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Long term chemo-hydro-mechanical behavior of compacted soil bentonite polymer complex submitted to synthetic leachate

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ABSTRACT

An experimental program is carried out to investigate the long term hydro-mechanical behavior correlated with chemical one of compacted soils with low concentration of Ca-bentonite and Ca-bentonite polymer mixture. The effect of prehydration on the hydraulic performance is compared to the polymer adding effect. All specimens are submitted to synthetic leachate (LS) under different permeation conditions. Several issues are studied: mechanical stability, hydraulic performance, chemical exchange of cations validated with microstructure observations. Scanning Electron Microscope (SEM) observations demonstrate two distinct behaviors: dispersive for Bentonite (B) and B with Polymer P1 (BP1) and flocculated for B with Polymer P2 (BP2). Direct shear tests show that bentonite adding increases the Soil (S) cohesion and decreases the friction angle. Polymer adding behaves similarly by maintaining the soil cohesion and increasing the friction angle. Hydraulic conductivity of prehydrated soil bentonite (SB) and direct permeation of polymer added soil bentonite are studied (SBP1 and SBP2). Hydraulic test duration are in range of 45 days to 556 days long. Prehydration allows to delay the aggressive effect of the LS in short term but seems to increase its negative effect on the hydraulic conductivity value in long term exposure. SB and SBP1 behave similarly and seem to act in the long term as a granular filler effect. SBP2 presents positive results comparing to the other mixtures: it maintains the hydraulic conductivity and the chemical resistance. Chemical analysis confirms that all specimens are subjected to Na⁺ dissolution and Ca²⁺ retention which are more pronounced for prehydrated specimen. The short term effect of prehydration and the positive effect of SBP2 are also confirmed.

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1. Introduction

Demographic growth leads to an increase of household waste production. Presently, it is becoming increasingly difficult to find sites dedicated to the construction of waste storage facilities with the agreement of the entire population. An alternative should be considered into increase the existing municipal solid waste disposal capacity to receive large amounts of waste. Several issues must be taken into account: workability of materials, movement of machines, compactness of soil, mechanical stability, hydraulic performance, short-term chemical resistance and the long term one.

Bareither et al. (2012) stated that waste loading coupled with decomposition decreases the compressibility (Cc) owing to removal of compressible organic solids and stiffening of the waste matrix. According to Stoltz et al. (2010), in France, waste from landfill contains 54% of biodegradable matter.

Different processes are tested to accelerate the waste degradation in order to gain a volume of storage. One of these processes is the bioreactor. Leachate is pumped and reinjected into the waste in order to activate the organic matter degradation. The reinjection of leachate increases its aggressiveness and induces a need of strong passive barrier performance in case of leakage of the active barrier.

French regulation recommends an average lifespan of 30 years for waste storage structures.

Longevity of the waste storage structure under a unit hydraulic gradient can be approximated to the time required for a drop of leachate to pass through a compacted soil layer of 1 m thick with a hydraulic conductivity coefficient of 10⁻⁹ m/s. The design of waste storage facility is mainly based on criteria related to hydraulic flow of leachate through the sealing barriers.

To achieve this lifetime, bentonite is known to be used to enhance hydraulic performance of soil in place when they do not meet the criteria of hydraulic conductivity set by the regulations (Razakamanantsoa et al., 2008; Couradin et al., 2008). Bentonite is a phyllosilicate with Tetrahedral-Octahedral-Tetrahedral structure (T-O-T structure). The mineral composition is mainly dominated by montmorillonite, a member of smectite group. Montmorillonite is naturally constituted of sodium (Na⁺) which is the primary mineral of the platelets whose outer surfaces are negatively charged (Grim, 1968). Sodium bentonite is usually used to control the flow of contaminant transport because of the low hydraulic conductivity with water. In contact with the water, clayey material constitutes an immobile water phase that reduces the hydraulically active pores responsible of flow condition (API, 1971) and transport (Jo et al., 2001; Kolstad et al., 2004).

According to Mc Bride (1994), the effectiveness of the bentonite as containment barrier is intimately linked to the osmotic absorption of water molecules between montmorillonite platelets, which occurs as swelling in macroscale.

Katsumi et al. (2008) confirmed that the low hydraulic conductivity of clayey material is attributed to osmotic swelling. The soluble cations included between the crystal interlayer spaces play an important role in the swelling of the bentonite. Presence of multivalent cations limit the expansion of the crystal layer and cause a loss of swelling accompanied with loss of hydraulic performance.

The potential of osmotic swelling depends on the ionic strength of the hydrating solution and the quantity of monovalent cations (Jo et al., 2005; Benson and Meer, 2009; Scalia and Benson, 2011).

In that case, the chemical resistance of the bentonite is very important because, the concentration and valence of electrolyte component of the permeant solutions affect the swelling and chemical performance of bentonite.

High ionic strength and domination of multivalent cations (ex. Ca²⁺) reduce the osmotic swelling and cause an increase of the hydraulic conductivity. Low hydraulic conductivity occurs when the exchange is composed predominantly of monovalent cations with low to moderate ionic strength (Shackelford et al., 2000; Jo et al., 2001; Kolstad et al., 2004; Katsumi et al., 2008). Field study shown that dissolution of calcite (CaCO₃) as an accessory mineral in bentonite or in soil can be a source of exchange of Ca²⁺ (Scalia and Benson, 2011; Guyonnet et al., 2005).

Aldaef and Rayhani (2014) studied the influence of the combined temperature and leachate exposures on the compacted clay liners (CCL). They concluded that the reduction of hydraulic conductivity value due to leachate permeation was slower at high temperature. This mechanism is attributed to the lower viscosity of permeant fluid and a lower clogging of the CCL at high temperature (55 °C).

Sensitivity of Na bentonite to chemical interactions has spurred development of amended bentonite for hydraulic barrier applications (Kolstad et al., 2004; Katsumi et al., 2008; Ashmawy et al., 2002; Razakamanantsoa et al., 2012).

Use of chemically modified bentonite appears as an alternative solution against the permeation of multispecies electrolyte. Several types of process are developed to reinforce calcium bentonite properties, in order to improve the bentonite swelling ability and chemical resistance. These properties were enhanced by activation with Na₂CO₃. By so, the activated Ca-bentonite can have the same hydraulic properties as sodium bentonite with water: good swell ability and low hydraulic conductivity. However, long term exposure of the activated calcium bentonite to multispecies fluids

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