



EFFECT OF ADDING DUNE SAND ON THE GEOTECHNICAL AND MECHANICAL PROPERTIES OF A CLAY

MEZIANI Faroudja^{1*}, KAHIL Amar¹

¹ Civil Engineering Department, University Mouloud MAMMERI, Tizi-Ouzou, Algeria.

*Corresponding author: mfaroudja@yahoo.fr

Reçu le: 14/05/2023

Accepté Le: 04/07/2023

ABSTRACT

This present research work consisted in the study of the mechanical behavior of a clay partially substituted by dune sand, which is found in an abundant way in Algeria (60% of the national territory). This sand has characteristics that allow to anticipate a valorization in the field of geotechnics, particularly for the improvement of the mechanical characteristics of clayey soils. The objective of this work was to experimentally evaluate the influence of dune sand on the mechanical behavior of clay. An experimental program was conducted on samples of clay comprising 4, 6 and 8% dune sand as addition, through identification tests, Proctor, and shear strength measurements. The objective was to improve the use of dune sand from southern Algeria that is abundant in almost inexhaustible quantities. This study has shown a high mechanical performance of natural clay treated with dune sand.

Keywords: Clay, dune sand, mechanical behavior, Proctor, shear strength.

1. INTRODUCTION

Clay soils are composed of fine particles and are generally characterized by high plasticity, low strength and high sensitivity to water content variation, observable through volume changes [1]. Swelling and shrinkage deformations are likely to cause a lot of damage to constructions [2, 3]. However, there are many applications for clay soils in the field of civil engineering construction, either as natural soil (foundations, slopes, retaining walls, excavations) or as compacted material for construction of embankments, dams, trenches and walls [4].

As in numerous countries, clayey soils are widely represented in Algeria, where, as elsewhere, they bring their share of difficulties to construction projects. In terms of reuse, these materials are often unsuitable for use in backfills. However, their use has a great interest on an environmental and economic level [4, 5]. The treatment of clayey soils for use in civil engineering offers as a consequence an opportunity for reuse.

The treatment of clayey soils involves a set of techniques widely tested and commonly used in civil engineering construction projects [6, 7], with the objective of making it possible to reuse these materials in backfills. These techniques consist in improving the physical and mechanical performances of soils to reach the targeted goals in terms of compactness, water tightness, bearing capacity and strength [8]. These techniques can be classified into three groups: a mechanical process (compaction) [9, 10], a physico-chemical process using binders (cements, lime, fly ash) and a last process by adding inert materials (sand, marble powder). The choice of one of these techniques depends on the nature of the clay soil, its availability, the proximity of the borrow area, the type of structure to be built, and the expected performance.

The treatment techniques by addition of inert materials consist in adding to the clayey soil an inert material, such as a sand [11, 12], in a proportion to be determined, before compacting the whole. This addition makes it possible to improve the physical properties of the clay soil, by reducing its plasticity, and to improve its mechanical characteristics, with an increase in its stiffness and its resistance [13].

This work is dedicated to the study of the treatment of a clay by adding dune sand. This choice is justified by the interest that this technique presents in Algeria [14], where soils of this type exist in abundance and are used at low cost. On the environmental level, it is justified in terms of recovery of local materials [15, 16]. In this experimental program, the clay samples come from the region of FREHA in the wilaya of Tizi -Ouzou, while the dune sand comes from Oued Maiter in the wilaya of Boussaâda in Algeria (Fig. 1).



Fig.1. Maiter sand of the wilaya of Boussaâda

2. PREPARATION OF SAMPLES

The extracted clay was air-dried on a tray until it reached at least 200% gravimetric moisture. Then, the partially dried clay was sieved on a 5 mm mesh screen to remove large particles [17, 18]. The particles smaller than 5 mm were used for the mechanical testing, and the results of the particle size analysis are reflected in the curve shown in the figure 3.

The consistency of the sample is very important for clay (Fig. 2), as the water content can easily dry out. Therefore, the water content of the sample should always be checked regularly before mixing. In order to prepare the specimens, the natural clay samples were mixed with 4%, 6% and 8% dune sand. These percentages are the minimum amount that can influence the mechanical properties of the clay.

