Experimental investigation on soil-water retention properties of compacted GMZ01 bentonite with consideration of temperature and initial dry density

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Abstract

Soil-water retention curve (SWRC) of clay is mainly influenced by its initial dry density and temperature. Soil-water retention tests were conducted on compacted GMZ01 Bentonite with consideration of initial dry density and temperature, corresponding SWRCs were obtained. Results show that for high suctions, the water retention capacity of confined compacted GMZ01 bentonite decrease with increasing temperature. Whereas for low suctions, the influencing rate of temperature on water content decreases as temperatures increases. The influence of initial dry density on water retention property of GMZ01 bentonite is very little for high suctions, while significant for low suctions.

Key words: GMZ01 bentonite, soil-water retention curve, temperature, initial dry density, suction

1 Introduction

During the operation of the repository, the bentonite will experiences a process from unsaturated to saturated state by absorbing water from the surrounding formations accompanied by bentonite blocks expansion to the nearby voids. As a result, dry density of the barrier will decrease from the manufacturing density of the blocks (Villar, 2007). At the same time, decay heat from the canister, which will induce the variation of temperature in the barrier, is another factor influencing the water retention capacity of bentonites (Villar and Lloret, 2004).

Contributions have been made for investigation on influence of dry density on water retention property of compacted bentonite. Based on an in-situ hydration test performed at the Grimsel test site (Switzerland), ENRESA (2000) reported that the final overall dry density of the barrier was 1.6 g/cm^3, which was lower than its manufacturing density 1.7 g/cm^3 of the FEBEX blocks. This observation confirmed the dry density variation of the barrier during the hydration of bentonite blocks. Therefore, for an appropriate characterization of the hydro-mechanical behavior of deformable clays, knowledge of the dependence of the water retention curve on dry density is necessary (Simms and Yanful, 2005). Using the vapor phase method, Sánchez (2004) obtained the SWRCs of confining high-compacted bentonite with different initial dry densities. It turned out that the initial dry density can strongly influence the water holding capacity of confined high-compacted bentonite over the low suction range.

For investigating temperature effects on the water retention properties of compacted bentonite, various experimental and theoretical explorations (Villar and Lloret, 2004; Sánchez, 2004; Villar et al., 2010; Tang and Cui, 2005; Ye et al., 2009; Wan et al., 2015) were conducted. Villar and Lloret (2004) conducted water retention tests on FEBEX bentonite by means of the vapor equilibrium technique. Results showed that the higher the temperature, the lower the water holding capacity of the highly compacted bentonite for both under confined and unconfined conditions.

Gaomiaozi (GMZ) bentonite, collected from Inner Mongolia Autonomous Region of China, has been considered as a buffer/backfill material in the Chinese HLW repository (Ye et al., 2010). Using the osmotic technique for low suction and the vapor equilibrium technique for high suction control, Chen et al. (2006) measured the water retention property of highly compacted GMZ bentonite specimens with initial dry density of 1.70g/cm^3 under constant volume and free-swelling conditions. Results show that there was a closed relationship between water retention property of bentonite and its microstructure. With the SWRCs of confined/unconfined highly compacted GMZ bentonite specimens (1.70g/cm^3) measured at temperatures 20℃, 40℃ and 60℃, Ye et al. (2009) analyzed the effects of temperature and constraint condition on the water retention capability of GMZ bentonite.

In this work, complementary suction-controlled water retention tests were conducted on the compacted GMZ01 bentonite specimens with initial dry densities of 1.50g/cm^3 and 1.90g/cm^3 at temperatures 20°C, 40°C and 60°C. Soil water retention curves were thereby obtained at corresponding temperatures and dry densities. Combined with the SWRCs of GMZ01 bentonite specimen previously measured by Ye et al. (2009) at temperatures 20°C, 40°C and 60°C, a modified model for describing the water retention behavior of compacted GMZ01 bentonite was proposed and verified with consideration of temperature and initial dry density effects.

