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UNIAXIAL COMPRESSION TEST OF BENTONITE UNDER VARIOUS CONDITIONS

Masaki Yanai[1], *****Shinichi Kanazawa[2], Rie Suzuki[1] and Osamu Yoshino[3]

[1] Social Environmental Systems Engineering Course, National Institute of Technology, Fukushima College, Advanced Course Program, Japan
[2]Civil and Environmental Engineering, National Institute of Technology, Fukushima College, Japan
[3]Nishimatsu Construction CO., LTD

*Corresponding Author, Received: 15 Jun. 2020 Revised: 10 Jan. 2021, Accepted: 28 Jan. 2021

ABSTRACT: At present, underground geological disposal at depths greater than 300 m are considered a viable disposal option for high-level radioactive waste generated from the reprocessing of spent fuel used in nuclear power plants. In geological disposal, bentonite is employed as the primary component of buffer material filling gaps between waste and geologic rock. Bentonite has remarkable water absorption swelling capability and low permeability characteristics. Bentonite buffers are generally mixed with silica sand to improve workability and reduce costs. However, specification details have yet to be completely determined. It is anticipated that the buffer material will be exposed to high temperature due to the heat generated by the vitrified solid. In this study, uniaxial compression tests were carried out on specimens made of a mixture of bentonite and silica sand. The purpose of this study is to clarify the mechanical properties of bentonite silica sand mixed specimens by comparing the results of this study with those of the previous study [1~5]. In addition to using the temperature change by water tank curing, as carried out in the previous study, the uniaxial compression test was also carried out while continuously applying temperature to the specimen. As a result of the test, it was confirmed that the maximum compressive strength tended to decrease with increasing temperature, and it was indicated that the bentonite mixed with silica sand had temperature dependence.

Keywords: Bentonite, Geological disposal, Temperature, Uniaxial compression test

1. INTRODUCTION

In the nuclear fuel cycle, which reuses nuclear fuel, radioactive effluent is generated when uranium and plutonium are extracted. The mixture of radioactive effluent and glass into canisters is called high-level radioactive waste. In Japan, geological disposal for the safe disposal of high-level radioactive waste. It is believed that this method can safely dispose of high-level radioactive waste via the multiple barrier system, which combines an engineered barrier system and a natural barrier system.

At present, the use of bentonite as a buffer material for geological disposal is being examined. Bentonite fills gaps due to its water intake swelling properties and low permeability, thus preventing the leakage of groundwater contaminated with high levels of radiation. [6] is In Japan Nuclear Cycle Development Institute, various tests, such as swelling pressure tests and uniaxial compression tests, have helped to characterize swelling performance and mechanical properties of bentonite. During the disposal period, the bentonite buffer is exposed to various conditions, It is feared that backfill materials and buffer materials may permeate and saturate from the surrounding bedrock due to heat generation from the vitrified material and infiltration and saturation of groundwater during the disposal period. Kanazawa S, Yanai M, Ichikawa N, Muto N, and Ishiyama K, [7], conducted uniaxial compression tests of bentonite silica sand mixed specimens in which the silica sand content and silica sand particle size were changed. and, the test in which the temperature change was given to the test piece was also similarly carried out. From the test results, it is reported that the compressive strength tends to decrease with increasing silica sand content and temperature. In this study, in order into understand the mechanical properties of bentonite buffer materials, the uniaxial compression test was carried out with varying degrees of saturation and specimen temperatures. In addition to tests using temperature change by the water tank curing, and the uniaxial compression test equipment was improved, and the test in which the temperature was continuously applied was also carried out.

2. TEST METHOD

The initial conditions were set at a dry density of 1.6 Mg/m^3 and a saturation of 30% and 90%. Temperatures of 30 ℃, 50 ℃, 70 ℃ and 90 ℃ were applied to bentonite (Kunigel V1) with No. 5 silica sand ratios of 30%. The test with 90% saturation was carried out at 30 ℃, 60 ℃ and 90 ℃. Table 1 summarizes the physical and chemical properties of Kunigel V1 and silica sand.

