Influence of Thermal Cycles on the Volume Change of Ulexite Added Sand-Bentonite Mixtures

Sukran Gizem Alpaydin and Yeliz Yukselen-Aksoy

Abstract Bentonite and sand-bentonite mixtures are recommended as engineered barriers. In waste disposal facilities, especially radioactive waste, a significant temperature increase occurs. The engineering properties of sand-bentonite mixtures change depending on temperature. Sand-bentonite mixtures used as buffer material should be able to maintain their properties unchanged at high temperatures and under thermal cycles. In the present study, the volumetric deformation behavior of sand-bentonite mixtures containing 10% bentonite was investigated under room temperature and thermal cycles. In addition, ulexite, one of the boron minerals known for its high resistance to high temperature and low thermal expansion coefficient, was added to these mixtures at rates of 10 and 20% by dry weight. The compression-swelling behavior of ulexite added sand-bentonite mixtures under room temperature and thermal cycles was investigated. According to the results of the present study, when ulexite was added to the sand-bentonite mixture, the compression amount increased at room temperature, while the swelling amount decreased. However, the total compression amounts were reduced by half when thermal cycles were applied compared to the tests performed at room temperature.

Keywords Sand-Bentonite mixtures · Ulexite · Volume change · Thermal cycles

1 Introduction

Soils exposed to high temperature and temperature changes are an important topic to be investigated in geotechnical engineering. Soils surrounding energy geo-structures, which are exposed to long-term temperature changes, undergo thermal, hydraulic and mechanical changes during time. In order to prevent problems that may arise at the end of the long term, thermal, hydraulic and mechanical changes of the soil must be examined. For this, it can be determined how the soils will behave in the long term under high temperature with laboratory studies and numerical models.

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Earlier studies on clayey soils were reported that volume of soils decreased at elevated temperatures in drained conditions [1–3]. In the study by Sinha and Kusakabe [4], the volumetric deformation of sand-bentonite mixtures at high temperature (up to 75 °C) was investigated. It was reported that the change in pore water pressure is temperature dependent under normally consolidated conditions. In other words, the void ratio changes with the temperature change [4]. While the volume of normally consolidated clays contracts with increasing temperature, the volume of over consolidated clays can even show expansion with increasing temperature [5, 6]. Plum and Esrig [7] observed a contraction in two clays with different plasticity at normally consolidated (NC) or low over consolidated ratio (OCR) condition. However, no volume change was observed in OCR = 1.7 [7] Baldi et al. [5] also showed that the transition between contraction and expansion increased when OCR = 2.5 at 58 °C [5].

Volumetric deformation of soils may cause damage around energy geo-structures. For that reason, additives can be added to buffer materials (bentonite/sand-bentonite) in order to minimize the damages that may occur. Boron mineral, which has low thermal expansion, can be considered as an additive material. Industrially important boron compounds are under the main grouping of borax (tincal, sodium-based boron compounds), colemanite (calcium-based boron compounds), ulexite (sodium-calcium-based boron compounds). Since boron reduces the expansion, it increases the resistance to thermal shocks. It also has an important place in the production of heat-resistant glassware and high-quality glasses to be used in electronics and space exploration, as it significantly reduces the thermal expansion of the boron glass, protects the glass against acid and scratching, and provides resistance to vibration, high temperature and heat shocks [8].

In the present study, boron mineral namely; ulexite, was added to 10% bentonite–90% sand mixture. Volume deformation of the mixtures was examined under room temperature (25 °C) and thermal cycle (25−80−25 °C).

2 Materials and Methods

2.1 Materials

In this study, sand-bentonite mixture and boron mineral, namely; ulexite, were used. The bentonite was a sodium (Na) containing bentonite with a high liquid limit value. The Na-bentonite was supplied from Eczacıbaşı Esan Mining Company. Ulexite was gathered from Eti Mining Operations General Directorate of Turkey. The sand was classified as well-graded (SW) according to the Unified Soil Classification System (USCS) [9]. The physico-chemical properties of the materials are summarized in Table 1.

The Na-bentonite and sand samples were used after drying for 24 h in the oven (105 °C). The sand and bentonite were used by sieving through No. 6 (3.35 mm) and

Table 1 Physico-chemical properties of the materials

	Sand	Na-bentonite	Ulexite
Specific gravity	2.63	2.70	1.98
Liquid limit (%)	–	476	33
Plastic limit (%)	–	70	25
Plasticity index (%)	–	406	8
pH	–	9.50	9.13
No. 200 (%)	1.64	100	100

No. 200 (0.075 mm), respectively. Ulexite was used in its natural water content (7%) as its structure changes with temperature. The natural water content of the ulexite was considered at the sample preparation.

2.2 *Test Methods*

The oedometer tests [10] were performed on additive-free sand-bentonite mixture (10% bentonite–90% sand and 10 and 20% ulexite added sand-bentonite mixtures (9B-81S-10U and 8B-72S-20U). The tests were conducted at room temperature (25 °C) and under thermal cycle (25–80–25 °C). The samples were prepared at the 2% wet side of the optimum water content and compacted in three layers in a ring. After the ring was placed in a water-filled cell, a seating pressure of 6.9 kPa was applied for 24 h. In the tests at room temperature, loading steps were applied as 24.5, 49, 98, 196, 392 and 784 kPa. After the consolidation was completed, the sample was unloaded to the vertical stress to 196 kPa and then to 49 kPa.

The oedometer test system was modified for thermal cycle tests. A specially designed heat ring was used to get high temperature and temperature control was provided using thermostat. A rubber membrane was placed on the cell to minimize evaporation. In addition, with low flow rate of water was provided to the cells from the water tank continuously, so that the water level would not decrease during the tests. Temperatures were controlled by means of K-type thermocouples.

