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Geotechnical characterization of geomaterial blends with Bentonite of Maghnia for use as landfill liners

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ABSTRACT — Compacted soil-bentonite mixtures are often chosen as a liner material in landfill applications. Saturated hydraulic conductivity of $k_{sat} \leq 10^{-9}$ m/s and shear strength (friction angle: ϕ>25°) are required in the design of engineered barriers. The effects of the bentonite additions are reflected in lower water permeability, and relatively acceptable shear strength. The first step in this study consists in presenting the results of the physical and chemical tests of the characteristics of tuff, calcareous sand and bentonite used for the experiment, which are available local materials in Laghouat and Maghnia (Tlemcen) regions respectively. After that, a study of the hydraulic characteristics of the mixtures containing 10% bentonite +% calcareous sand+% tuff was conducted through free swelling test and the oedometric test. A mechanical study of the characteristics of these mixtures compacted with the optimum Normal Proctor condition was carried out by means of direct shear test and unconfined compression test. Finally, results show that a mixture of 10% bentonite, 20% calcareous sand and 70% tuff meets the requirements of hydraulic conductivity and shear strength. The mixture represents a readily material available alternative for the design of barrier liners.

Keywords: *landfill liners, hydraulic conductivity, shear strength, unconfined compression, bentonite, calcareous sand, tuff*

I.Introduction

In Algeria, until the end of 2001, there was enter the Geotechnical engineering and legal instruments for the wastes management in the landfill practices and a lot of concern about the impact of wastes on the environment. In socioeconomic situations such as that of developing countries, the discharge is usually considered the only way for household wastes disposal [1]. According to the Chief Minister of Planning, Environment and Tourism of Algeria (MPET, 2015), Algeria was too installed 124 landfill sites on the national territory for minimizing the quantity products of domestic wastes (10, 3 million tons / year).
The safety of these centers is based on sustainability and reliability of manufactured and natural materials that constitute them. For this, the Algerian regulations impose, in the bottom of landfills sites, the presence of a layer contains material with a maximum hydraulic conductivity of 10^{-9} m/s.

That is why the clayey soils or the sand-bentonite mixture is often used as passive barriers in these processing units targeting an aim of slowing down the migration of pollutants into the groundwater (Fig.1). The abundance of tuffs in our country, which covers an area of about 300,000 km^2 [2]. Particularly in arid and semi-arid areas, tuff and calcareous sand present a cheap alternative to sand as an additive to the bentonite, which be used as a passive barrier meeting the recommendations for the realization of funds bottom waste disposal site. Previous studies have shown that the hydraulic conductivity of a mixture of 6% bentonite at most and 94% tuff is almost equal to 10^{-10} m/s [3]. Kouloughli, (2007) shows that a sand-bentonite mixture with a content of 10% bentonite and compacted to about 2% from the

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wet side of the optimum Normal Proctor either moisture content of 15% is qualified to serve in the realization at landfill sites that meets the standards for hydraulic conductivity and provides a good stability (angle of internal shear mixing relatively high 25°) [4].

This paper studies the reuse of a local material basis of calcareous sand, tuff in Laghouat region and bentonite of Maghnia for use as landfill liner. Characteristics of the barrier (i.e. barrier material, geometry, alignment, and depth) are the most important factors that should be considered in design. Thus, the significant characteristics of the present study are: (1) characterization of calcareous sand, tuff and bentonite used for the experiment, (2) Hydro-mechanical studies on calcareous sand, tuff and bentonite mixtures for engineering barriers and (3) based on the results obtained, results proposed a formulation that meets the regulatory criteria ($k_{sat} \leq 10^{-9}$ m/s and $\phi \geq 25°$) will be adopted.