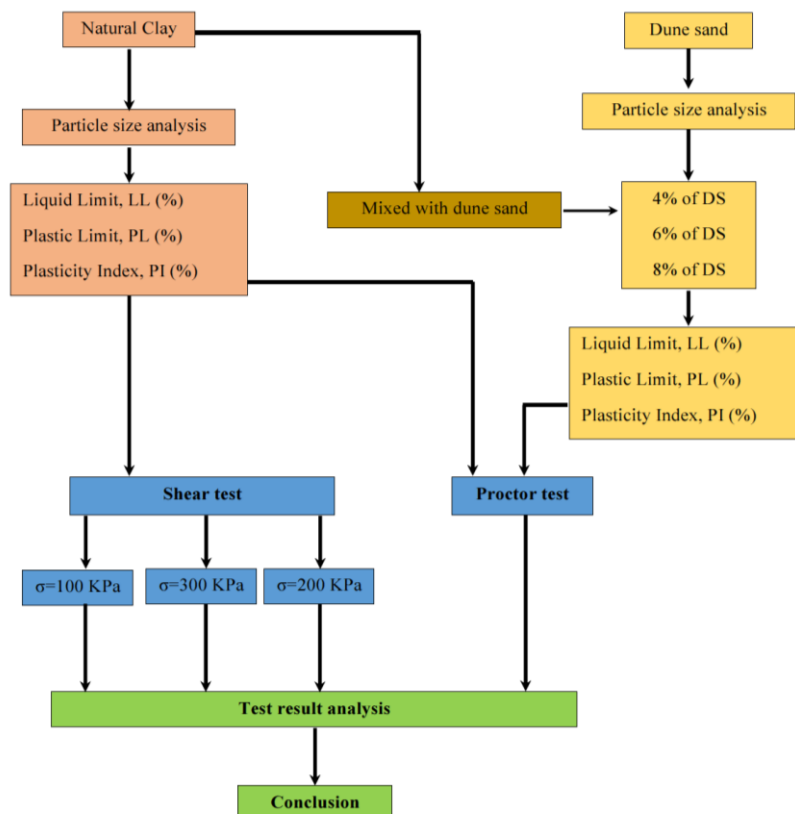


Fig.2. Diagram of sample testing

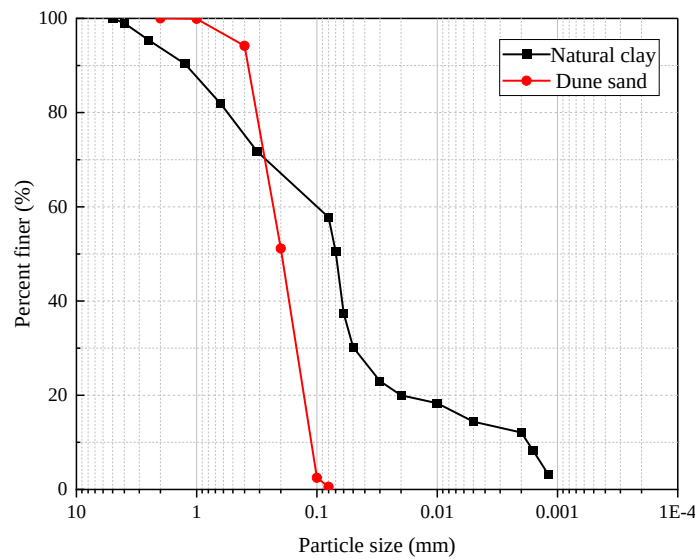


Fig.3. Grain-size distribution curves for clay and the dune sand.

To find the plasticity index of clay and clay mixed with dune sand, the Atterberg limit test was also performed according to the standard test method described by NF P 94-05 [19]. Table 1 shows the physical characteristics of the clay-sand mixes used in this study (Fig. 4).

Table .1 Characteristics of the clay soil used in this study

Characteristics	Clay	Dune Sand		
		4%	6%	8%
Liquid Limit, LL (%)	41.02	36.6	33.5	30.6
Plastic Limit, PL (%)	26.12	22.69	10.13	19.38
Plasticity Index, PI (%)	14.88	13.91	13.37	11.22