2 Materials and methodology

2.1 Materials

The material tested in the present work is GMZ01 bentonite, which originates from GaoMiaoZi (GMZ) in the Inner Mongolia Autonomous Region, 300 km northwest from Beijing, China (Ye et al., 2009). As a light gray Na-bentonite powder, it is dominated by montmorillonite (75.4% in mass). Basic physical and chemical properties of GMZ01 bentonite are presented in Table 1 (Wen, 2005). A high cation exchange capacity and adsorption ability can be identified (Ye et al., 2010; Ye et al., 2012).

2.2 Specimen preparation

The GMZ01 bentonite powder with an initial water content of 10.7% was statically compacted to target dry densities of 1.50g/cm^3 and 1.90g/cm^3 respectively. Compaction was displacement-controlled at a speed of 0.1 mm/min. Cylindrical specimens with dimensions of 10 mm in height and 50 mm in diameter were obtained.

2.3 Methodology

For suction control at given temperatures, the setups developed by Ye et al. (2012) for the vapor equilibrium technique (Fig.1) and the osmotic technique (Fig. 2) were employed in this study. Generally, the vapor equilibrium technique (for suctions higher than 4 MPa) and the osmotic technique (Delage et al., 1998) (for suctions lower than 4 MPa) were used for suction control in a combined way, in order to obtain SWRCs over a large suction range. Detailed descriptions for these two techniques can be found elsewhere (Ye et al., 2012; Blatz and Graham, 2000; Lloret et al., 2003).

Table 1 Basic physical and chemical properties of GMZ01 bentonite (Wen, 2005)

Property	Description
Specific gravity of soil grain	2.66
pH	8.68-9.86
Liquid limit（%）	276
Plastic limit（%）	37
Total specific surface area（m^2/g）	597
Cation exchange capacity （mmol/100g）	77.3
Main exchanged cation （mmol/100g）	Na^+（43.36）, Ca^{2+}（29.14）, Mg^{2+}（12.33）, K^+（2.51）
Main minerals	Montmorillonite（75.4%）, Quartz（11.7%）, Feldspar（4.3%）, Cristobalite（7.3%）

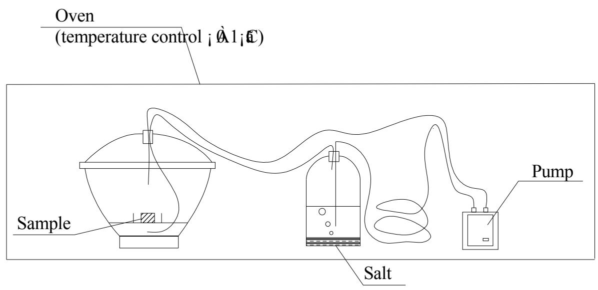

Fig. 1 Setup for the vapour equilibrium method with temperature control (Ye et al., 2012)

For consideration of temperature influence, salt solutions and their corresponding suctions at different temperatures calibrated by Tang and Cui (2005) for the vapor equilibrium technique were referred in this paper (Table 2). However, according to the calibration result reported by Tang et al. (2010), the influence of temperature on suction measured by the osmotic technique was insignificant. Therefore, for suction controlled by the osmotic technique at different temperatures did not consider any temperature corrections in this work.

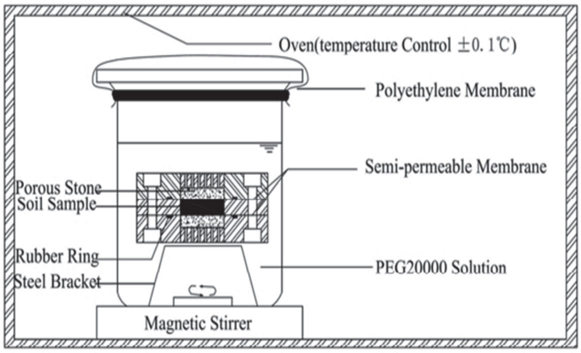

Fig. 2 Setup for the osmotic technique with temperature control (Ye et al., 2012)