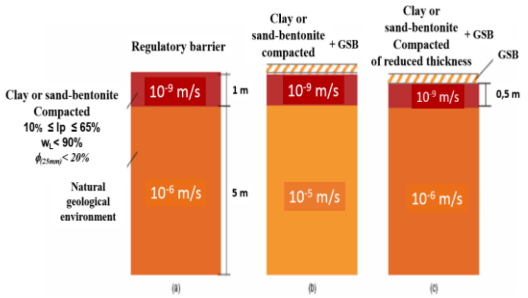

Fig. 1 Different layer of a passive waterproof barrier: (a), (b) and (c); GSB: Bentonite GeoSynthetics.

II. Materials and methods

II.1. Materials and characteristics

A Three basic materials have used in this investigation. The first material is bentonite of Maghnia; it is extracted from the Hammam Boughrara deposit (Maghnia -Tlemcen). It is untreated and finely crushed [5]. The results of particle size analysis of the bentonite show that over 60% of the grains have diameters less than 2 µm (Fig. 2). The results of the chemical analyses are summarized in Table 1. Its main mineral constituents are silica (55-65%) and the alumina (12-19%). The ratio SiO_2/Al_2O_3 varies between 3.4 and 4.6, this is in agreement with that of the bentonite or this ratio must be between 2 and 5.5 [6]. With a liquid limit (LL) of 141% and a plasticity index (PI) of 93%, the bentonite of Maghnia is classified as very clayey soil and very plastic (At) according to the USCS classification. According to the equation of Tran Ngoc, 1981, based on the total specific surface determined from the test to the methylene Bleu [7], bentonite of Maghnia shows the presence of a high percentage of montmorillonite.

Table 1. Chemical analysis of bentonite Maghnia

B	*SiO_2*	*Al_2O_3*	*Na_2O*	*CaO*	*K_2O*	*MgO*	*Fe_2O_3*	*PF*
%	*55 – 65*	*12– 19*	*1 – 3*	*1 - 2*	*0,5– 1,18*	*2 – 3,4*	*1 – 3,4*	*8,2*

Table 2. Chemical analysis of Tuff and calcareous sand

Elements	*Tuff*	*Calcareous sand*
pH	7.64	9.32
Insoluble (%)	27.7	17.2
$CaCo_3$ (%)	66.00	55.00
$CaSo_4.2H_2o$ (%)	0.46	0.52
NaCl (%)	0.057	-
Mg (mg/kg)	950.00	860
NH^+_4 (mg/kg)	27.00	44
CO_2 Aggressive (mg/kg)	56.00	Traces
Classification of aggressive environments according to the standard NF P 18-011	Weakly Aggress -ve	Weakly Aggressive

Both calcareous sand and tuff materials were sifted through sieve N° 5 mm. The particle size analysis of calcareous sand and tuff are made according to standard test NF P 94-056 (Fig.2) [7]. The results of particle size analyze are shown in Table 3. From these curves, the uniformity and curvature coefficients of calcareous sand are respectively Cu =18.783 and Cc =2.264. It is classified (using the USCS) among clean and well-graduated sands with silt (SW-SM). For the tuff, the uniformity and curvature coefficients are respectively Cu =6.57, Cc =0.4. Hence, the tuff ranks as a silty sand (SM). The maximum dry density and optimum moisture content were determined according to the NF P 94-093 standard [7]. According the results of Atterberg limits [7], tuff and calcareous sand are classified as low-clay soil. This corresponds with the results of similar tests carried sand according to EN 933-8 standard and shows that the calcareous sand and tuff are slightly clayey sands with SE = 70%, SE = 30% respectively.

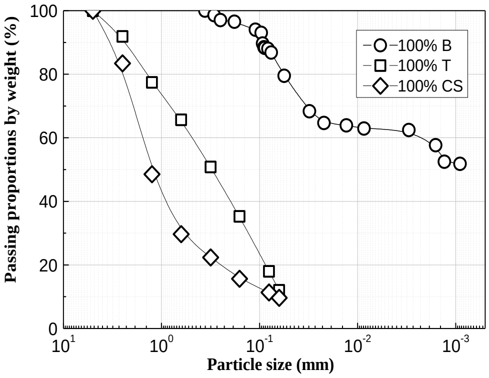

Fig.2 Grain size distribution of Bentonite (B), Tuff (T) and Calcareous Sand (CS).