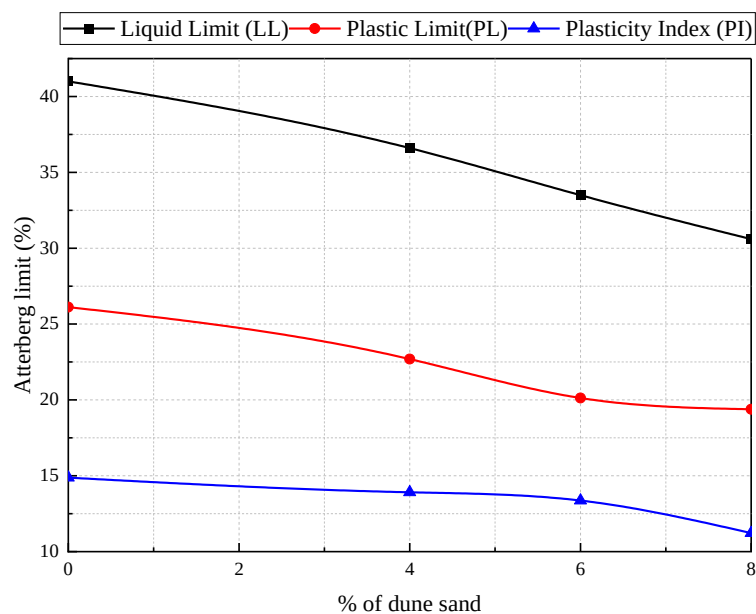


Fig.4. Influence of dune sand on the Atterberg limits

The influence of dune sand on the Atterberg limits for all the tests performed is presented in figure 4. When analyzing these results, one can see:

- A decrease of the liquid limit with the increase of the dune sand content, these variations can be the result of the change of behavior of the mixtures after the addition of inert materials: the transition of the clay from a very plastic state to a plastic state for added quantities of dune sand.
- This reduction is due to the decrease of the content of active fine elements that contribute to plasticity. Furthermore, these results show that there is not a clear link between the dosage of dune sand and the liquidity limit, which indicates that there are other influencing factors, other than the decrease of the clay fraction. It is also the decrease of the specific surface of water adsorption. And the reduction of the number of bonds between clay particles that contribute to the reduction of this liquidity limit.

This reduction is also due to the decrease of the content of active fine elements and the increase in the amount of inert materials. It also confirms the change in behavior of the material at very high dune sand content.

- The curve of shows a decrease in the plasticity index with dune sand content. This reduction is due to the decrease of the liquidity and plasticity limits. Its rate of reduction was significant because the decrease in the liquidity limit is greater than that of the plasticity limit, and since the plasticity index is nothing but the difference between these two limits, then its decrease was significant. This decrease of the plasticity index generates the reduction of the extent of the plastic domain, which confirms the transition from a very plastic material to a less plastic and therefore less swelling material.

3. PROCTOR TEST

The purpose of the Proctor test is to determine the optimum compaction characteristics of a soil, defined by a water content and a dry density for a specified compaction energy [20]. The test involves compacting samples (table 2) with different water contents, in a standardized mould, using a standardized ram and a standardized number of strokes. The Proctor curves show the variation of dry density of the soil as a function of water content. They have a maximum, which indicates the optimal searched.

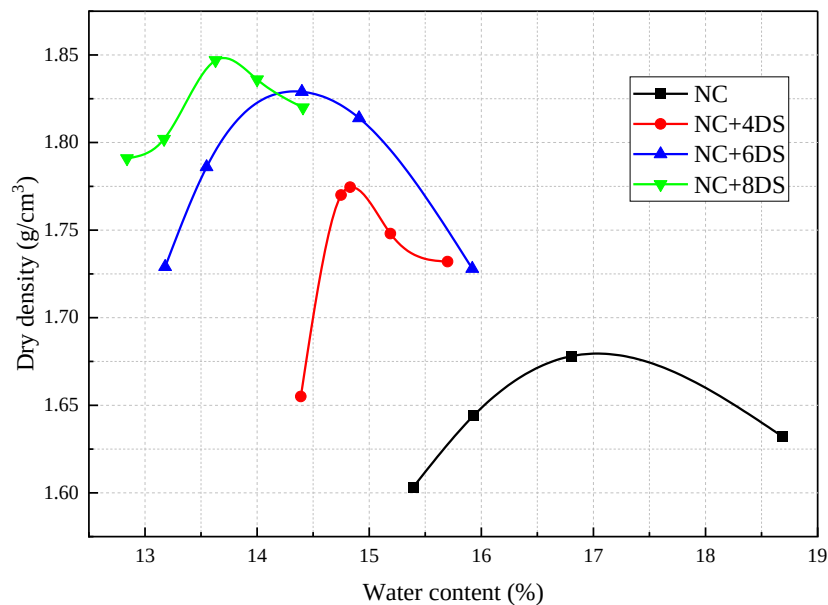
The x-axis of the Proctor curve maximum represents the optimum water content ω_{dopt} and the y-axis the optimum dry density ρ_{dopt} . There are two types of Proctor tests, depending on the compaction energy used, the normal Proctor test or the modified Proctor test.

