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Effect of landfill leachate on the hydromechanical behavior of bentonite-geomaterials mixture

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HIGHLIGHTS

- MSW Leachate reduces compressibility and hydraulic conductivity.
- MSW Leachate increases unconfined compressive strength and tensile strength.
- MSW Leachate led to an increase in the cohesion C_{uu} value and a decrease in the fraction angle φ_{uu}.

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ABSTRACT

The paper presents an experimental study on the compressibility, conductivity hydraulic (k_{sat}) shear strength, unconfined compressive strength and unconfined tensile strength and chemical characteristics of compacted bentonite-geomaterials mixtures used as landfill bottom liners. To complete each experiment, MSW landfill leachate was used to determine the stress of strength under the effect of pollution on the mineralogy of the optimal mixture (the least permeable mixture). All three materials used in this study, including bentonite and two types of geomaterials (tuff and calcareous sand (crushed sand)) were obtained in the Laghouat, South Algeria, region. First, a study of the geotechnical properties of all selected materials and mixtures (under the effect of leachate) was carried out. A mineralogical survey was also conducted on these three materials to better understand the experimental results obtained. Measurements of the pH and EC of leachate-contaminated mixtures indicated a decrease in pH values and an increase in EC values. Interaction results of these mixtures with the MSW landfill leachate indicated that it the compressibility behavior, decrease the saturated hydraulic conductivity and increase the compressive strength and tensile strength. As for shear strength, an increase was observed in shear strength with an increase in calcareous sand content. The shear strength of the previously contaminated optimal mixture is shown an increase in the cohesion and a decrease in the friction angle. This observation was demonstrated by the Fang and Hirst (1973) method (Modified Mohr-Coulomb failure criterion). Finally, a consolidated drained study of the optimal mixture was carried out using a triaxial test. Results showed that the optimal mixture behavior is normally consolidated, and the internal friction angle value has attained 35°. It can be summarized that the 10% bentonite – 20% calcareous sand – 70% tuff mixture (named: $B_{10}CS_{20}T_{70}$) meets the design requirements for landfill bottom liners.

1. Introduction

The geological quality and natural protection of groundwater resources is certainly the main and best-known environmental criterion for design a new landfill. A major criterion is to have a large surface area and a volume available in the long term. Another point is to have a good local availability of earth materials to cover the construction work or the different stages of the landfill. Controlled landfills require a large volume of these materials to cover the waste. This can be achieved partly by using inert building materials (e. g. crushed sand), but neighboring quarries are also necessary to provide the necessary equipment. These local quarries can also be the following cells of the landfill. Otherwise, transportation costs will be too expensive to be efficient.

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An impermeable bottom liner is important to reduce leachate infiltration (garbage juice) into the groundwater. Compacted bottom liners in a landfill site are usually constructed of geosynthetic clay liners (GCL), soil-bentonite, cement-bentonite and different local materials [1–3]. Several studies propose the use of mineral layers from locally available materials. Also, the use of sand in prepared mixtures with low bentonite content provides load support that improves macroscopic hydromechanical stability [4]. In addition, these mixtures are less sensitive to freezing damage and reduced potential for volume changes during the drying-wetting cycle than pure clay-liners [2–5]. This requires geotechnical knowledge to find good material in the region that can be compacted, with high density and low permeability.

As a result, sufficiently thick soil-bentonite mixture layers can act as barriers to the migration of many hazardous polluted. Typically, saturated hydraulic conductivity of $k_{sat} \leq 10^{-9}$ m/s, shear strength (internal friction angle: $\varphi' \geq 25°$), chemical resistance (structural stability of mineralogy), low compressibility, low shrinkage-swelling effects and/or no impact and compressive strength ($\sigma_c > 200$ kPa) are required in the design of landfill technical linings by various publications worldwide [6–12]. On the other hand, compacted soil liners and covers must be resistant to the tensile cracking stresses generated in most cases by desiccation (during construction or after landfilling), machine loads or differential settlement. Tensile cracking can negatively affect structural performance, especially on unsaturated soils, by reducing the overall strength and load-bearing capacity of the soil liner, thus increasing the hydraulic conductivity of hydraulic barriers [13]. Therefore, it can be observed that there are important parameters that have a significant effect on the tensile behavior such as the type of soil and the effect of water content (or suction) on its condition (saturated or unsaturated). Barzegar et al. [14] and Tamrakar et al. [15] showed that tensile strength increases as the proportion of clay and fine grain increases in the sandy soils (due to the increase in the plasticity index). Tamrakar et al. [15] indicated that the higher the water content, the more similar the tensile strength and suction values are for clay-sand mixtures; however, the lower the water content, the greater the difference increases with decreasing water content.