Table 3. Physical, mechanical and chemical characteristics for Calcareous Sand and tuff

Parameter	**tuff**	***calcareous sand***
$\Phi \leq 80\mu m$	18%	11,5%
$\Phi \leq 2mm$	85.46%	67.8 %
C_u	6.57	18.8
C_c	0.4	2.3
ES	30%	70%
V_B *(0/2)*	0.84	0.35
$S(m^2/g)$	17	7
LL (%)	33	17
LP (%)	25	-
PI (%)	8	/
G_S	2.7	2.7
$\gamma_{dmax}(kN/m^3)$	17,2	19,5
w_{opt} *(%)*	*13.85*	*8.75*

As part of reuse the local materials (tuff and calcareous sand) from the region of Laghouat and the bentonite of Maghnia, five mixtures containing 10 % of bentonite, different percentages of the calcareous sand and different percentages of tuff. Are used:

- *Mixture 1 : 10% B + 10% CS+80% T,*
- *Mixture 2 : 10% B + 20% CS+70% T,*
- *Mixture 3 : 10% B + 30% CS+60% T,*
- *Mixture 4 : 10% B + 45% CS+45% T,*
- *Mixture 5 : 10% B + 60% CS+30% T.*

(With, B : Bentonite ; CS : Calcareous Sand ; T : Tuff)

The Normal Proctor test is carried on different mixtures. Figure 3 shows the influence of the addition of calcareous sand on the optimum characteristics of compaction. The incorporation of calcareous sand permit to improve the material by increasing its maximum dry density of from 16.625 to 17.825 kN/m^3 and reducing the optimum moisture content of 14.4% to 9%.

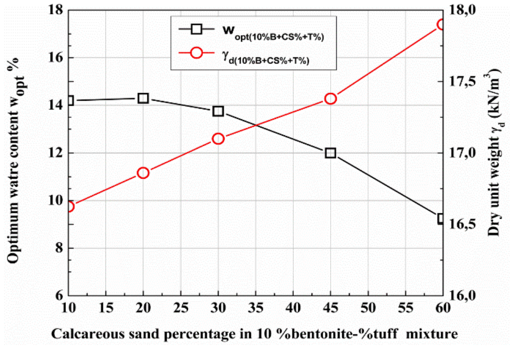

Fig. 3 Effect of calcareous sand percentage on Proctor Normal parameters mixtures.

II.2. Methods

II.2.1. Free swelling tests

Swelling tests are carried out using a classical odometer. Dimensions of samples are 50 mm in diameter and 20 mm in height. The test is realized according to the free swelling method [8]. The 10% bentonite-% calcareous sand-% tuff mixtures samples are prepared by a static compaction (at a displacement rate of 1.27 mm/min) for water contents and dry densities corresponding to the optimum Proctor condition. This free swelling test presented by Cowland in 1990 [9] shows a good correlation with the hydraulic conductivity tests. The total free swelling G (%) is computed using the following relation:

$$G(\%) = \frac{\Delta H}{H} x100 \qquad (1)$$

where H_0 is the initial height (before swelling), H_f is the final height (after swelling), and H is the height of specimen.