Table .2 Mass clay and dune sand were used for the Proctor and shear test

Samples notation	Samples description	Mass of samples for proctor test		Mass of samples for shear test	
		Natural clay mass (g)	DS Mass (g)	Natural clay mass (g)	DS Mass (g)
NC	Natural clay	2500	0	700	0
NC+4DS	Natural clay + 2 % of DS	2450	50	686	14
NC+6DS	Natural clay + 4 % of DS	2400	100	672	28
NC+8DS	Natural clay + 6 % of DS	2350	150	658	42

3.1. Effect of adding dune sand on Proctor parameters

The effect of sand addition on the compaction characteristics of clay sand mixtures is shown in figure 5. These characteristics were obtained using the normal Proctor test [20]. The normal Proctor curves provide the maximum dry density and optimum moisture content of the mixtures.

**Fig.5.** Proctor curves for the different additions

The results show that the normal Proctor curves depend strongly on the addition of dune sand and its proportion in the mix. In the state plane (w , d) of figure 5, the normal Proctor curves progressively migrate to lower water contents and higher densities compared to natural clay with increasing sand proportion (Table 3). The presence of sand leads to a reduction of the pore volume.

Table .3 Proctor parameters of clay+ dune sand mixtures.

Percentage of dune sand	Wopt (%)	Density
0	16.612	1.678
4	14.784	1.774
6	14.558	1.831
8	13.698	1.848

3.2. Evolution of optimal water content and dry density

The effect of the addition of dune sand on the optimum moisture content is presented in figure 6. The optimum water content of the mixtures decreases with the addition of dune sand. An increase of more than 11.004%, 12.365% and 17.542% is noted for an addition of dune sand of 4%, 6% and 8% respectively. This variation can be explained by the decrease of the pore volume in the mixtures.

Figure 6 shows the evolution of the samples dry density values at the normal Proctor optimum as a function of the proportion of dune sand. The dry density increases with the percentages of sand, it goes from 1.678 g/cm³ in the natural clay to 1.848 g/cm³ for the mixture with 8% of sand. An increase in density of 5.721%, 9.118%, and 10.131% for the natural clay is observed for the samples with 4%, 6%, and 8% dune sand respectively.

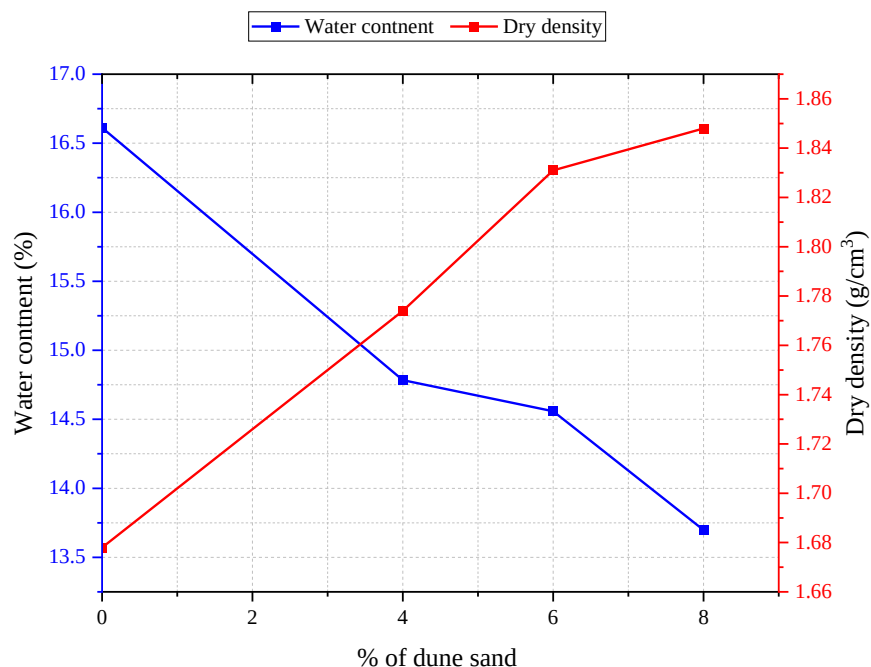


Fig.6. Graph of maximum dry density and water content as a function of dune sand addition.

