ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Volume 11, Issue 8, August 2024

Experimental Study of the Physical and Mechanical Behavior of a Clay by Incorporating Sand

[1] Meziani Faroudja, [2] Kahil Amar, [3] Khettaoui Cylia

[1][2][3] Civil Engineering Department, Faculty of Construction Engineering, University Mouloud MAMMERI, Tizi-Ouzou, Algeria

Email: [1] faroudja.meziani@ummto.dz, [2] amar.kahil@ummto.dz, [3] cyyliakhetta92@gmail.com

Abstract— Prior to the construction of infrastructure works, the reuse of site materials for construction requires soil with good characteristics (physical and mechanical). To avoid construction problems, soil treatment techniques are often used to improve the inadequate geotechnical properties of the soils encountered on site for a given function in the structure. Clay materials are often complex natural mixtures of minerals whose grain size and physical, chemical and mechanical properties often vary. Treatment by substitution of a fraction of an inert material such as sand is an appropriate solution for considering the re-use of clay soils in construction projects. The aim of this experimental study is to investigate the influence of the type and percentage of sand used on changes in the physical and mechanical characteristics of a clay. The results obtained show that the treatment carried out by adding sand has a positive influence on the physical and mechanical characteristics of the clay studied. The addition of sand reduces plasticity and improves the compaction characteristics and shear parameters of the mixes studied.

Index Terms— Clay, dune sand, mechanical behavior, Proctor, shear strength

I. 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].

The treatment of clayey soils involves a set of techniques widely tested and commonly used in civil engineering construction projects[5, 6], 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 [7].

These techniques can be classified into three groups: a mechanical process (compaction) [8, 9], a physico-chemical process using binders (cements, lime, fly ash) and a last process by adding inert materials (sand, marble powder)[1, 10].

This study examined the impact of two distinct sand types, quarry sand and dune sand on the changes in the mechanical and physical properties of clay.

II. EXPERIMENTAL PROCEDURE

A. Sample preparation (clay and sand)

The material is prepared in such a way as not to alter its characteristics. After removing samples were dried in an oven at a temperature of 50°C, then crushed and sieved. The clay samples come from the region of FREHA in the wilaya of Tizi –Ouzou (Figure 1), while the dune sand comes from Oued Maiter in the wilaya of Boussaâda in Algeria (Figure 2).

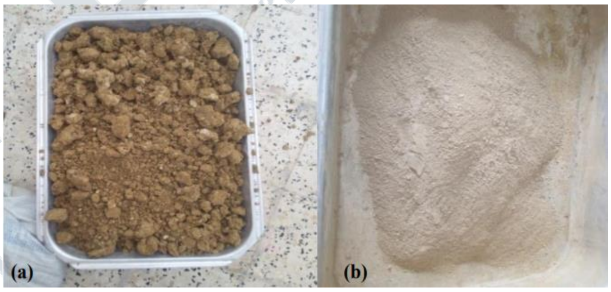

Fig.1. Clay used (a-Clay before crushing; b-Clay after crushing and sieving)

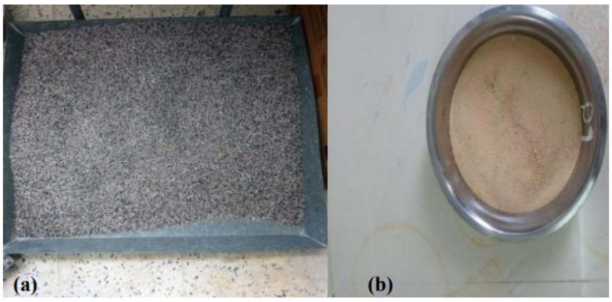

Fig.2. Types of sand used (a- Quarry sand, b- Dune sand)

B. Physical identification parameters

The results of laboratory tests carried out on the different samples used (clay and sand) are presented in tables 1 and 2.

IFERP
Explore Your Research Journey.