II.2.2. Saturated Hydraulic conductivity, an indirect method test

The indirect methods for evaluating saturated hydraulic conductivity (k, m/s) is based on the results of the odometer test (permeameter with rigid walls). The odometer test consists of vertical consolidation. For all mixtures, a specimen with 50 mm in diameter and 20 mm in height is prepared by static compaction at optimum normal Proctor condition. The specimen is placed in a metal ring and saturated for 24 h. In this study, the odometer test of 24 h incremental loading was carried out to investigate the variation of hydraulic conductivity during consolidation. An incremental loading ratio σ'_{i+1}/σ'_i of 2 is used (σ'_i (kPa)) is the vertical stress applied) according to geometric progression. The applied vertical stress to the specimen was from 10 kPa to 800 kPa [11]. The hydraulic conductivity (k) is obtained from both the coefficient of consolidation C_V (m^2/s) evaluated by Taylor's approach and the coefficient of volume compressibility m_v (kN/m^2) (see Eq. (2)). In this method, the coefficients C_V and mv are deduced from compressibility curves and consolidation curves, respectively, in order to obtain the hydraulic conductivity. In this study, the hydraulic conductivity k is written as:

$$k_{sat} = C_v \times m_v \times \gamma_w \quad (2)$$

II.2.3. Direct shear strength test in partially saturated sample

As stated above another important property, for these insulation barriers, is their mechanical behavior. In this section, the shear strength for different mixtures is investigated. The direct shear test in the box has used to determine the parameters of the shear resistance of cohesion and the angle of internal friction of 10% bentonite-% calcareous sand- % tuff mixtures according to NF P 94-071-1[7]. Thus, the unconsolidated undrained (U.U) direct shear test is used. This test allows studying the short-term behavior of the soil in place. The dimensions of the samples are 60x60x20. The values of the friction angle and cohesion are obtained analytically from the Coulomb law:

$$\tau = C_u + \sigma tg\phi \quad (3)$$

Where, τ : Total shear strength (kPa) ; σ : Normal stress (kPa); ϕ : Total friction angle (degrees); C_u : Total cohesion (kPa).

The samples have been compacted by static compaction to a speed 1.27mm/min according to optimum Normal Proctor conditions (w_{opt} and γ_{dmax}) of each mixture. For each direct shear test, three normal constraints have been used 100, 200, and 300 kPa with a speed of slow shear of 0.5mm /min.

II.2.4. The unconfned compression test

Sometimes a very rapid estimate is required of the shear strength of a slow-draining soil, but it is necessary to test a reasonably sized soil element (e.g. on an earthworks scheme a minimum shear strength of around 40 kN/m^2 might be required for earth-moving traffic). Consequently, a test is to follow the hardening phenomenon, called self-stabilizing, specimens of different mixtures compacted by measuring the change in time of the strength to simple compression and index used for assessing the cohesion of compacted materials ($C_u=R_c/2$) [10-11].

The cylindrical specimens (of dimensions φ = 50 mm, H = 100 mm) were prepared from the 0/5 mm fraction of all mixtures. The mixture was statically compacted at the optimum PN (v = 1.27 mm/min) in a double-piston mold making it possible to homogenize the stress over the entire height of the test piece. The sample is placed between two platens, one of which is fixed and the other movable (Fig.4). The compression tests were performed at age 0, 3, 7, 14 and 28 days. Indeed, each specimen is subjected to a compression force applied parallel to the axis of the cylinder by means of a piston at a constant speed of 1.27 mm / min until rupture.

Fig.4 The unconfined compression test.

III. Results and discussions

III.1. Results of free swelling

The curve of figure 5, represents the relative variation of height according to the logarithm of time [ΔH/H= f (log (t))]. From the curve, two phases are distinguished for swelling: a primary swelling that takes place very early, and a secondary swelling, which the linear portion of the curve [12].

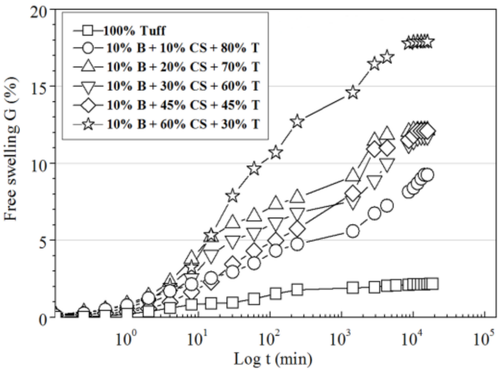

Fig. 5 Free swelling evolution in function of the time.