4. DIRECT SHEAR TEST

The shear tests were performed according to standard [21]. The direct shear test is one of the laboratory analytical methods used to determine the shear strength parameters of clay in its natural state and with the addition of dune sand (Table 2). The samples were placed in a square-shaped shear box (60 mm x 60 mm and 20 mm high). The purpose of the tests was to determine the mechanical parameters (C, ϕ) of the four samples: natural clay (NC) and natural clay (NC) with the addition of 4, 6, and 8% dune sand (Table 2).

The test performed is the drained consolidated test. The normal stresses used are 100, 200, and 300 kPa. The shear rate used is 0.5 mm/min. The sample is placed between two half-boxes that can move relative to each other. In addition, a piston is used to exert a normal stress (axial load) to the shear plane. The lower half of the box is driven horizontally at a constant speed. The total shear force is measured with a ring attached to the upper half of the box.

4.1. Relationship between shear stress and horizontal displacement

The relationship between shear stress and horizontal displacement for all tests performed is presented in figures 7 through 10.

Several graphs were plotted from the results obtained on the natural clay and the natural clay reinforced with dune sand. The samples used were tested at three different normal pressures of 100, 200 and 300 kPa.

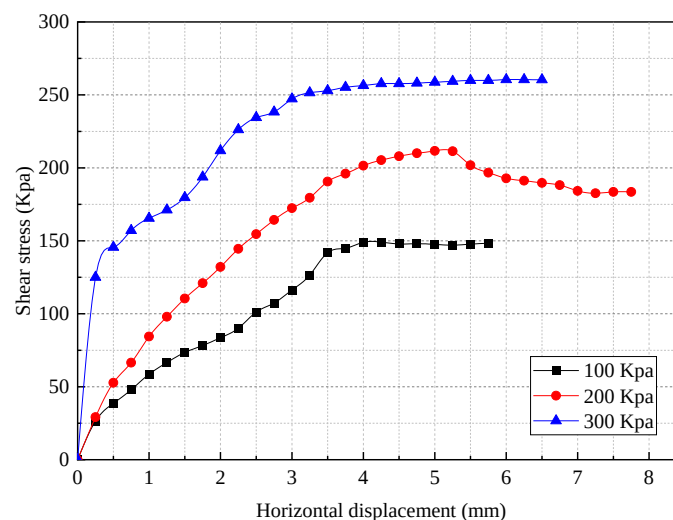


Fig.7. Graph of shear stress versus horizontal displacement for natural clay.

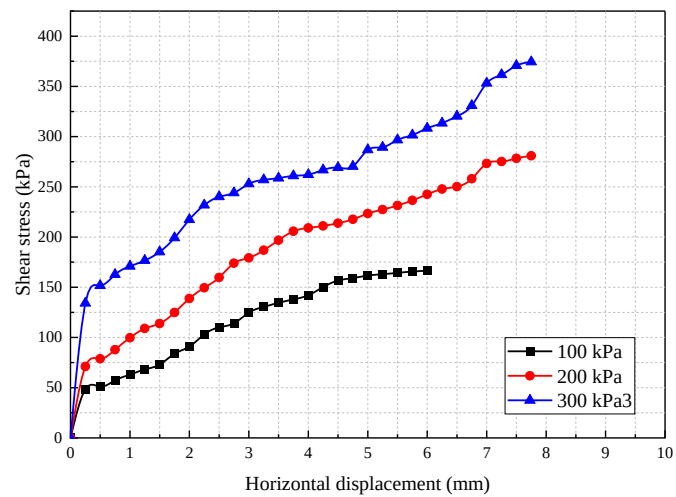


Fig.8. Graph of shear stress versus horizontal displacement for natural clay and 4% DS.

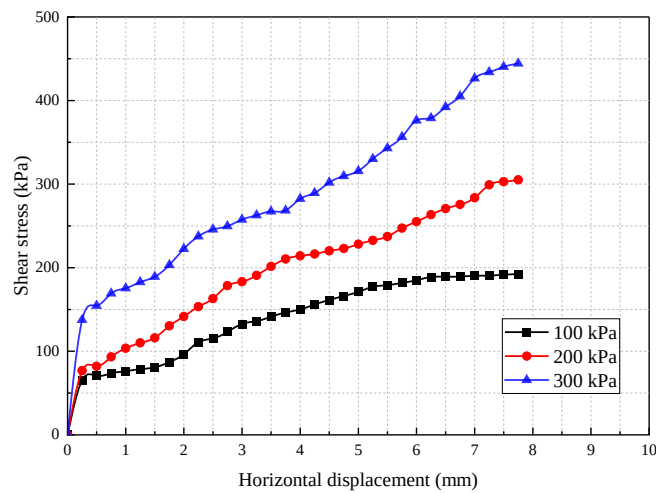


Fig.9. Graph of shear stress versus horizontal displacement for natural clay and 6% DS.