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Volume 11, Issue 8, August 2024

Table 1. Identification parameters for the clay studied

Parameters	Values
Water content of clay (%)	23.11
Density of solid particles ρ_s (g/cm^3)	2.59
Dry density ρ_d (g/cm^3)[11]	1.85
Apparent density ρ_h (g/cm^3)	1.45
Wet density ρ (g/cm^3)	2.16
Liquidity limit W_L (%)	41.00
Plasticity limit W_P (%)[12]	26.12
Plasticity index I_P (%)[12]	14.88
80µm clay sieve (%)[13]	57.77
Methylene blue value (%)[14]	7.10

Table 2. Identification parameters for sands used

Sand	Parameters	Values
Quarry	Water content (%)	6.14
	80µm clay sieve (%)	0.32
	Sand equivalent value (%)	97.00
	Curvature coefficient C_c	1.19
	Uniformity coefficient C_u	6.00
Dune	Water content (%)	6.74
	80µm clay sieve (%)	0.56
	Sand equivalent value (%)	59.63
	Curvature coefficient Cc	1.83
	Uniformity coefficient Cu	0.85

The particle size analysis of the clay, dune and quarry sands used in our study, is shown in figure 3, below.

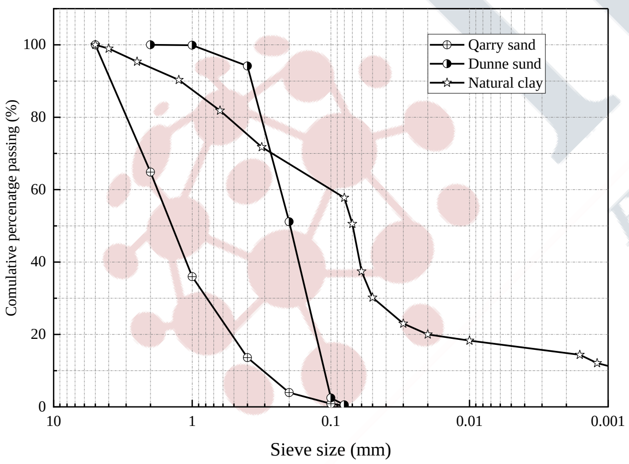

Fig. 3. Sieve size curves for clay and sand used

To find the plasticity index of clay and clay mixed with sand, the Atterberg limit test was performed according to the standard test method described by NF P 94-051 [12].

Figures 4 show the variation in physical characteristics (Atterberg limits) of the clay studied, as a function of the nature of the sand (quarry and dunes) and the percentage of addition.

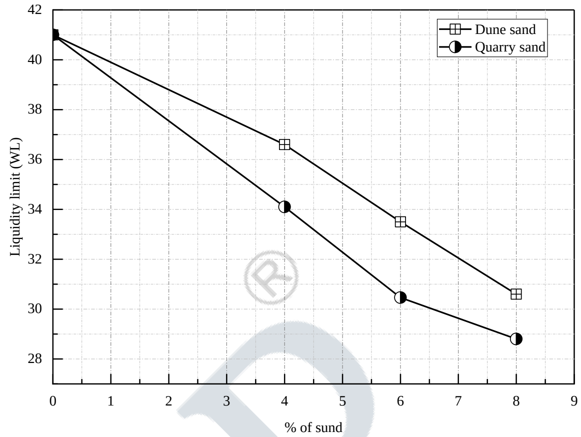

Fig. 4. Variation of liquidity limit as a function of addition percentage

Figure 4 shows that the liquidity limits of the clay used in our study, are influenced by the different types and percentages of sand used.

The effect of adding 4%, 6% and 8% of dune sand results in a decrease in the value of the liquidity limit of by 36.62%, 33.9% and 30.76% respectively.

The liquidity limit value obtained by adding 4% quarry sand is 34.40%. With the addition of 6% and 8% quarry sand, the liquid limit values obtained after testing are 30.52% and 28.80% respectively.

