© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Study of the Mechanical Properties of Gypsum Tuff – Dunes Sand Mixture for Use in Saharan Road Construction

Khellou Abderrezak[1*], Kriker Abdelouahed[1], Hafsi Abdelatif[2], Mokhtari Khadija[1], Siad Hind[1]

[1]Laboratory of Exploitation and Valorization of Natural Resources in Arid Zones,
University of Kasdi Merbah Ouargla, 30000 Ouargla, ALGERIA

[2]Laboratory of Public Works of the South Unit of Ouargla, ALGERIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijie.2021.13.04.024
Received 22 February 2020; Accepted 17 March 2021; Available online 01 May 2021

Abstract: This work fits into the context of minimizing the use of non-renewable and depleting natural resources, such as gypsum tuff. Its objectives are to study the mechanical properties of a mixture of gypsum tuff (GT) and economical material which is dunes sand (DS), considered in the selection of road material by Algerian public works laboratories, in order to have the possibility of integrating it into Saharan pavements. The results obtained showed an improvement of Bearing index (Immediate bearing index, IBI and Bearing index after soaking, IBas), evaluated by the CBR test, of the mixture composed of 80% of GT + 20% SD in comparison with that of the gypsum tuff alone. Whereas its simple compressive strength decreased slightly at the age of 28 days. This decrease led us to treat the mixture with lime and to examine the evolution of the compressive strength according to the curing time.

Keywords: Gypsum tuff, dunes sand, bearing index, compressive strength, treatment, Saharan roads

1. Introduction

The gypsum-calcareous materials, known by encrusting tuffs or simply by the tuffs, are part of the local materials widely used in Saharan road construction, particularly in the Southeastern regions of Algeria. In the literature, encrusting tuffs are defined as tender, friable, porous, light and light-colored rocks that go back to the Quaternary period [1], [2].

These rocks are of the variable constitution and result from a certain number of exchanges by dissolution and precipitation [1],[3]. According to their chemical composition, these materials are grouped into three categories: limestone tuffs, gypsum tuffs (called gypsum sand) and mixed tuffs. The tuffs in general, after wet compaction then desiccation, acquire a considerable cohesion, which decreases when the degree of saturation increases. They are therefore sensitive to water. Another peculiarity that characterizes tuffs is to harden with age. It is this hardening, also called self-stabilization or slab effect, which allows their use in pavement [3]-[5].

Extraction and transport of gypsum tuff, considered as non-renewable natural resources, often a lot of important expenses that have had an impact on the project costs without forgetting the modification of the landscape and the degradation of the environment.

In order to limit the use of this resource, the substitution, partially or totally, by other economic materials is a necessary solution to overcome this problem. The idea of studying the mechanical properties of tuffs combined with other materials is the subject of several research projects, such as; Morsli [2], Goual et al. [5]-[7], Ameraoui [8], Cherrak et al. [9], Daheur et al. [10], Khellou et al. [11] and Akacem et al. [12].

*Corresponding author: khellou11@yahoo.fr

In this context, this work focuses on the study of the mechanical properties, considered in the selection of Saharan road material by Algerian public works laboratories, of a mixture composed of gypsum tuff and dunes sand which is an economical material and is found in abundance in southern Algeria. The first phase of the study consists in determining the optimal mixture which gives both the maximum value of the dry density of Proctor and the best bearing index. The second phase is devoted to the observation of the evolution of the compressive strength with the age of the optimal mixture without treatment and with lime treatment.

2. Materials and Methods

2.1 Materials

This section presents the geotechnical characteristics of the materials used in this study. The table1 summarizes the different types of characterization tests and the standards used.