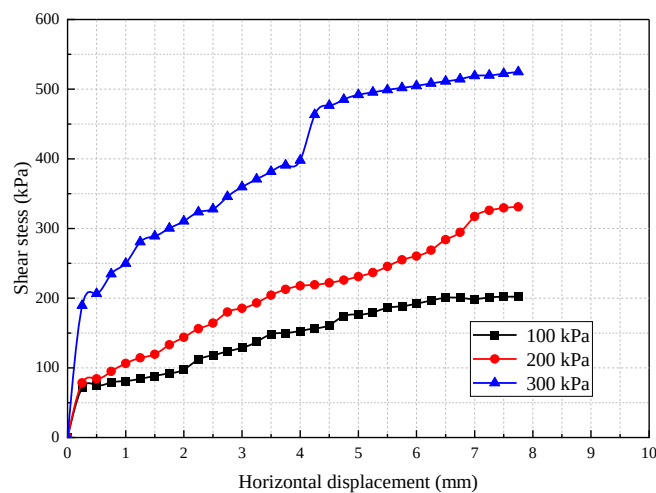


Fig.10. Graph of shear stress versus horizontal displacement for natural clay and 8% DS.

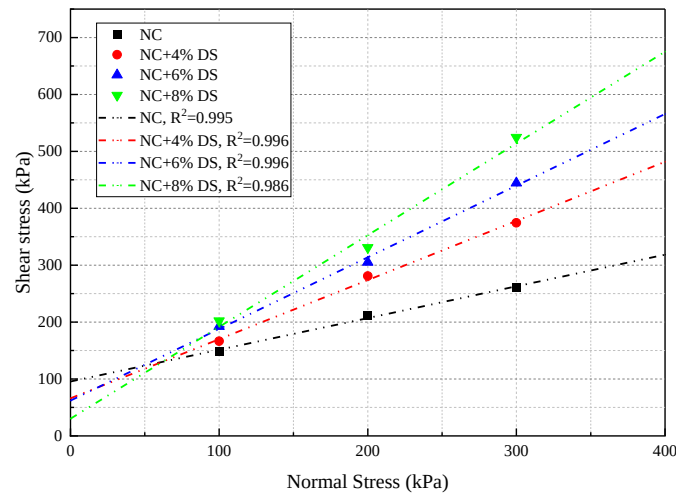


Fig.11. Cohesion and friction angle variations for the samples.

According to Mohr-Coulomb theory, the shear strength of soils can be expressed by the following equation.

$$\tau = C + \sigma \tan \phi \quad (1)$$

Where σ is the vertical pressure, indicates the shear strength, C is the cohesion and ϕ represents the internal friction angle.

According to equation (1), the shear strength of a material is composed of the cohesion c and the angle of internal friction. In particular, for the soil composed of fine particles, the cohesion c includes not only the interaction between the fine particles, but also the cohesion between the dune sand particles.

The relationship curve of the variation of shear stress (τ) versus normal stress (σ) is drawn in figure 11. The intercept of the straight lines with the Y-axis represents the cohesion c , and the slope angle represents internal friction angle (see figure 12).

The relationship between the variation of the cohesion and the friction angle as a function of the percentage of dune sand is shown in figure 12. As it can be observed, with the increase of the percentage of dune sand, the cohesion decreases with a reduction rate of 31.01%, 64.89 and 68.31% for percentages of 4%, 6% and 8% respectively. Contrary to the cohesion, the incorporation of dune sand in clay increases the cohesion with a rate of 60.52%, 86.78% and 113.22% for the values of 4%, 6% and 8% of dune sand respectively.