The trend of the change in free swelling with time is the same for all mixtures. From the curves, the maximum values of swelling are obtained with mixtures 20% and 60% of the added calcareous sand, which achieve a swelling ratio of 13 and 18% respectively. These results are consistent with those obtained by Chalermyanont and Arrykul, (2005) [13] that show the swelling ratio varies from 1 to 10% for bentonite percentages ranging from 3 to 9%. Mishar et al., (2011) [14] indicated that the hydraulic conductivity is inversely proportional to the exchangeable sodium percentage (ESP) and the free swelling bentonite. Therefore, there is a possibility that the mixtures, which provides low permeability value, are mixtures continent 20% and 60%CS.

III.2. Results of the hydraulic conductivity, an indirect method test

The results of the saturated hydraulic conductivity of 10%bentonite -%calcareous sand - %tuff mixtures based on the vertical stresses applied are presented in Figure 6.

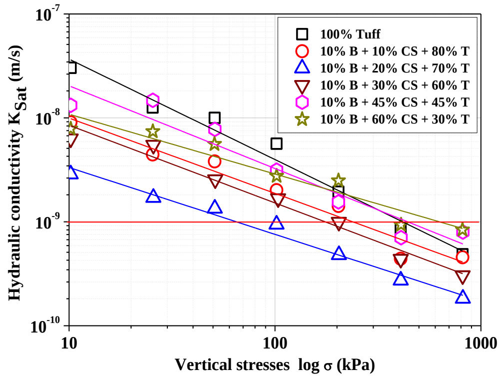

Fig.6 Hydraulic conductivity of 10%bentonite -% calcareous sand - %tuff mixtures, as a function of the vertical stress applied.

The results of hydraulic conductivity show that:

- The hydraulic conductivity decreases with the consolidation pressures applied;
- The hydraulic conductivity decreases with 20% CS (K= 1.83 10^{-10}m/s). After that percentage up to 60% of CS, the hydraulic conductivity is increased (K=8.38 10^{-10}m/s);
- The optimal mixture a low hydraulic conductivity which it is not linked with the strong swelling mixtures (for 60%CS: G=17%; k= 8,38 10^{-10}m/s). This is can be explained by the proportional increase in pores volume due to the increase of the added calcareous sand;
- The maximum dry density does not affect the permeability of the mixture;
- The oscillation curves because of the heterogeneity of the soil and hydraulic conductivity is given generally to one or two significant digits [15-16].

III.3. Results of Direct shear strength

The determination of the mechanical parameters of 10%bentonite -%calcareous sand - %tuff mixtures is obtained by tracing the lines of Coulomb (intrinsic curves) on an orthonormal reference which presents, on the horizontal axis the vertical stress (σ_{vi}) and ordered the constraints of maximum shears (τ_{imax}), (Fig. 7).

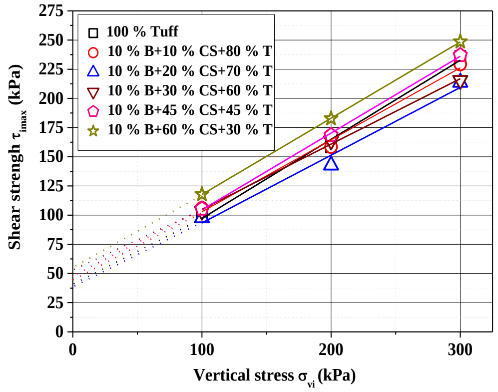

Fig.7 Shear tests compaction moisture content for the 10% bentonite-% calcareous sand -% tuff mixtures.

From Fig. 7, it is noted that the friction angle decreases with the increase of the calcareous sand added up to 30% CS. The variations in the friction angle and the cohesion of 10% bentonite -% calcareous sand - % tuff mixtures, show that the mixture which contains from 60% CS gives maximum value of C_u and ϕ ,and the mixture with 30%CS gives a minimum value of ϕ by compared the other mixtures as shown in Table 4.