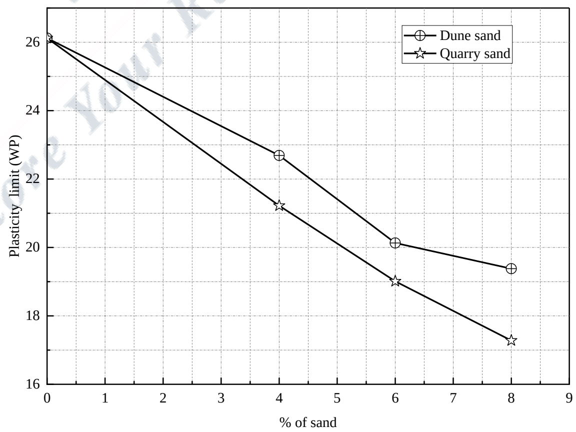

Fig. 5. Variation of plasticity limit as a function of addition percentage

According to the results obtained in figure 5, the plasticity limits decrease with increasing proportion of added sand (quarry or dune), in different percentages.

The plasticity limit of the clay studied, in its natural state, is 26.12% compared to dune sand, the value of the plasticity limit with the addition of 4% is 22.23%. This limit decreases to 20.16% and 19.91% at 6% and 8% respectively.

Quarry sand has an influence on the plasticity limit, compared with the natural state. Reductions of 21.22%,

IFERP Explore Your Research Journey.

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Volume 11, Issue 8, August 2024

19.01% and 17.28% for addition percentages of 4%, 6% and 8%, respectively.

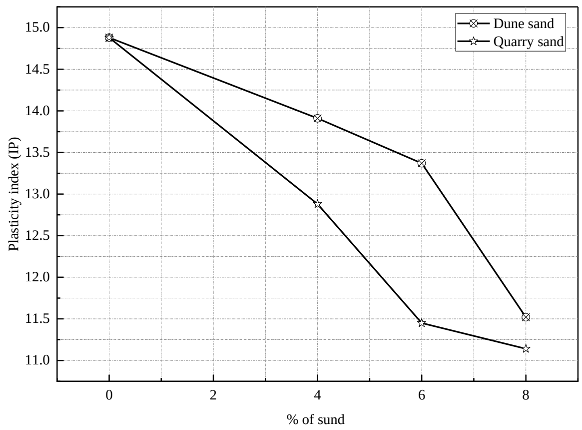

Fig. 6. Variation in plasticity index as a function of addition percentage

The results presented in figure 6 also show decreases in plasticity index with the proportion of sand added. Untreated clay has a plasticity index IP =14.88%, the addition of (4%,6%,8%) dune sand produces decreases in the plasticity index which are respectively (13.91%,13.37%, 11.22%.).

The results also show decreases in plasticity index with the proportion of sand added. The addition of (4%, 6%, 8%) quarry sand produces significant decreases in the plasticity index respectively (IP = 12.88%, IP = 11.52%, IP = 11.45%).

The decrease in the plasticity index is due to the simultaneous decrease in the liquidity and plasticity limits. This reduction is due to the change in behavior of the mixture from a clay-type soil to a sandy-clay-type soil.

III. MECHANICAL TEST

To study the effect of adding dune and quarry sand to clay on Proctor optimum and shear behavior, 18 formulations were prepared with different proportions of sand addition. Table 3 summarizes the detailed proportions of the clay mixes prepared.

Table 3. Different types of samples produced

Samples ID	Samples description
NC	Natural clay (NC)
NC+4SD	Natural clay + 4% of dune sand
NC+6SD	Natural clay + 6% of dune sand
NC+8SD	Natural clay + 8% of dune sand
NC+4QS	Natural clay + 4% of quarry sand
NC+6QS	Natural clay + 6% of quarry sand
NC+8QS	Natural clay + 8% of quarry sand

A. 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 [16]. The test involves compacting samples 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 effect of sand addition on the compaction characteristics of clay sand mixtures is shown in figure 7. These characteristics were obtained using the normal Proctor test [16]. The normal Proctor curves provide the maximum dry density and optimum moisture content of the mixtures.