The Laghouat geology region in southern Algeria is represented by very thick marl and calcareous rock complex at the base and a tuff crust grouping at the surface (from about 20 cm to about 2 m). In these areas, due to precipitation (100 mm < H < 350 mm per year, at an irregular rate) in winter and high waste moisture (76% of organic waste) in landfills and open dumping, leachate leaks can lead to soil and groundwater contamination. However, the tuff crust has an estimated hydraulic conductivity of 3.04×10^{-8} m/s [3]. This value is similar to that found by Abeel et al. [16] for tuff in the Los Alamo area (New Mexico - United States). Several researchers have studied mechanical behavior to assess the cohesion of tuff and calcareous sand (crushed rocks waste) under dry and wet conditions [17]. Cohesion for these materials depends on suction and cementing with $CaCO_3$ carbonate (by sedimentation process) [17,18]. The addition of sand to the tuff to increase the cohesion of the compacted backfill after full saturation [19,20]. The mechanical behavior of compacted 20% calcareous sand-80% tuff mixture uses a modified Proctor with presented an effective cohesion C' value of about 56 KPa and benefits a compressive strength of about 4 MPa corresponding to a gain of 8% compared to raw tuff [17]. These characteristics make tuff a good local material to add to bentonite for use as a landfill bottom liner.

Iravaniana and Bilsela [13] demonstrated that unconfined compressive strength extends to its highest interest in 90 days for both the 85% sand-15% bentonite mixture and the 85% sand-10% bentonite-5% cement mixture, which 90% strength is obtained in 28 days of curing. The maximum 90-day value was approximately 300 kPa and 1900 kPa for the sand-bentonite mixture and the sand-bentonite-cement mixture, respectively. For shear strength, Wood and Kumar [21] and Vallejo and Mawby [22] shown that shear strength is controlled by the cohesive state when the clay fraction is greater than 40% and by the granular state when the sand fraction is greater than 75% [8].

The effect of leachate on the hydromechanical properties of the soil-bentonite mixture was not treated as the effect of chemical solutions. Glatsteina and Francisca [23] showed that the hydraulic behavior of a compacted 90% silt – 10% bentonite mixture can be modified by stimulating microorganisms in the pores of the mixture by injecting the nutrient. The authors observed that the decrease in hydraulic conductivity from 3×10^{-9} to 5×10^{-11} m/s due to the accumulation of microbial biomass in the pores of the mixture. The authors concluded that biological soil monitoring is useful when the impact of microorganisms is understood in terms of increasing or decreasing the hydraulic conductivity of the silt-bentonite mixture.

Thullner et al. [24] and Dupin and McCarty [25] observed a similar trend for sandy soils. The authors summarize that the growth of the microorganism (present in the landfill leachate) can help to reduce the bentonite content required to achieve a hydraulic conductivity of less than 10^{-9} m/s. Li et al. [12] examined the permeability of the 92.5% sand – 7.5% bentonite mixture by three types of liquid including tap water, landfill leachate (MSW) and industrial leachate (Perfluorinated compounds PFC = 0.01 mg/l). The authors showed that the hydraulic conductivity was almost constant for all three-test cells, between 10^{-12}–10^{-11} m/s. Alawaji [26] concluded that the volume compressibility of the sand-bentonite mixture decreases with the increasing concentration of $NaNO_3$ and $Ca(NO_3)_2$ in the saturation liquid. Dutta and Mishra [27] showed that the effect of various concentrations of $CaCl_2$ and NaCl on the consolidation behavior of two bentonite varying mineralogy. The results show that the compression index C_c, the coefficient of volume changes m_v and the time t_{90} required for 90% of the consolidation of bentonite decreased; while the coefficient of consolidation C_v increases with increasing salt concentration, indicating that samples were consolidated more rapidly in saline solution than in water. Ray et al. [28] showed that the increase in heavy metal concentration (Cu^{2+} et Zn^{2+}) (0.5 and 1000 mg/L), C_c, m_v and t_{90} of bentonite decreased, while C_v increased.

Watanabe and Yokoyama [29] achieved undrained shear strength used triaxial cells, which showed that the internal friction angle (φ') of the compacted pure bentonite (B) and compacted 70% sand-30% bentonite (SB) mixture (OCR > 2) saturated with distilled water was 26.6° and 28.6°, respectively, and after immersion with NaOH and $Ca(OH)_2$ was 32.5° (B)/34.5° (SB) and 23.8° (B)/15.4° (SB), immersed for 273 and 322 days, respectively. Thereafter, the internal friction angle in NaOH solution is reduced to near the initial value (with water) of the bentonite and sand-bentonite mixture immersed for 532 and 581 days.

The aim of this study is to examine the behavior of local materials (cover crusts and crushed sand) in the interaction of landfill leachate, which is use as a landfill bottom liner. Thus, a series of oedometer tests, unconfined compressive strength, tensile strength, shear strength and chemical characteristics tests were carried out to study the influence of MSW leachate on the hydromechanical behavior of mixtures with bentonite, calcareous sand (cracked rocks waste) and tuff. Compressibility, shear strength and compressive strength are important characteristics of landfill liner construction and have not yet been clarified of soil –bentonite mixture with landfill leachate interaction.

The reminder of the paper is organized as follows: Section 2 provides the context for this study. Section 3 presents the