Table 1 - Different types of characterization tests

Types of Tests	Standard
Chemical analysis	NF P 15-461; BS 1377; NF P 94-048;
Granular size analysis	NF P 94-056
Atterberg limits test	NF P 94-051
Methylene blue value test	NF P 94-068
Modified Proctor test:	NF P 94-093
CBR (California bearing ratio) test	NF P 94-078;
Compressive strength test	Test adapting to materials in Technical Saharan Road [2], [7]

2.1.1 Gypsum Tuff (GT)

The studied gypsum tuff (Fig. 1) was extracted from a deposit located in the region of Ouargla, 758 km south-east of Algiers, characterized by its dry climate. The geotechnical identification of tuffs as currently practiced in Algerian road laboratories is performed according to classical geotechnical standards, however, with some modifications according to the recommendations of the Technical Saharan Road.

Fig.1 Sample of gypsum tuff extracted

The chemical analysis was performed to determine the rates of insoluble (mainly quartz), calcium sulphates ($CaSO_4$), calcium carbonates ($CaCO_3$), and salts. This analysis, as shown in table 2, reveals the dominance of the rate of “$CaSO_4$”, which confirms the gypseous nature of our material.

Table 2 - Summary of chemical analysis results

$CaCO_3$ (%)	$CaSO_4$ (%)	SO_3 (%)	Insoluble (%)	NaCl (%)	Other (%)
12	70,80	13,18	26.62	0.29	3,73

The results of the XRD analysis (see Fig. 2) also reveal that the base material is mainly composed of gypsum ($CaSO_4 2H_2O$).

The particle size analysis (Fig. 3) shows that our material has a maximum diameter (D_{max}) of 10 mm. It contains a high rate of fines (<0.80 mm), about 38%. The granulometric curve is located above the Saharan spindle of Beni-Abbès [2], [8], [13]. which classifies this tuff as fine material (family III). The other geotechnical characterization results of gypsum tuff are summarized in Table 3.