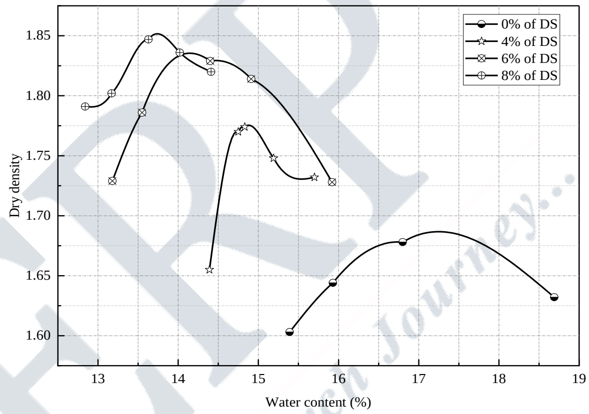

Fig. 7. Influence of dune sand on compaction parameters

Figure 7 shows the evolution of the dry density of mixes at the normal Proctor optimum as a function of the proportion of dune sand. The dry density increases with the percentage of sand, rising from 1.774 in the mix (clay-4% dune sand) to 1.848 in the mix (clay-8% dune sand). It decreases from over 14.784 to 14.558% with the addition of 4% and 6% dune sand, and decreases with the addition of 8% dune sand to 13.698%.

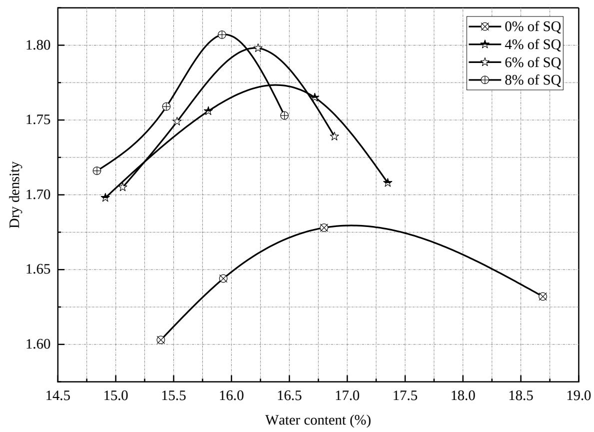

Fig. 8. Influence of quarry sand on compaction parameters

The results in figure 8 show that the curves of the normal Proctor test are strongly dependent on the addition of quarry sand and its proportion in the mixture (clay - sand). It can be seen that the addition of quarry sand at different percentages leads to an increase in maximum dry density, which rises from 1.768 for the addition of 4% sand to 1.798 for the addition of 6% sand, to 1.807 for the addition of 8% sand. The optimum water content decreases from 16.396% for the addition of 4% sand to 16.168% for the addition of 6% sand, then to 15.90% for the addition of 8% quarry sand.

B. Shear test

The prepared samples will be subjected to the Casagrande box shear test at different normal stresses (100, 200 and 300 kPa), enabling us to assess how the soil's shear strength varies as a function of the normal stress applied. This makes it possible to characterize soil behavior under different stress conditions and determine shear strength parameters (cohesion and angle of internal friction) at different percentages of dune and quarry sand additions [15].

Figures 9 to 15 show the variation in shear stress as a function of displacement for natural clay samples and clay-sand mixtures (SD and QS). These figures show how shear stress increases with displacement until the sample reaches its maximum strength.

