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Swelling Behavior of a Clay-Pellets Mixture Intended for the Isolation of Spent Nuclear Fuel

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INTRODUCTION

Deep geological repository is the most favorable option for the safe disposal of high-level nuclear waste (HLW) and spent nuclear fuel (SNF). The design of such a facility relies on the multi-barrier system, encompassing a cylindrical metallic container (encapsulating the HLW/SNF), an engineered barrier system (EBS, around the metallic container); and the host-rock (or natural barrier). The most preferred buffer material to construct the EBS is bentonite clays. They are being considered as potential buffer materials because of, amongst other reasons, their high swelling capacity provides mechanical stability to the metallic canister containing the HLW/SNF; their good thermal conductivity assists to dissipate the heat released by the HLW/SNF; their low permeability delays the flow of water and gas through the system [1].

Bentonites are highly swelling smectites clays that exhibit significant volume increase when wetted under free-swelling conditions, and develop high swelling pressure upon soaking when the volume change is restricted. It is envisaged that the EBS will be built using blocks of compacted bentonites (Fig. 1a), or a combination of high-density clay-pellets mixtures and blocks of compacted bentonites (i.e., where the metallic container sits, Fig. 1b). Clay-pellets are also considered as possible seal materials to fill gaps that will be present in this type of system, e.g., the gap between the EBS and the surrounding host-rock [2]. Therefore, a better understanding of the swelling capacity and behavior of the bentonite in these two forms (i.e., compacted-clay and clay-pellets mixtures) is critical for a proper design and evaluation of the long-term performance of geological repositories for HLW/SNF.

Most of the research conducted in this area has been main focused on compacted bentonites looking, e.g., at the influence of several factors on their swelling pressure capacity, namely, type of clay minerals, initial dry density, water content (or degree of liquid saturation), and type of water [3]. More recently, investigations have been conducted to study the behavior of high-density pelletized clay mixtures [e.g. 4, 5], however, relatively less attention has been placed in this type of material. Clay-pellets presents a number of advantage, e.g., they are very suitable for filling (small) technological voids (Fig. 1a), there is no need for additional in-situ compaction when they are used as a buffer/backfill material (Fig. 1b), and it is relatively easy to manufacture them.

This research presents the methodology developed at Texas A&M University (TAMU) to manufacture high-density clay-pellets. The two constant volume cells developed at TAMU to investigate the swelling pressure (SP) behavior of clays are also briefly introduced in this work. The paper also discusses the SP results obtained from two samples, one sample was made of compacted bentonite and the other one from a pelletized clay mixture.

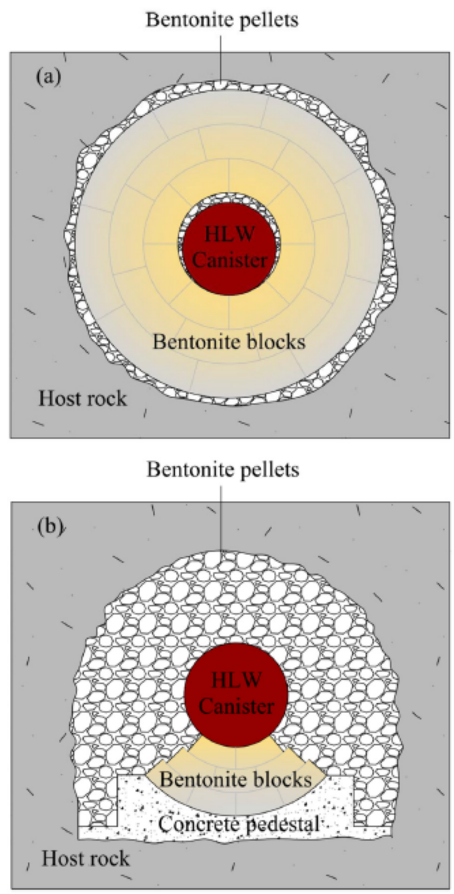

Fig. 1. The use of pellet in the geological disposal concept. (a) Filling technological voids; (b) As main buffer/backfill materials [2].

Material

The MX-80 Wyoming bentonite (provided by Cetco) is the material adopted in this investigation. TABLE I lists the main basic physical properties of this material.

TABLE I. Basic physical properties of MX 80 bentonite.

Property	Value
Smectite content (%)	≥70
Moisture content (%)	8.7
Specific gravity of solid	2.74
Particle size (mm)	0-2.0
Liquid limit (%)	534
Plastic limit (%)	56
CEC (meq/100g)	≥90
Free swell (ml/2g)	≥25
Hydraulic conductivity at 35kPa (m/s)	$1x10^{-10}$

The MX-80 bentonite has been adopted in several research projects aimed at investigating the performance of EBS for HLW [e.g. 6]. Several key properties of this clay make it a very appropriate barrier material, namely, extremely low permeability, self-healing ability, low ion transport capacity, high chemical stability, and high swelling capacity [7].