Table 2 Salt solutions and their corresponding suctions (MPa) (Tang and Cui, 2005)

Salt solution	20℃	40℃	60℃
$LiCl_2$	309	319	340
$MgCl_2$	150	162.4	187.7
K_2CO_3	113	122	144.8
$Mg(NO_3)_2$	82	103.1	139
$NaNO_2$	57		
$NaNO_3$	39	49.5	61.6
NaCl	38	40.6	44.2
$(NH_4)_2SO_4$	24.9	32.2	
KCl	21	27.8	33.4
$ZnSO_4$	12.6		
KNO_3	9		
K_2SO_4	4.2	5.1	5.5

2.4 Water Retention Tests

In this study, using the vapor equilibrium technique for high suctions and the osmotic technique for low suctions, water retention tests on compacted GMZ01 bentonite specimens with initial dry densities of 1.50g/cm^3 and 1.90g/cm^3 were performed at temperatures 20^{0}C, 40^{0}C and 60^{0}C, respectively. With the previous results reported by Ye et al. (2009) on GMZ01 bentonite specimen with dry density of 1.70g/cm^3 at different temperatures, SWRCs of GMZ01 bentonite with initial dry densities of 1.50g/cm^3, 1.70g/cm^3 and 1.90g/cm^3 at temperatures 20℃, 40℃ and 60℃ were obtained.

3 Results and discussion

3.1 Influence of temperature on the water retention properties

Measured water retention curves of confined compacted GMZ01 bentonite specimens with initial dry density 1.90g/cm^3 following wetting path at different temperatures are presented in Fig. 3. It can be observed form the results in Fig.3 that, under constant volume conditions, temperature influence on compacted GMZ01 bentonite depends on suction level. For high suctions (>4 MPa), water retention capacity of the specimen decreases as temperature increases. It may be attributed to that, under constant volume conditions, the transfer of tightly bound intra-aggregate water to free inter-aggregate water caused by temperature. This inter-aggregate water will consequently occupy a greater pore volume and give rise to higher degrees of saturation (Villar and Lloret 2004).

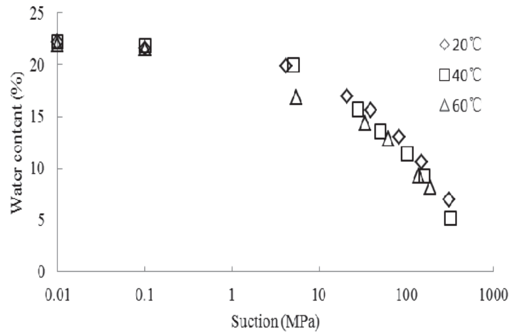

Fig. 3 Influence of temperature on water retention properties (initial dry density 1.90g/cm^3)

It can be observed form the results in Fig.4 that, for high suctions, the water retention curve of GMZ01 bentonite specimens measured at different temperatures are nearly linear and parallel to each other, which indicates that they almost have the same slope. This observation is consistent to that reported by Ye et al. (2009) on confined compacted GMZ bentonite specimen with an initial dry density of 1.70g/cm^3.

It also can be calculated from the curves in Fig.4 that, for a given water content, the decreasing rate of suction with increasing temperature ($\Delta \log s / \Delta T$) is approximately -2.5×10^{-3} (log MPa/℃). This data is approximately to -2.9×10^{-3} (log MPa/℃), which was reported by Tang and Cui (2005) on temperature effects on water retention curves of compacted MX80 bentonite.

For low suctions (<4MPa), temperature influence on water retention capacity is insignificant, especially for suction lower than 0.1MPa, the influence of temperature is hardly observed. It may be attributed to that, under constant volume conditions, decreasing suction could not make more water moving into large pores because most pores has already been filled by water in the case of low suctions (Villar and Lloret 2004).