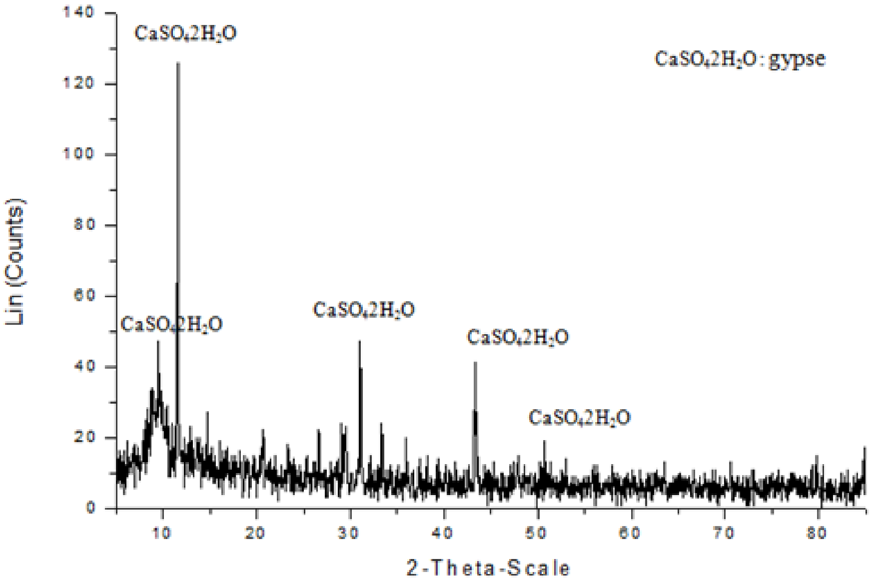


Fig. 2 - X-ray diffraction of gypsum tuff

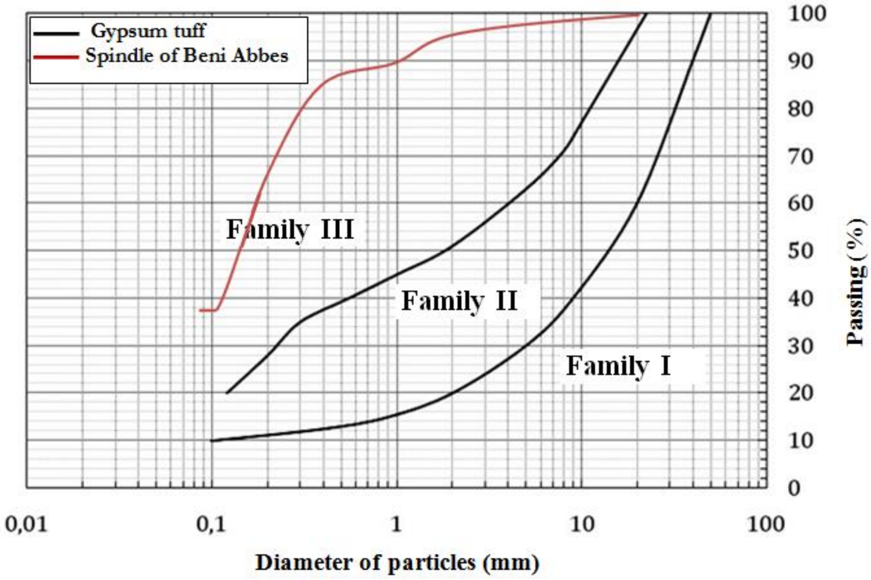


Fig. 3 - Grain size distribution curves for gypsum tuff compared to the spindle of Beni -Abbès

Table 3 - Geotechnical parameters of gypsum tuff

Parameter	Gypsum Tuff
Dmax (mm)	20
%< 2 mm	95%
%< 80 µm	38%
Uniformity Coefficient: Cu (%)	2, 33
Hazen Coefficient (curvature): Cc (%)	0,87
Limits of liquidity: Wl	23,70 %
Limit of plasticity: Wp	not measurable
Blue value: VB (0/D)	0,92
Optimum water content: Wopm	11 ,10%
Maximum dry density γ (gr/cm^3)	1,64
Immediate bearing index, IBI	53 ,59%
Bearing index after soaking (4 hours), IBas	33,8%
Simple Compressive strength at 28 days	1,86 MPa

According to the "Roads Excavation Guide" GTR [14], the material under study belongs to class A1 where it is considered a fine soil, see Fig. 4.

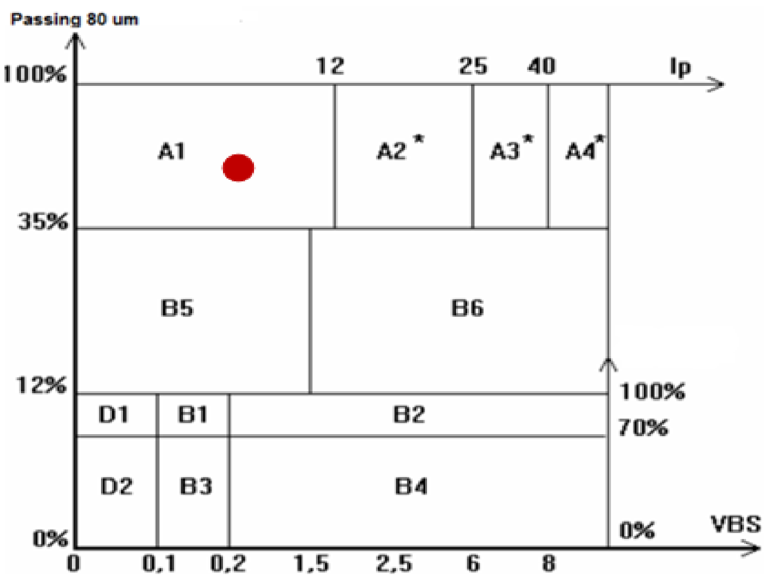


Fig. 4 -Classification of gypsum tuff according to GTR [14]

2.2.2 Dunes Sand

In the great south of Algeria, especially in the region of Ouargla, the dunes sand, which is found in the moving dunes, is very abundant materials and easy extraction. It is practically little exploitable despite the possible characteristics that it may present. More use of sand in the public works sector can help preserve noble materials whose exploitation is expensive. The dunes sand generally has a very simple chemical composition, more than 95% silica, 1 to 2% limestone and traces of different oxides. Because of this constitution, the sand has a slightly yellow-white color and ocher. It dries out and easily loses cohesion on the surface [15]. Particle size analysis, as shown in Fig. 5, and physical characteristics (Table. 4) show that the sand is poorly graded, which is said to be "homometric" and devoid of fines.