Table 1 Physical and chemical properties of Kunigel V1 and Silica sand

Kunigel V1	
Silica sand No.5	
Soil particle density (Mg/m^3)	2.61
Montmorillonite content (%)	51
Silica sand No. 5 particle density (Mg/m^3)	2.62
Silica sand No. 5 particle size(mm)	0.3~0.8

2.1 Sample Preparation Method

A mixed sample of bentonite and silica sand was prepared at a ratio of 7:3 for Kunigel V1 and silica sand particle size no. 5. The properties of each sample are shown in Tables 2. Equation (1) was used for the effective clay density [6] of JAEA.

$$\rho_e = \frac{\rho_d(100-R_s)}{(100-\frac{\rho_d R_s}{\rho_s})} \quad (1)$$

Equation (1) where, ρ_e: effective clay density, ρ_d:dry density, ρ_s : soil particle density of silica sand, R_s : silica sand mixing ratio

Table 2 Properties of each sample at the 7:3 mixing ratio

Silica sand No.	No.5
Mixed soil particle density (Mg/m^3)	2.610
Void ratio	0.631
Effective clay density (Mg/m^3)	1.371

2.2 Methylene Blue Adsorption Test

The montmorillonite content of bentonite in Table 1 was measured with reference to the Methylene blue adsorption measurement method [8] of AIST.

The methylene blue adsorption test is a test to estimate surface area and cation adsorption capacity using the adsorption of methylene blue by montmorillonite, which is a main component of bentonite. In this test method, methylene blue is added to a solution in which bentonite is dispersed, and a drop of the solution is dropped on filter paper to make a dark blue spot of 1 cm in diameter. Fig.1 shows the adsorption amount of methylene blue. When the amount of added methylene blue is large, blue bleeding, called a halo, appears around the spot. The halo is considered to the methylene blue that the bentonite could not adsorb. In this study, the appearance of a halo is judged to be the maximum adsorption of methylene blue on bentonite.

The calculation of the amount of adsorbed methylene blue is given by the following equation:
Adsorbed amount of methylene blue (MB) per 100 g of sample [mmol] = concentration of MB solution [mmol/l] × amount of MB solution added [ml] × (1/1000) × (100 [g]/Weight of the sample [g])

As a result of the test, the montmorillonite content of the Kunigel V1 used in this study was 51%.

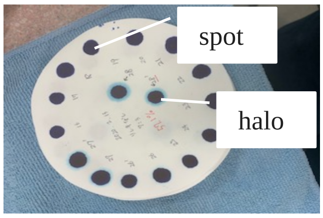

Fig. 1 Methylene blue adsorption test

2.3 Water Content Adjustment

The water content of the mixed samples was adjusted to a saturation of 30% and 90%. The procedure is shown below.

(1) The sample was mixed using a spray and mixer as shown in Fig. 2 (a).
(2) For the water content adjustment at high saturation, the water content of the sample was adjusted using a humidifier and a tent to shorten the time, as shown in Fig. 2 (b).
(3) The water content was measured using a microwave oven (500 W, 15 min) to shorten the time.

(a) Mixer and sample (30%) (b) Humidifier and sample

Fig. 2 Water content adjustment

2.4 Specimen Molding

The sample was divided into five layers, each placed in the mold and compacted. Afterwards, static compaction (40 MPa, 10 min) was applied with a hydraulic jack to produce the test specimen.
Equations (2) and (3) were used for the mass of the specimen, assuming that the volume of the specimen was constant.

$$e = \frac{\rho_s}{\rho_d} - 1 \tag{2}$$

$$S_r = \frac{w\rho_s}{e\rho_w} \tag{3}$$

Equation (2) where, e : void ratio, ρ_s : soil particle density, ρ_d: dry density : (3) and where, w : water content, ρ_s : soil particle density e : void ratio, ρ_w : water density (1.00Mg/m^3).

2.5 Temperature Change

2.5.1 Temperature change by water tank curing

To avoid water contact with the sample, an impervious sheet was attached to the sample. After that, it was cured in a water tank (30℃, 50 ℃, 70 ℃, 90℃) for 24 hours, and the temperature was kept constant during that time. After curing, the impervious sheet was removed from the sample. The volume after curing was measured and uniaxial compression tests were performed. Figure 4 shows the temperature curing of the specimen in the water tank.