Table 4. Shear properties (UU) of bentonite-% 10% limestone sand -% tuff mixtures

10%B+CS+T	*10% CS*	*20 %CS*	*30 %CS*	*45 %CS*	*60 %CS*	*100% TUFF*
w_{opt}(%)	14.2	14.25	13.75	12,00	9.25	14.00
C_u(kPa)	41.25	35.25	48.83	38.76	52.28	29.40
ϕ °	31.46	29.7	29.23	33.11	33.44	34.04

Results of the shear strength for all the mixtures provide satisfactory recommendations of stability (angle of internal shear of the mixture relatively high 25° [4]) for the artificial barriers.

III.4. Results of unconfined compression test

The evolution of the compressive strength of uncovered specimens according to the time is given in Fig.8.

These results show that the compressive strength increases in a fast way at young age (<3 days). This is explained by the rapid reduction in the water content due to the fast drying of the surface zones.

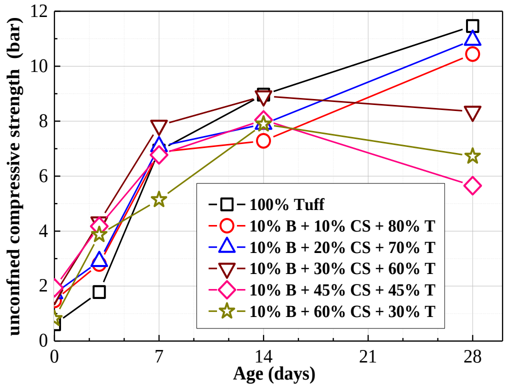

Fig.8 Effect of storage time on unconfned compressive strength for the 10% bentonite-% calcareous sand - % tuff mixtures.

The mixture contains 30% CS gives good resistance compared to other mixtures until the age of 14 days. After this age, the resistance decreases for the three mixtures 30%, 45% and 60% CS. For the tuff and the 10% CS and 20% mixtures resistance is increased until the 28 days. The reduction in resistance in the mixture is due to the material heterogeneity. The results of the compressive strength are compared the maximum waste loading on a landfill of the Laghouat region (Center Ben Nacer Ben Chohra) (Fig. 9). The waste tonnage of 5 years of exploitation is 177.870 tons and maximum volume is 153.600m^3 (at 7 m of depth). Therefore, the maximum waste pressure on 1 m^2 is 0.795 bars. It is noted that the value of waste pressure is low than the compressive strength obtained at the age of 28 days with a value of 10 bars for the mixtures containing 10% and 20% of CS. Therefore, mixtures generally satisfy in term of the recommendations compressive strength.

From Table 5, it is noted that the cohesion values obtained for the shear load are lower than those obtained for the compression test except for the mixture, which contains 60% CS. This is because the vertical, effective stress is often the major principal stress and this stress has been found to play the major role in the compression and shear of soils (Lee and Seed 1967).

Table 5. Comparison between the cohesion values.

10%B+CS+T	*10% CS*	*20 %CS*	*30 %CS*	*45 %CS*	*60 %CS*	*100% TUFF*
C_u(kPa)	41.25	35.25	48.83	38.76	52.28	29.40
$C_u=R_c/2$ -0 days	73.84	86.58	84.03	96.76	40.74	30.55

Fig. 9 Location of landfill site - Measuring scale: 2km and 100m.

IV. Conclusions

The interest of this investigation lies in the presentation of an original methodology based on the valorization of local materials by 10% bentonite, and the combination of different percentages of calcareous sand and tuff.

It is concluded that the mixture based on 10% of bentonite -20% calcareous sand and 70% tuff named $B_{10}CS_{20}T_{70}$ adopted perfectly meets the requirements of the regulations and constitutes an economical material for the barriers conception.

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