Table 4-Physical characteristics of dunes sand

	γ_{app}	γ_{abs}	M_f (%)	E.Sp%	Cu = d60/d10
Dunes sand	1,64	2,50	1.20	94,38	2

γ_{app} = Apparent density, γ_{abs} = Absolute density, M_f = Modules of finesse, E.Sp = equivalent of sand (piston)

The diameter of its largest elements is 0,63mm, its uniformity coefficient (Cu) is of the order of 2 and the value of the equivalent of sand is about 94.38%, which illustrates the cleanliness of the sand.

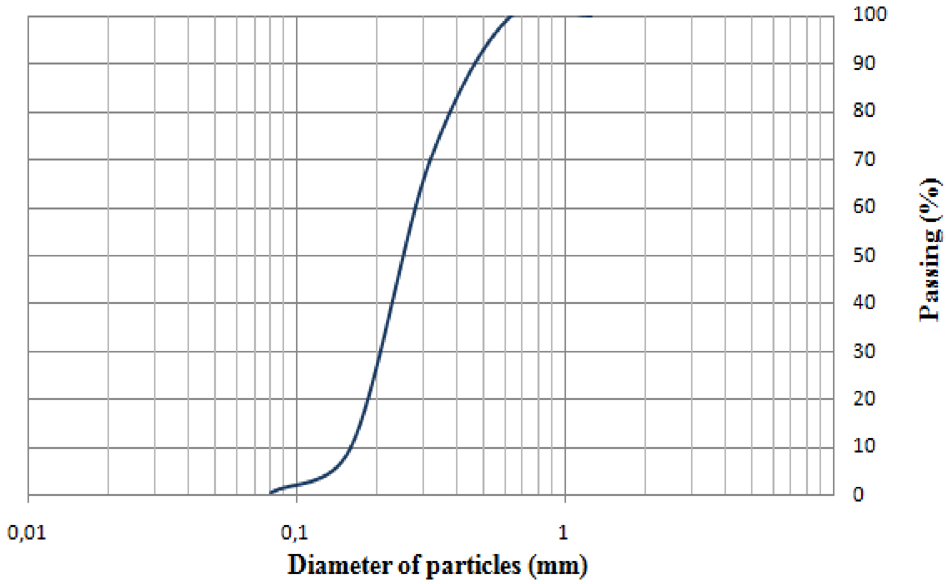


Fig. 5 - Grain size distribution curves for Dunes sand

3. Method

In this study, first of all, we determined, by means of the modified Proctor test and the CBR test, the optimal mixture among the mixtures (GT-DS) produced (Table 5). Then, simple compression tests were carried out on the optimal mixture alone and treated with lime in order to see the evolution of the mechanical resistance according to the age.

Table 5 - Various mixtures prepared MGT-DS

Mixture	Gypsum Tuff (GT)	Dunes Sand (DS)
MGT-10DS	90%	10%
MGT-20DS	80%	20%
MGT-30DS	70%	30%