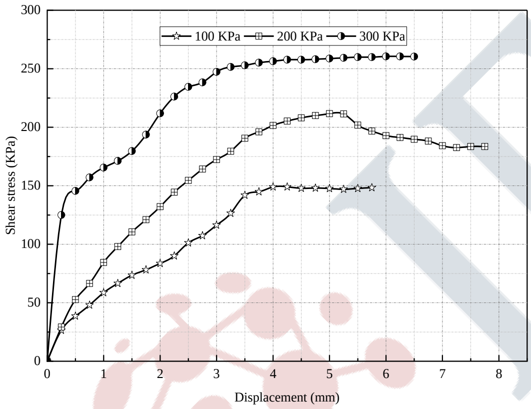

Fig. 9. Shear stress curves for NC

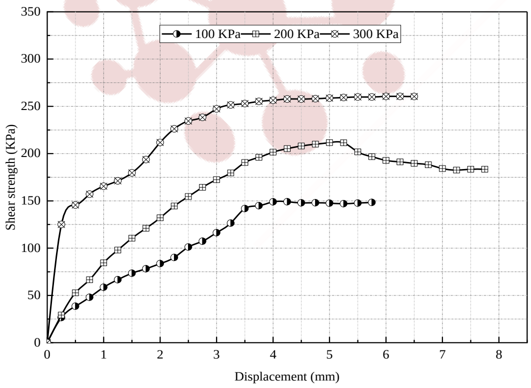

Fig. 10. Shear stress curves for NC+4%SD

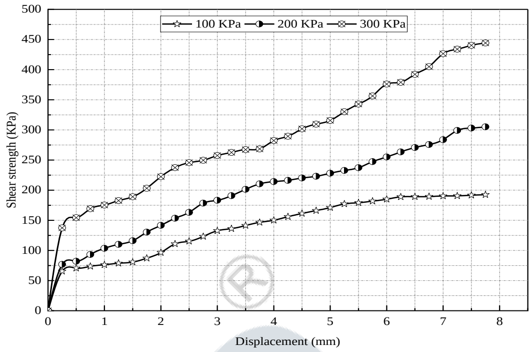

Fig. 11. Shear stress curves for NC+6%SD

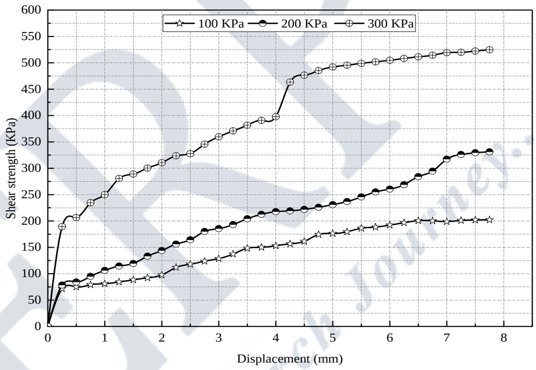

Fig. 12. Shear stress curves for NC+8DS

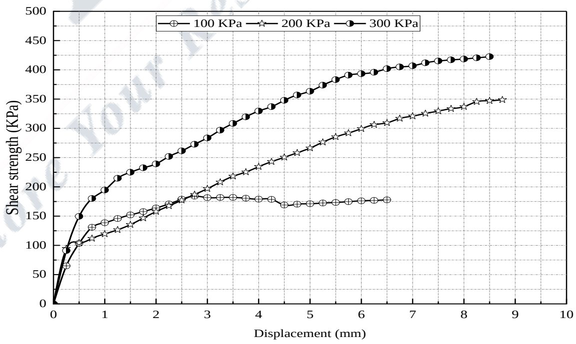

Fig. 13. Shear stress curves for NC+4%QS

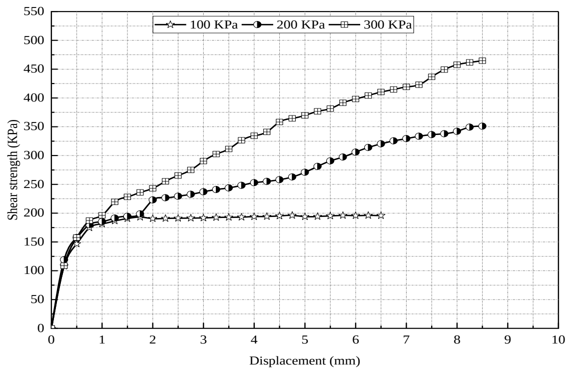

Fig. 14. Shear stress curves for NC+6%QS

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Volume 11, Issue 8, August 2024