For the preparation of pellets, MX-80 bentonite powder with an initial water content of 5.5% was weighed to achieve a target dry density of 2.10 Mg/m^3. Then, the clay powder was poured into a cylindrical mold, 50 mm diameter and 100 mm height. Afterwards, the material was statically compacted in a hydraulic press machine (50-ton capacity) until reaching the desired dry density in a clay sample of dimensions 50 mm diameter and 27 mm height (Fig. 2). The maximum load was kept for one hour for homogenization of the specimen [2]. The compacted bentonite specimen was then extruded from the mold and crushed into small and irregular pellets using a jaw crusher for producing particles of different sizes, from P10 (10 mm) until P0.075 (0.075 mm), as shown in Fig. 3. Particles coarser than 0.3 mm were regarded as coarse size classes, whereas the others were considered as fine size classes.

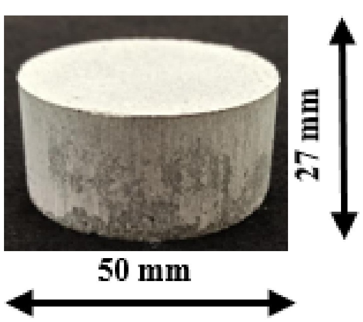

Fig. 2. Compacted bentonite sample before crushing.

Methods

Two high capacity stainless steel constant volume cell were designed and manufactured at TAMU to study the development of swelling pressure during wetting.

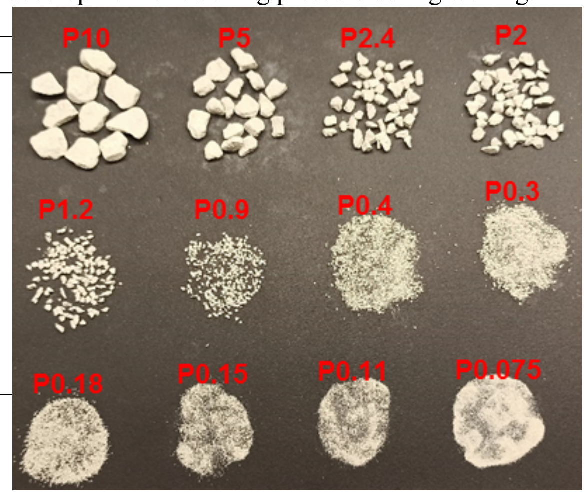

Fig. 3. The twelve size classes of crushed pellets with sizes ranging from 10 mm to 0.075 mm.

The cells consist of a bottom cap (100 mm outer diameter, and 100 mm height) able to accommodate the granular pellets manufactured in this research. The 50 mm inner diameter of the cell hosting the clay sample is five times larger than the bigger pellets. The cell includes two water inlets for water injection and a top cylindrical piston with two outlets for air evacuation. A built-in stainless-steel rigid frame ensures the constant volume conditions of the sample. A calibrated load cell in contact with the piston measures the development of the swelling pressure during the water injection. An external LVDT was used to measure any potential axial deformation between the piston and the load cell (Fig. 4). The samples were hydrated with distilled water. A high-quality pressure-volume controller (Wille) was used to maintain a constant injection pressure of 2MPa and to measure the water intake during the test.

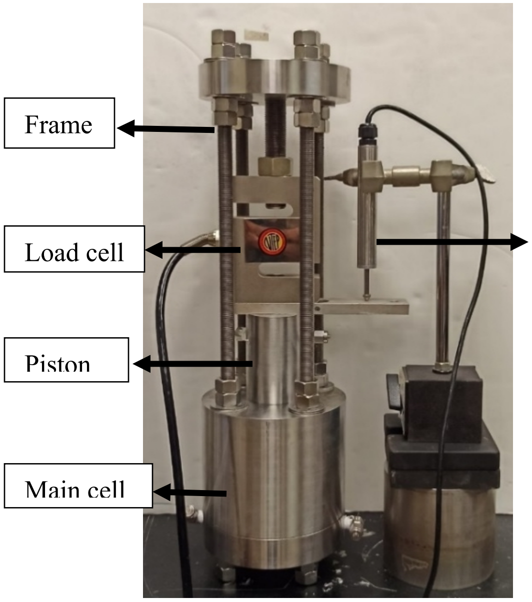

Fig. 4. Experimental setup for swelling pressure test.

Two types of samples were investigated. One of them was made up from compacted bentonite, and the other one from clay-pellets. Both cells have the same initial condition with a dry density around 1.5 Mg/m^3 and a liquid degree of saturation S_r ~ 18% (i.e. ratio between the volume of liquid and the volume of voids). The clay powder was statically compacted using a hydraulic press machine up to the target sample size (i.e. 50 mm diameter, and 50mm height), and specimen was kept for one hour under the final constant load for homogenization. The pellet mixture sample was prepared by selecting 80% of coarse pellets size and 20% fine powder (% by dry mass). To ensure a homogenous material, the filling of the cell was conducted by packets, spreading a layer of pellets over the base of the cylinder and adding the corresponding amount of powder, maintaining constant the adopted pellets/powder percentage.