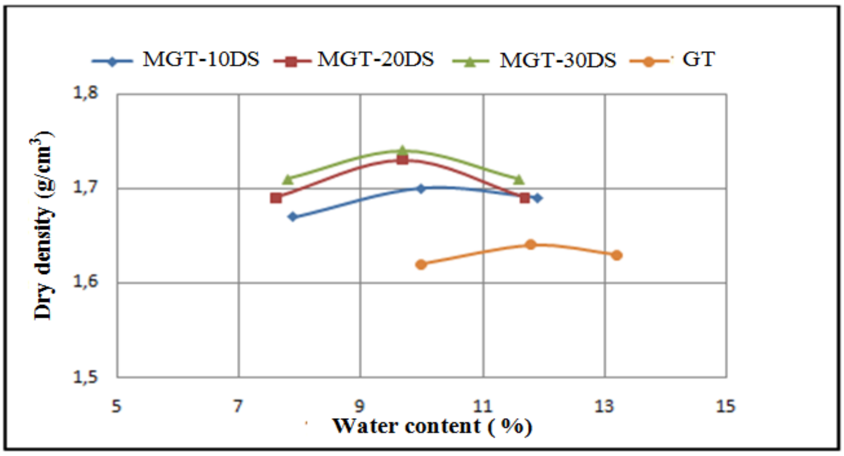
4. Results and Discussion

4.1 Compaction Behaviour of the Mixture MGT-DS

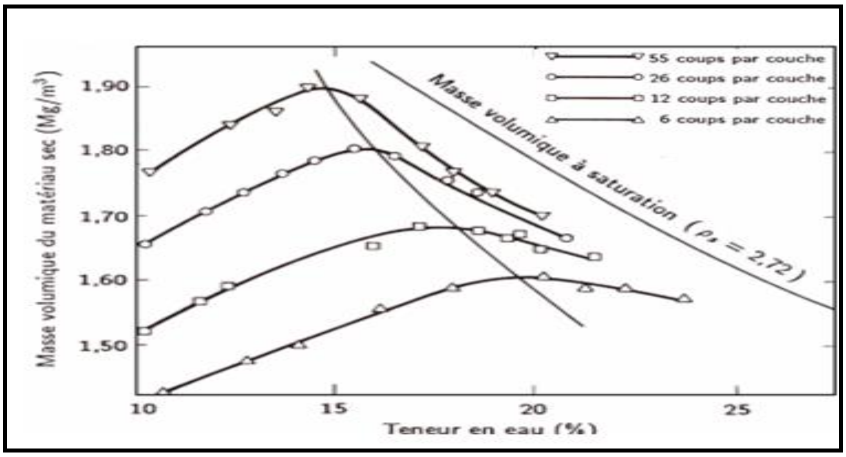
The compaction behavior was studied through the modified Proctor test, which consists in determining the optimal conditions to achieve good compaction. The compaction test illustrates that mixing gypsum tuff with dunes sand changes Proctor coordinates (maximum dry density and optimum moisture content). They are shifted to the left, increasing the maximum dry density and reducing the optimal water content (Fig. 6(a)). This behavior of the mixtures can be likened to that of a compacted material with different energies found in the literature. Everything happens as gypsum tuff was compacted alone at higher energies (Fig. 6(b)).

Fig. 7 and Fig. 8 present respectively the variation of the maximum dry density and the optimum water content according to the percentage of dunes sand introduced into the MGT-DS mixtures .Incorporating dunes sand with 30% in the mixture increased the maximum dry density, 6% higher than that of gypsum tuff alone (Fig. 7) and decreased the optimal water content by approximately 21% (Fig. 8).

These results are consistent with those obtained by Morsli [2], during studies carried out on a mixture of limestone tuff from Bechar region, located in southwest Algeria, and dunes sand. The explanation given for the increase in the dry density is the reduction of the rate of fines and their replacement by dune sand particles which, by their shape and their size, play a role of lubricant. As the percentage of sand increases, the latter lubricates particles of the base material and facilitates their displacement by orienting them to form a denser structure.