Before the thermal cycle was applied, the test was performed at room temperature under the vertical stress of 196 kPa and then temperature was increased to 80 °C. As soon as the test reached equilibrium in terms of deformation, the temperature was reduced back to room temperature. When the compression/swelling behavior were over as a result of the thermal cycle, the vertical stress was increased to 392 kPa for ulexite added samples and to 785 kPa for additive-free mixture. Then, to examine the swelling behavior of the samples under thermal cycles, the stress was reduced to 196 kPa and thermal cycling (25–80–25 °C) was applied again.

3 Test Results

In the present study, oedometer tests of the sand-bentonite and ulexite-added sand-bentonite mixtures were performed at room temperature and under thermal cycle. The compression and swelling behavior of the samples were determined according to the test results. The compression curves of 10% bentonite–90% sand (10B-90S) mixtures in the presence of ulexite at room temperature are shown in Fig. 1. The amount of compression increased when ulexite was added to the 10B-90S mixture. The compression amount of the 10B-90S mixture increased from 6.6 to 8.1% in the presence of 10% ulexite, and to 12.4% with 20% ulexite.

It was seen that the amount of swelling decreased when ulexite was added to 10B-90S mixtures. The amount of swelling decreased to 1.14% in the presence of 10% ulexite and 1.09% in the presence of 20% ulexite. Increasing the amount of ulexite from 10 to 20% did not significantly change the swelling deformation amount.

The compression-swelling curves of ulexite added sand-bentonite mixtures under thermal cycles are presented in Fig. 2. The deformation amounts in the compression-swelling stages for ulexite added 10% bentonite samples under thermal cycling were almost the same and the values were very low. In other words, 9B-81S-10U and 8B-72S-20U mixtures did not show significant deformation under thermal cycling. However, compared to the tests performed at room temperature, the total compression amount was reduced by half. The samples, which were not very affected by the increase in temperature to 80 °C (0.1%), were slightly more compressed (0.4%) at room temperature.

The compression amount of sand-bentonite mixtures increased at room temperature in the presence of ulexite. The increase in fine content ratio may be the reason for this (sand-bentonite content was decreased as much as the percentage of ulexite).

When the behavior of ulexite added mixtures with the effect of thermal cycling was examined, the deformation amount decreased compared to the room temperature. Permanent deformation occurred during the compression phase when the cycle was

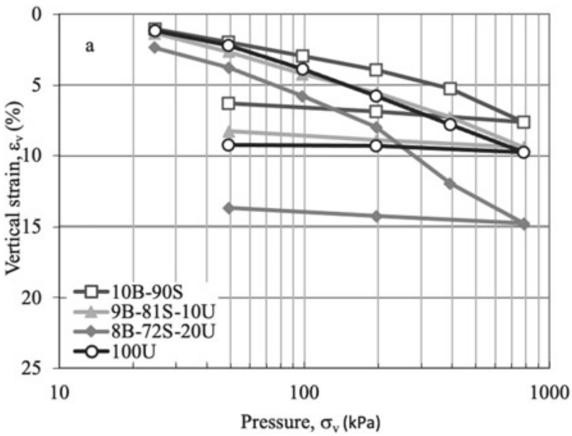

Fig. 1 Stress–strain curves of sand-bentonite mixtures in the presence of ulexite at room temperature

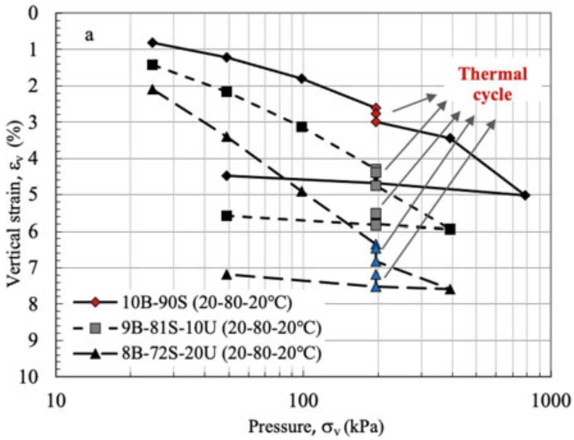

Fig. 2 Stress–strain curves of sand-bentonite mixtures in the presence of ulexite under thermal cycles

applied, and this behavior was not reversed by reducing the temperature. Paaswell [11] explained that under high temperature, the adsorbed water molecules move more easily from the diffuse layer, and when the water molecules ejected, the double layer thickness decreases, causing an irreversible volume reduction by approaching the clay particles [11].

4 Conclusions

In the present study, the volume deformation behavior of ulexite added sand-bentonite mixtures at room temperature and thermal cycles (25–80–25 °C) was investigated. Based on the results obtained, the following conclusions can be drawn:

1. The compression amount of sand-bentonite mixtures with the addition of ulexite increased significantly at room temperature.
2. The effect of ulexite on the compression amount of sand-bentonite mixtures under thermal cycles was negative (increasing) for 10B−90S mixtures.
3. The total compression amounts of additive free sand-bentonite mixture and ulexite added sand-bentonite mixtures under thermal cycles decreased compared to those at room temperature.
4. It was observed that ulexite additives reduce the swelling amount of sand-bentonite mixture under thermal cycles.
5. For boron added mixtures, vertical deformation continued when the temperature was increased to 80 °C under thermal cycling, and even the decrease in the void volume continued when the temperature was returned to room temperature. This indicates that high temperature causes irreversible deformation.
6. For the swelling stage, the deformation at high temperature was generally reversed by decreasing the temperature.

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