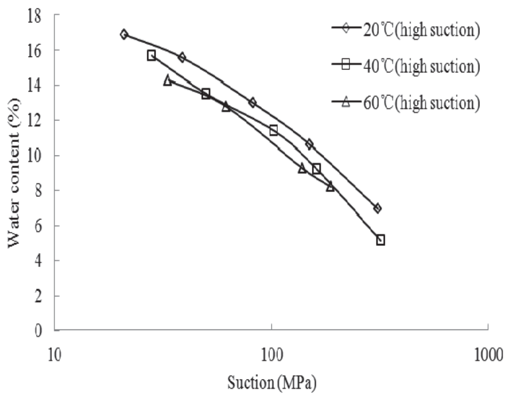

Fig. 4 Influence of temperature on SWRCs of GMZ01 bentonite at high suctions (1.90g/cm^3)

3.2 Influence of dry density on water retention capacities

Measured water retention curves of confined compacted GMZ01 bentonite specimens with different dry densities following wetting path are presented in Fig. 5 (20℃). It can be observed from he measured data in Fig. 5 that, under constant volume conditions, influence of dry density on the water retention capacity also can be analyzed at high and low suctions separately.

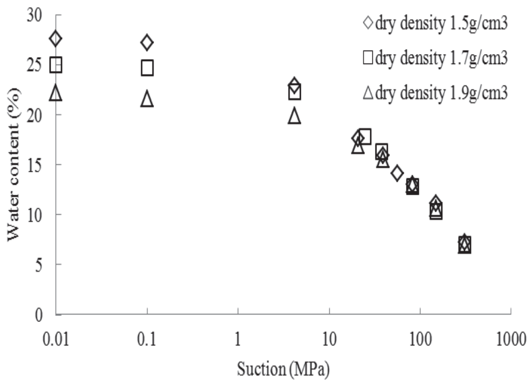

Fig. 5 Influence of dry density on water retention curves（20℃）

For suctions higher than 10MPa, dry density influence on the water retention curve is insignificant. Explanations to this observation could be that the water must be predominantly in the microstructure, and because the density changes affect mainly the macrostructure, they are not reflected on the retention curve (Villar, 2007). Similar results were obtained by other authors (Villar et al., 2002; AGUS, 2005; DELAGE et al., 2006; IMBERT et al., 2005).

For lower suctions (<10 MPa), i.e. for high relative humidity and when the specimen is approaching saturation, the lower the dry density of the bentonite the greater the water content for a given suction. This is the expected behavior, as the porosity of samples of low density, and consequently the pore volume available for water uptake, is greater.

The same results were observed at the different temperatures of 40℃ and 60℃ respectively.

4 Conclusions

In this paper, the soil-water retention curves of confined compacted GMZ01 bentonite specimen with different dry densities at different temperatures 20°C, 40°C and 60°C were determined from a series of suction-controlled tests. Influences of temperature and dry density on the water retention capacity of the highly compacted GMZ01 bentonite were analyzed. The following conclusions can be reached.

For high suctions, the water retention capacity of compacted GMZ01 bentonite under confined conditions decreases as temperature increases. For low suctions, water content decreases with increasing temperature. For suction lower than 0.1 MPa, the temperature influence on the water retention capacity of compacted GMZ01 bentonite was insignificant.

For suctions higher than 10 MPa, dry density influence on the water retention curve is insignificant. Explanations to this observation could be that the water must be predominantly in the microstructure, and because the density changes affect mainly the macrostructure, they are not reflected on the retention curve.

For suctions lower than 10MPa, the lower the dry density of the bentonite the greater the water content for a given suction. This is the expected behavior, as the porosity of samples of low density, and consequently the pore volume available for water uptake, is greater.

Acknowledgements

The authors are grateful to China Atomic Energy Authority (Project [2011]1051) and the National Natural Science Foundation of China (Projects No. 41030748) for the financial supports.

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