(a)



(b)

Fig. 6 - (a) Proctor curves of the various mixtures (GT-DS); (b)Modified Proctor curves of compacted samples at different compaction energies [16]

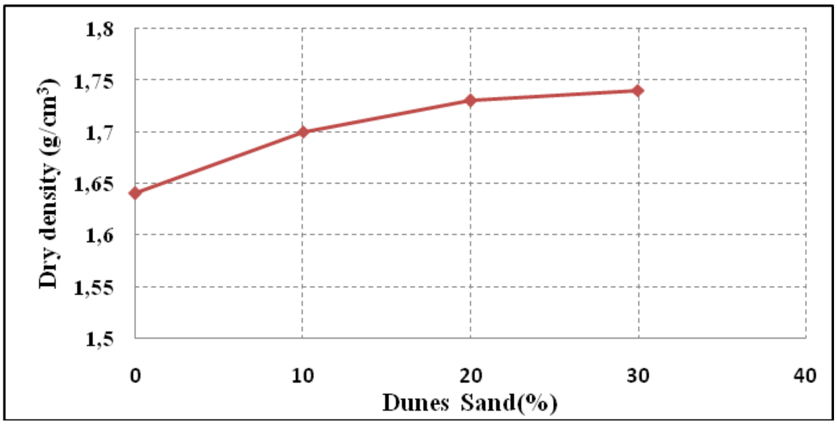


Fig. 7 - Variation of maximum dry density of mixtures (GT-DS) according to the percentage of DS incorporated

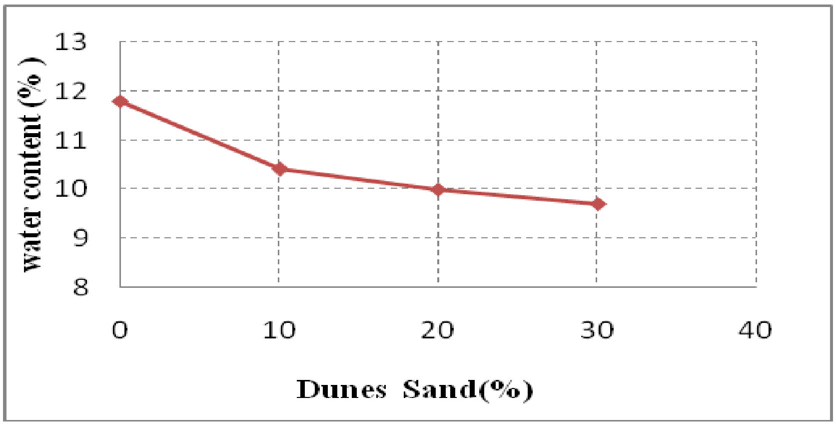


Fig. 8 - Variation of the optimal water content of the mixtures (GT-DS) according to the percentage of DS incorporated

4.2 Bearing Index Evolution

The lift of the mixture is estimated by the CBR test. This test consists to measure the forces to be applied on a cylindrical punch (19.35 cm^2 of the section) to make it penetrate at a constant speed (1.27 mm/min) into a test specimen of compacted material.

The results show that the incorporation of dunes sand up to 20% improves overall lift (Fig. 9). The maximum value of IBI was recorded at 10%, while that of IBas was located at 20%. At the addition of 30% of the sand, both indices show a decline, which can be justified by the reduction of the rate of gypsum tuff particles and its replacement by another dunes sand which becomes predominant in the mixture.

Good compaction behavior and improved lift (immediate and after immersion) when adding 20% dunes sand into the mixture (MGT-DS) compared to that of gypsum tuff alone, allows the mixture (MGT-20DS) to be adopted as an optimal mixture to analyse the evolution of the simple compressive strength in the following.