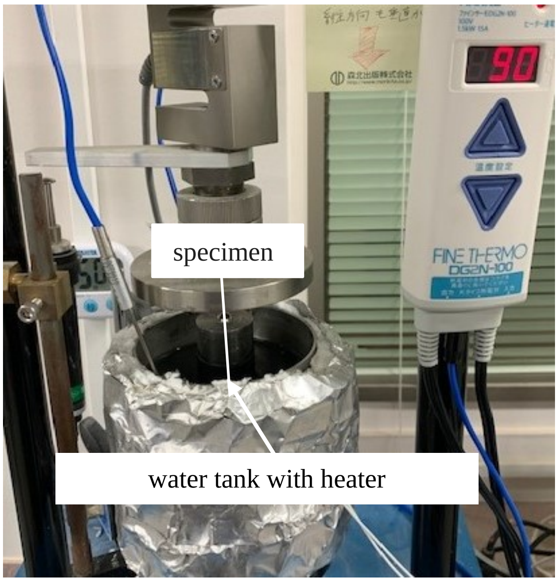

Fig. 3 Temperature change by water tank curing

2.5.2 Uniaxial compression test in a temperature environment

A rubber sleeve was attached to the specimen to prevent water from coming to contact with the prepared specimen. Next, a water tank container capable of keeping the temperature constant was installed in the main body of the uniaxial compression tester, and the test piece with the compression assist device was installed in the water tank container for 25 minutes to reach the set temperature (30℃, 50℃, 70℃, 90℃). After this, the uniaxial compression test was carried out under continuous heating. It was confirmed that the curing time allows the specimen to reach the set temperature in advance.

Figure 4 shows the uniaxial compression test with continuous temperature.

Fig. 4 Uniaxial compression test in a temperature environment

2.6 Uniaxial Compression Test

The compression test was carried out at a fixed loading speed of 0.4 (mm/min). An electric screw jack system of 10 kN capacity was employed as a testing machine. The test method was carried out referring to the uniaxial compression test method of the JIS standard. [9]

3. TEST RESULTS AND DISCUSSION

Figure 5 shows the results of the uniaxial compression test in which the temperature was changed by curing in a water tank, and Figure 6 shows the results of the uniaxial compression test in a temperature environment. Figure 7 shows the compressive strength reduction percentages. Figure 8 shows the distribution of water content by curing in a water tank, and Figure 9 shows the distribution of water content in a test conducted under a temperature environment.

3.1 Results of Tests in Which the Method of Applying the Temperature Change was Varied

Figures 5 and 6 confirm that the maximum compressive strength decreased linearly in the water tank curing in the uniaxial compression test in which the temperature was changed. In the uniaxial compression test under the temperature environment, it was confirmed that the compressive strength tended to decrease rapidly with the rise in temperature from a certain threshold.

Figure 7 shows the compressive strength reduction percentages. Case1 is the uniaxial compression test in which the temperature was changed by curing in a water tank, and Case2 is the uniaxial compression test in a temperature environment. From Figure 7, it was confirmed that the rate of decrease in compressive strength in case 1 gradually decreased, while the rate of decrease in compressive strength in case 2 rapidly decreased.

With the rise of the temperature, the factors causing the reduced compressive strength appears to be multiple. The first factor is the expansion of specimen volume. It is possible that pore water and air expanded by heat were difficult to discharge due to the low permeability and air permeability of bentonite. According to Charles's law in [10], as the volume of gas is proportional to temperature, the expansion of air is about 1.07 times at 50°C, about 1.13 times at 70°C, and about 1.20 times at 90°C, compared to a temperature of 30°C. The volume expansion of water is about 1.01 times at 50°C, about 1.02 times at 70°C, and about 1.03 times at 90°C, based on the density of water at 30°C. Therefore, it is considered that the occurrence of minute cracks due to the expansion of water and air reduce strength characteristics. In addition, the effects of cracks generated by the drying shrinkage of the specimen surface is also considered.

Figure 8 shows the distribution of water content before and after the test in the water tank. In addition, Figure 9 shows the distribution of water content in the test conducted under the thermal environment. In both cases, it was confirmed that the water content after the test tended to decrease with increasing temperature. The higher the sample temperature, the higher the evaporation from the sample surface or the inside, and the cracking due to drying shrinkage occurs.

It is considered that the strength characteristics are lowered from these factors. In this test, the crack inside the specimen could not be confirmed, but in the test after surface curing, the crack by drying shrinkage was confirmed.