RESULTS

The swelling pressure test results involving the compacted bentonite and pellet/powder mixtures with an initial dry density ~ 1.5 Mg/m^3 are shown in Fig. 5. Note that these tests are still ongoing. The swelling pressure evolutions in both tests present slightly different patterns. For the case of the clay-pellets mixture, the SP increased quickly at the beginning of the test until reaching an initial peak. Then, the SP decreased until a minimum value, from where progressively increased afterwards until reaching a sort of final plateau, characterized by a slight increase of stress in time. The notorious decrease of the SP after the initial peak has been explained based on the collapse of the large inter aggregate pores between the clay-pellets [8]. The subsequent increase in the SP after the macrospores collapse, also known as secondary swelling is related to the slowly hydration of the high-density pellets [5]. As expected, the evolution of the SP of the compacted bentonite sample is more homogenous, with a monotonic increase of the stress during wetting until reaching a plateau. Both samples achieved a similar SP, around 3 MPa, with slightly higher value (around 0.4 MPa) for the clay-pellets mixture.

CONCLUSIONS

This research focused on the swelling pressure behavior of clayed materials intended as potential barriers materials for the safe isolation of the HLW/SNF. The process for manufacturing the granular clay-pellets samples was introduced together with the constant volume cells developed at Texas A&M University to investigate the swelling behavior of expansive clays. It has been shown that both materials developed similar maximum values of swelling pressures. However, the patterns associated with the swelling pressures evolutions are different, owing to the different pore structures associated with these two materials, which impact on the kinetic of clay hydration and swelling pressure evolutions.

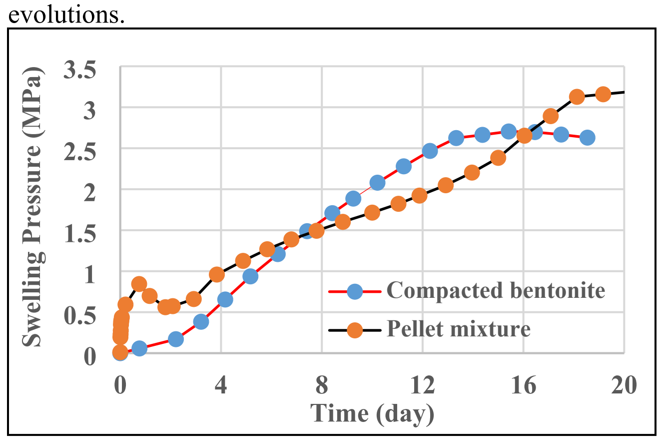

Fig. 5. Swelling pressure test results for compacted bentonite and clay-pellets mixture samples.

ENDNOTES

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REFERENCES

[1] M. SÁNCHEZ, B. POMARO, A. GENS, “Coupled THM analysis of a full-scale test for high-level nuclear waste and spent fuel disposal under actual repository conditions during 18 years of operation”. Géotechnique, 1-43 (2021).
[2] Z. LIU, W. YE, Z. ZHANG, Q. WANG, Y. CHEN, Y. CUI, “Particle size ratio and distribution effects on packing behavior of crushed GMZ bentonite pellets”. Powder Technology 351, 92–101, (2019).
[3] C. IMBERT, M.V. VILLAR, “Hydro-mechanical response of a bentonite pellets/powder mixture upon infiltration”. Applied Clay Science 32, 197–209, (2006).

[4] A. GENS, B. VALLEJAN, M. SÁNCHEZ, C. IMBERT, M.V. VILLAR, M. GEET, “Hydro mechanical behavior of a heterogeneous compacted soil: experimental observations and modelling”. Géotechnique 61, No. 5, 367–386, (2011).
[5] M. SÁNCHEZ, A. GENS, M.V. VILLAR, S. OLIVELLA, “Fully Coupled Thermo-Hydro-Mechanical Double-Porosity Formulation for Unsaturated Soils”. International Journal of Geomechanics 16(6): D4016015, (2016).
[6] A. GUERRA, Y. CUI, N. MOKNI, P. DELAGE, M. BORNERT, P. AIMEDIEU, A. TANG, F. BERNIER, “Investigation of the hydro-mechanical behavior of a pellet/powder MX80 bentonite mixture using an infiltration column”. Engineering Geology 243, 18–25 (2018).
[7] M.V. VILLAR, M. SÁNCHEZ, A. GENS, “Behavior of a bentonite barrier in the laboratory: Experimental results up to 8 years and numerical simulation”. Physics and Chemistry of the Earth. 33: S476-S485, (2008).
[8] M. SÁNCHEZ, A. GENS, L. GUIMARAES, S. OLIVELLA, “A double structure generalized plasticity model for expansive materials”. Int. J. Numer. Anal. Meth. Geomech., 29:751–787, (2005).