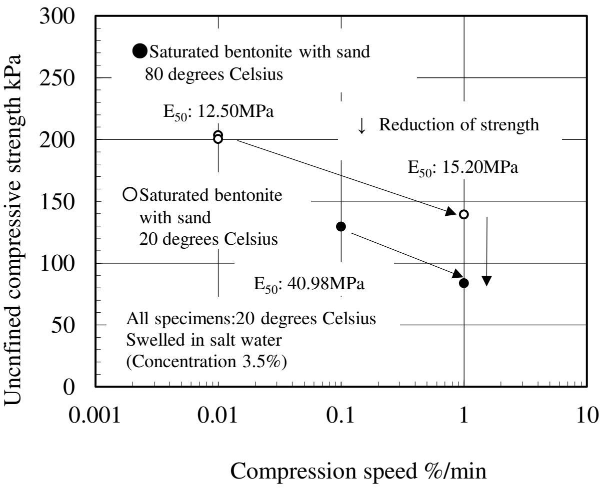


Fig. 8. Two factors revealed for saturated specimen swelled in salt water.

compression speed of 1.0 %/min. In order to verify strength of saturated having salt water, strengths were presented in Fig. 6 associated to data sets obtained from saturated specimen swelled in distilled water. It was essentially established that increment of compression speed produced reduction in strength. And salt water permeable as chemical exposure occurred decreasing of strengths. Comparing the difference between two compression speeds a limitations in saturated specimens swelled in salt water as Fig. 7. Vibrations according to axial strain were observed in stress and strain curve. Data sets of 1.0 %/min actually discovered smooth line. Changing of strength showed in Fig. 8 verified accurate that heating effort, salt water and compression speed were recognized as further important factors in THMC phenomena for saturated bentonite.

4 CONCLUSIONS

This study conducted out unconfined compressive strength for unsaturated/saturated bentonite with sand. Saturated bentonite was swelled in either distilled water or salt water having concentration of 3.5 %. This testing program corresponded to verify Chemo-thermo-hydro-mechanical properties for bentonite. Some summaries are mentioned as following:

(1) Unconfined compressive strength of saturated bentonite-sand was obviously lower than that of unsaturated condition due to saturation and elimination of suction.

(2) Saturated bentonite-sand swelled in distilled water described that unconfined compressive strength decreased due to from 20 degrees Celsius to 80 degrees Celsius. Unconfined compressive strengths of saturated bentonite-sand swelled in both distilled water and salt water with concentration of 3.5 % were compared that the influence of chemical exposure was established. Salt water revealed decreasing in strength of saturated bentonite-sand. Also, the influence of compression speed proved with results.

(3) Increment of temperature produced reduction of unconfined compressive strength of saturated bentonite-sand regardless of both distilled water and salt water.

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