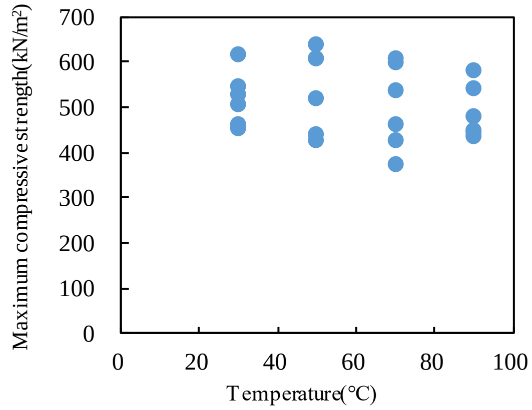

Fig. 5 Uniaxial compression test by water tank curing

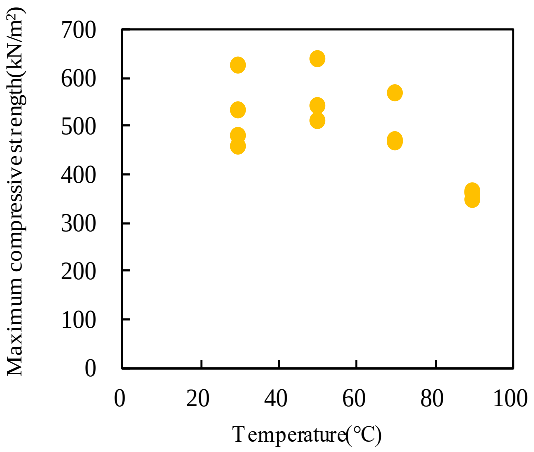

Fig. 6 Uniaxial compression test in a temperature environment

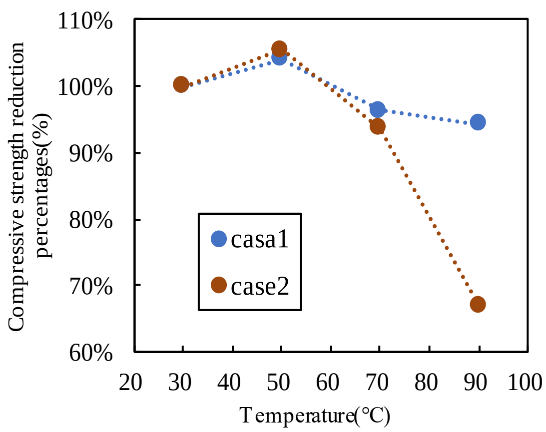

Fig. 7 Compressive strength reduction percentages

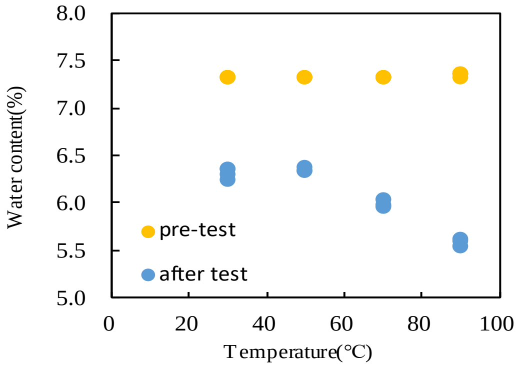

Fig. 8 Distribution of water content in water tank curing test

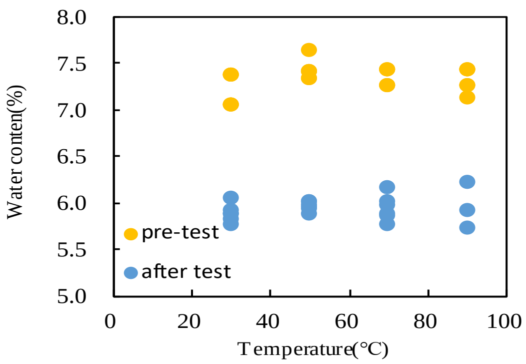

Fig. 9 Distribution of moisture content in the test in a thermal environment

3.2 Results of Uniaxial Compression Tests at High Saturation

Figure 10 shows the results of uniaxial compression tests with varying temperature and saturation. Figure 11 shows the stress-strain curve at 30°C, and 90% saturation, and Figure 12 shows the stress-strain curve at 90°C and 90% saturation. Figure 13 shows the distribution of water content.

Figure 10 shows that the results of the uniaxial compression test under a saturation degree of 90% could not confirm decreasing strength with a rise in temperature. However, the stress-strain curves in Figures 11 and 12 demonstrate different fracture patterns. Ductile fracture with large plastic deformation until fracture is observed in Fig. 11, and brittle fracture with rapid fracture is observed in Fig. 12. The change in water content is likely related to the cause of such fractures.