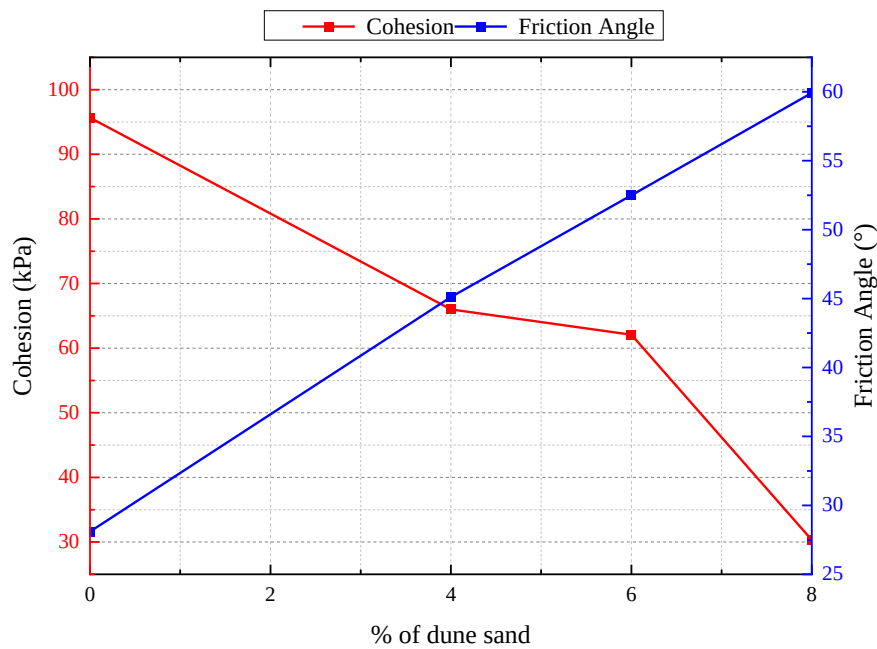


Fig.12. Cohesion and friction angle variations for the samples.

5. CONCLUSION

Unsuitable soils with high plasticity and low bearing capacity are frequently encountered. One is aware that clay soils are to be feared, since due to their mineralogical structure, they are evolutionary and are often the cause of important damages to buildings, especially during periods of prolonged drought. It is therefore necessary to improve these soils to make them acceptable for construction. These limitations could be overcome by improving the geotechnical properties of the soils using various methods. Treatment by adding sand is commonly used to avoid transport, valorize local materials, and involves soil stabilization at very attractive costs.

The main objective of our study is, to study the effect of the treatment of a clay through the addition of sand (of a different nature) on the physical and mechanical characteristics. A laboratory application of the treatment on a clay soil comprising different dune sand percentages of 4%, 6% and 8% has been performed.

Based on the results obtained, several conclusions have been drawn:

- The results obtained on the soil samples showed that the stabilization by adding sand considerably modifies the physical and mechanical characteristics.
- The Atterberg limits decrease following the increase of sand percentage; this makes the treated clay more manageable during wet periods.

- The addition of dune sand to the clay leads to a significant improvement of the physical characteristics by reducing the liquidity limit and the plasticity limit. The addition of sand has the effect of reducing the plasticity of the studied material.
- The addition of dune sand to the clay improves the maximum dry density and optimum moisture content in the mixtures. The most significant improvement is noted on the mixture of clay with 8% of dune sand.
- The addition of dune sand to the clay improves the shear parameters; an increase in shear strength was noted as well as the reduction of cohesion and increase in friction angles with the increase in the proportion of sand in the mixtures.

6. REFERENCES

- [1] S. Amri, M. Akchiche, A. Bennabi, R. Hamzaoui, Geotechnical and mineralogical properties of treated clayey soil with dune sand, *Journal of African Earth Sciences*, 152 (2019) 140-150. <https://doi.org/10.1016/j.jafrearsci.2019.01.010>.
- [2] L. Jones, V. Banks, I. Jefferson, Swelling and shrinking soils, Geological Society, London, Engineering Geology Special Publications, 29(1) (2020) 223-242. <https://doi.org/10.1144/EGSP29.8>
- [3] A. Smaida, B. Mekerta, M.K. Gueddouda, Physico-mechanical stabilization of a high swelling clay, *Construction and Building Materials*, 289 (2021) 123197. <https://doi.org/10.1016/j.conbuildmat.2021.123197>.
- [4] B.C. Mendes, L.G. Pedroti, M.P. Fontes, J.C.L. Ribeiro, C.M. Vieira, A.A. Pacheco, A.R. de Azevedo, Technical and environmental assessment of the incorporation of iron ore tailings in construction clay bricks, *Construction and Building Materials*, 227 (2019) 116669. <https://doi.org/10.1016/j.conbuildmat.2019.08.050>.
- [5] A. Modarres, Y.M. Nosoudy, Clay stabilization using coal waste and lime—Technical and environmental impacts, *Applied clay science*, 116 (2015) 281-288. <https://doi.org/10.1016/j.clay.2015.03.026>.
- [6] M. Deepak, S. Rohini, B. Harini, G.B.G. Ananthi, Influence of fly-ash on the engineering characteristics of stabilised clay soil, *Materials Today: Proceedings*, 37 (2021) 2014-2018. <https://doi.org/10.1016/j.matpr.2020.07.497>.
- [7] M.S. Pakbaz, R. Alipour, Influence of cement addition on the geotechnical properties of an Iranian clay, *Applied Clay Science*, 67 (2012) 1-4. <https://doi.org/10.1016/j.clay.2012.07.006>.
- [8] C.R.V. Prasad, R. Sharma, Influence of sand and fly ash on clayey soil stabilization, *IOSR Journal of Mechanical and Civil Engineering*, 334 (2014) 36-40.