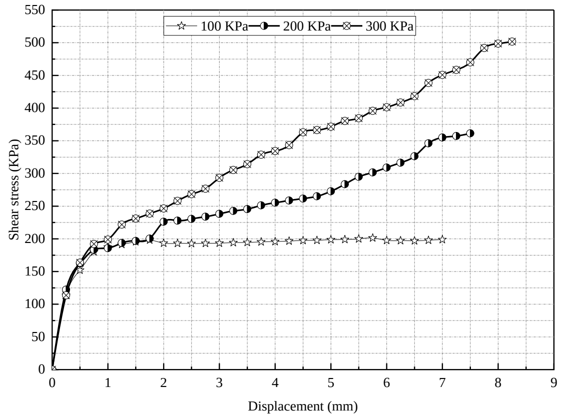

Fig. 15. Tangential stress curves for NC+8%SD

According to the curves obtained, the values of the tangential stresses of the mixtures (clay - sand) vary, on the one hand, according to the addition of different percentages of sand used (quarry or dune) as well as with the increase in vertical loading (100KPa, 200KPa ,300KPa), on the other hand.

The evolution of the angle of friction as a function of the percentage of sand added is a critical aspect to consider in geotechnical analysis. The angle of friction represents a material's resistance to shear stress and is a key parameter in understanding soil behavior.

Figures 16 and 17 show the evolution of the angle of internal friction and cohesion as a function of the percentage of sand added.

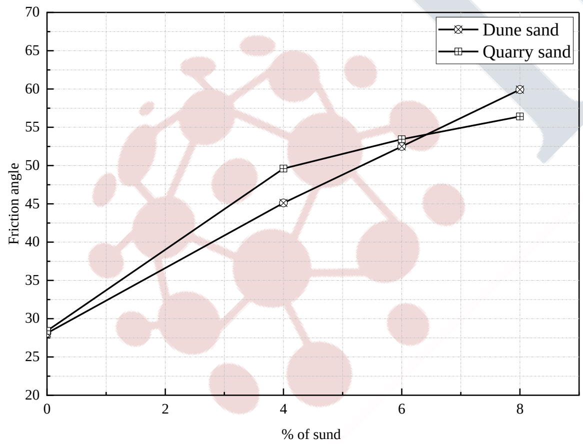

Fig. 16. Evolution of the friction angle as a function of the percentage of sand added

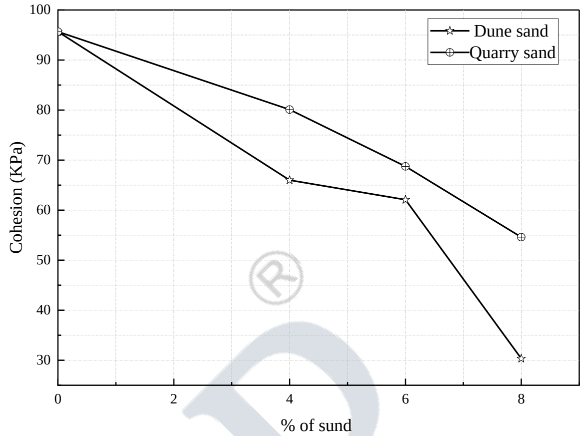

Fig. 17. Evolution of the cohesion as a function of the percentage of sand added

Figures 16 and 17 show that the cohesion value decreases as the proportion of dune and quarry sand in the clay mixture increases.

According to the shear stress curves, the shear stresses increase after the addition of dune sand with different proportions, so they are higher than the shear stresses found in the natural state of the clay.

Increasing the percentage of sand incorporated into the clay (4%, 6% and 8%) has the effect of decreasing cohesion and increasing the angle of internal friction compared to the natural state.

Dune sand and quarry sand result in a good improvement in the shear strength of clays, with an increase in the angle of friction and a reduction in cohesion. Quarry sand has a higher angle of friction than dune sand, due to the angularity of its grains and the roughness of its surfaces, which improves shear strength compared with dune sand.

IV. CONCLUSION

The aim of this study is to investigate the influence of the type of sand used, with different percentages of addition, on the physical and mechanical characteristics of a clay.

The results obtained in this study show that the addition of sand improves the physical characteristics of the treated clay. The variation in Atterberg limits translates into a decrease in the liquid limit, a decrease in the plastic limit, and consequently a plasticity index. The reduction in plasticity index indicates an improvement in the clay's workability.