The water content distribution in Fig. 13 confirms that the water content before and after the test did not change under the condition of 30°C, but the water content tended to decrease rapidly under the condition of 90°C. The test environment of 90°C is considered to have become a factor in decreasing the water content, and the fracture form exhibited brittle fracture with the lowering of the water content.

In addition, according to the uniaxial compression test conducted by Nishimura under high-temperature action [11], uniaxial compression strength was reported not to change with temperature rise.

These results suggest that the uniaxial compressive strength of bentonite specimens at high saturation did not change with increasing temperature.

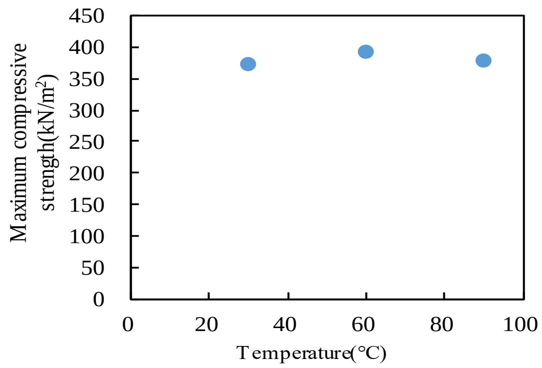

Fig. 10 Uniaxial compression tests varying temperature and saturation

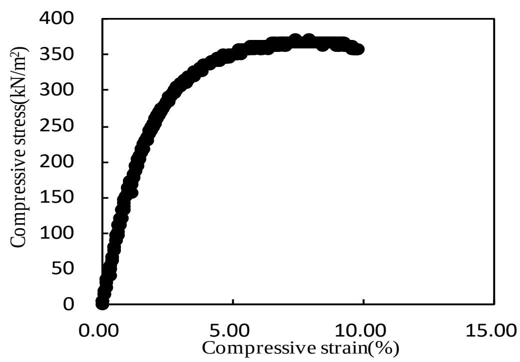

Fig. 11 Stress-strain curve (30°C)

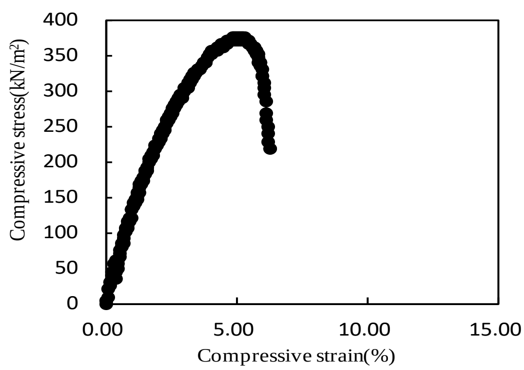

Fig. 12 Stress-strain curve (90°C)

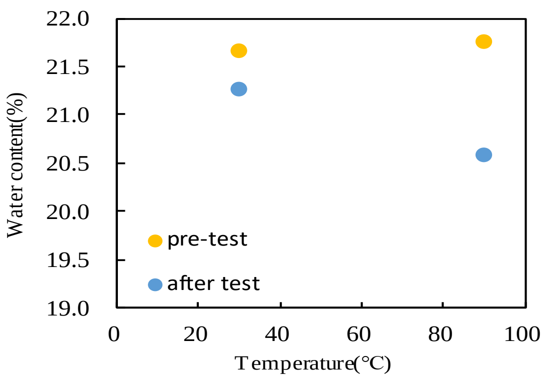

Fig. 13 Distribution of water content

4. CONCLUSION

In this study, the uniaxial compression test of bentonite mixed with silica sand was carried out considering temperature and degree of saturation. The findings from this study are as follows:

(1) The maximum compressive strength of bentonite-silica sand mixed specimens decreased linearly with increasing temperature.

(2) Since the water content of the specimen decreased after the test, cracks likely occurred on the surface and interior of the specimen, leading to the decrease in strength.

(3) In the uniaxial compression test at high saturation, the effect of the strength by temperature could not be confirmed, but the difference in the fracture form was apparent.

In future studies, the uniaxial compression test in which the degree of saturation is varied will be continuously carried out, and the data will be collected cumulatively.

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