- [9] V. Sivakumar, S. Wheeler, Influence of compaction procedure on the mechanical behaviour of an unsaturated compacted clay. Part 1: Wetting and isotropic compression, *Géotechnique*, 50(4) (2000) 359-368. <https://doi.org/10.1680/geot.2000.50.4.359>.
- [10] A. Zhemchuzhnikov, K. Ghavami, M. dal Toé Casagrande, Static compaction of soils with varying clay content, in: *Key Engineering Materials*, Trans Tech Publ, 2016, pp. 238-246. <https://doi.org/10.4028/www.scientific.net/KEM.668.238>.
- [11] A. Boudia, A. Berga, Effect of Grain Size and Distribution on Mechanical Behavior of Dune Sand, in: *Civil Engineering Journal*, 2021, pp. 1355-1377. doi: 10.28991/cej-2021-03091730.
- [12] P. Kolay, K. Ramesh, Reduction of expansive index, swelling and compression behavior of kaolinite and bentonite clay with sand and class C fly ash, *Geotechnical and Geological Engineering*, 34(1) (2016) 87-101. doi:10.1007/s10706-015-9930-4.
- [13] K. Farooq, K.A. Virk, Improvement of engineering characteristics of expansive clays by sand mixing, in: *Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering (Volumes 1, 2, 3 and 4)*, IOS Press, 2009, pp. 785-788. doi:10.3233/978-1-60750-031-5-785.
- [14] Z. Derriche, G. Cheikh-Lounis, Geotechnical characteristics of the Plaisancian marls of Algiers, *Bulletin of Engineering Geology and the Environment*, 63(4) (2004) 367-378. doi:10.1007/s10064-004-0246-5.
- [15] M. Cherrak, M. Morsli, R. Boutemur, A. Bali, Valorization of the use of calcareous tuff and dune sand in Saharan road design, *Journal of Civil Engineering and Architecture*, 9 (2015) 665-676. doi: 10.17265/1934-7359/2015.06.004.
- [16] A. Ghrieb, R. Mitiche-Kettab, A. Bali, Stabilization and utilization of dune sand in road engineering, *Arabian Journal for Science and Engineering*, 39(3) (2014) 1517-1529. doi: 10.1007/s13369-013-0721-z.
- [17] N. AFNOR, P94-057-Sols: reconnaissance et essais-Analyse granulométrique des sols-Méthode par sédimentation, in: *Association Française de Normalisation*, Paris, France, 1992.
- [18] N. AFNOR, 94-057. Sols: Reconnaissances et essais, analyse granulométrique des sols, méthode par sédimentation, in: *Book title*, Association Française de Normalisation, France (in French), 1992.
- [19] P. NF, 94-051, Sols: Reconnaissance et Essais-Détermination des limites d'Atterberg-Limite de liquidité à la coupelle-limite de plasticité au rouleau, in: *Association Française de Normalisation*, France (in French), 1993.

[20] N. AFNOR, 94-093, Sols: reconnaissance et essais–Détermination des références de compactage d'un matériau-Essai Proctor normal-Essai Proctor modifié, in: Saint-Denis La Plaine Cedex: AFNor, 1999.

[21] N. P94-071-1, Soil: Investigation and testing–direct shear test with shear box apparatus–part 1: Direct shear, in, Association Française de Normalisation France, 1994.