Depending on the type of sand used, quarry sand shows a greater reduction in Atterberg limits than dune sand, as quarry sand contains fewer fine particles than dune sand. Sand granulometry therefore plays a very important role in improving Atterberg limits, as dune sand is characterized by a rounded grain shape dune sand is characterized by a rounded grain shape, unlike quarry sand, which has angular grains.

The addition of sand modifies the compaction

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Volume 11, Issue 8, August 2024

characteristics of the Proctor test. The results confirm the positive role of sand in different proportions (4%, 6%, 8%) in improving the Proctor characteristics of the clay studied.

The addition of dune sand or quarry sand to clay improves shear parameters, with an increase in shear strength, a reduction in cohesion and an increase in friction angles as the proportion of sand in the mix increases. The best improvement was achieved with quarry sand.

REFERENCES

[1] Amri S, Akchiche M, Bennabi A, Hamzaoui R. Geotechnical and mineralogical properties of treated clayey soil with dune sand. Journal of African Earth Sciences 2019; 152:140-50.

[2] Jones L, Banks V, Jefferson I. Chapter 8 Swelling and shrinking soils. Geological Society, London, Engineering Geology Special Publications 2020;29:223-42.

[3] Smaida A, Mekerta B, Gueddouda MK. Physico-mechanical stabilization of a high swelling clay. Construction and Building Materials 2021; 289:123197.

[4] Mendes BC, Pedroti LG, Fontes MP, Ribeiro JCL, Vieira CM, Pacheco AA, et al. Technical and environmental assessment of the incorporation of iron ore tailings in construction clay bricks. Construction and Building Materials 2019; 227:116669.

[5] Deepak M, Rohini S, Harini B, Ananthi GBG. Influence of fly-ash on the engineering characteristics of stabilised clay soil. Materials today: proceedings 2021; 37:2014-8.

[6] Pakbaz MS, Alipour R. Influence of cement addition on the geotechnical properties of an Iranian clay. Applied Clay Science 2012; 67:1-4.

[7] Prasad CRV, Sharma R. Influence of sand and fly ash on clayey soil stabilization. IOSR Journal of Mechanical and Civil Engineering 2014; 334:36-40.

[8] Sivakumar V, Wheeler S. Influence of compaction procedure on the mechanical behaviour of an unsaturated compacted clay. Part 1: Wetting and isotropic compression. Géotechnique 2000; 50:359-68.

[9] Zhemchuzhnikov A, Ghavami K, dal Toé Casagrande M. Static compaction of soils with varying clay content. Key Engineering Materials 2016; 668:238-46.

[10] Meziani F, Kahil A, Khettaoui C. EFFET DE LA NATURE DU SABLE SUR LES CARACTERISTIQUES PHYSIQUES D'UNE ARGILE. Communication science et technologie 2022; 11:46-56.

[11] AFNOR N. Détermination de la masse volumique de particules solides des sols. Méthode du pycnomètre à eau 1991.

[12] NF P. 94-051, Sols: Reconnaissance et Essais–Détermination des limites d'Atterberg–Limite de liquidité à la coupelle–limite de plasticité au rouleau. Association Française de Normalisation, France (in French) 1993.

[13] NF P. 94-057. Analyse granulométrique des sols-Méthode par sédimentation, French Standard, AFNOR, Paris 1992.

[14] NF P. 94-068, Sols: Reconnaissance et essais, Mesure de la capacité d'adsorption de bleu de méthylène d'un sol ou d'un matériau rocheux, Détermination de la valeur de bleu de méthylène d'un sol ou d'un matériau rocheux par l'essai à la tache. Association Française de Normalisation, France (in French) 1998.

[15] NF P. 94-071-1. (Août 1994). Essai de cisaillement rectiligne à la boîte-Partie 1: Cisaillement direct. Association Française de Normalisation (AFNOR).

[16] AFNOR N., NF P.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.

Explore Your Research Journey...