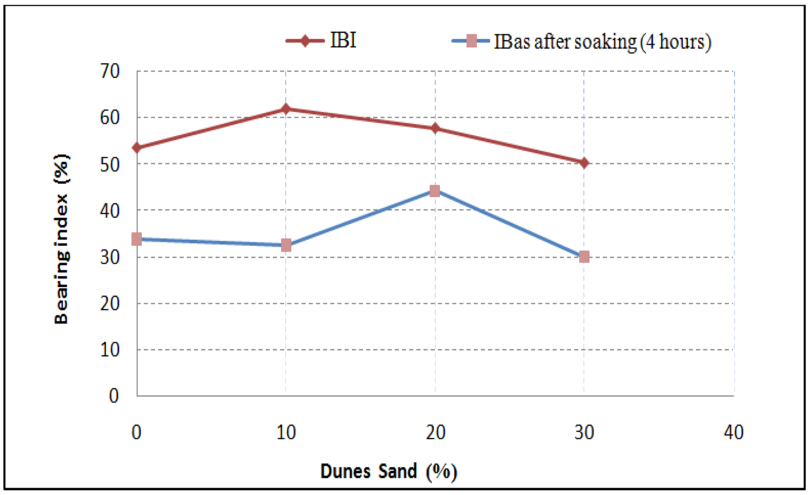


Fig. 9 - Variation of the Bearing index of the mixtures (GT-DS) according to the percentage of DS incorporated

4.3 Evolution of the Simple Compressive Strength (RC) of the Optimal Mixture MGT-20DS

The compressive strength is considered among the criteria of choice of materials in Saharan pavements construction. It is evaluated using the simple compression test that was adapted by Fenzy [13]. The test consists of appreciating the cohesion within the material. It is carried out on cylindrical specimens and on the fraction less than 5 mm. The specimens prepared at the optimum Proctor water content from gypsum tuff and 20% dunes sand (MGT-20DS) optimal mixture, were statically compacted in a cylindrical mold (Fig. 10) with double piston (50 mm in diameter and 100 mm in height).

Then, they were kept in an oven at 20oC for 3, 7, 14 and 28 days, at the rate of 03 specimens per duration. The crushing of the test pieces was carried out using a press at a speed of 1.04 mm/min.

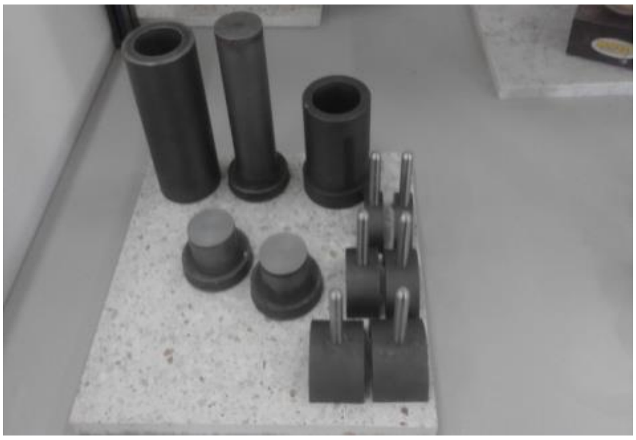


Fig. 10 - Simple compression mold

Fig. 11, which presents the evolution of compressive strength of GT and MGT-20DS according to age, shows in the first place that the resistance of the GT alone developed remarkably during a period of 3 to 7 days, then it tended towards an almost constant value. At 28 days, the Rc reached 1,8 MPa bars. These results are consistent with those obtained by Morsili [2] as well as by Goual [7], during the works done on limestone tuffs.

4.4 Evolution of the Resistance (Rc) of the Optimal Mixture (MGT-20DS) Treated with Lime

In the long term, the addition of dunes sand to gypsum tuff does not improve the compressive strength. As a result, the optimal mixture (MGT-20DS) treatment seems useful to overcome this problem. Fig.11 gives a comparison of the evolution of the resistance of MGT-20DS, MGT-20DS treated with 6% lime and GT alone.

The results obtained show that treating MGT-20DS with lime significantly improves compressive strength by comparing with untreated MGT-20DS and GT alone. At 28 days, Rc of the treated optimal mixture exceeded 2 MPa, 26% higher than the Rc of the untreated mixture and 20% of the gypsum tuff.

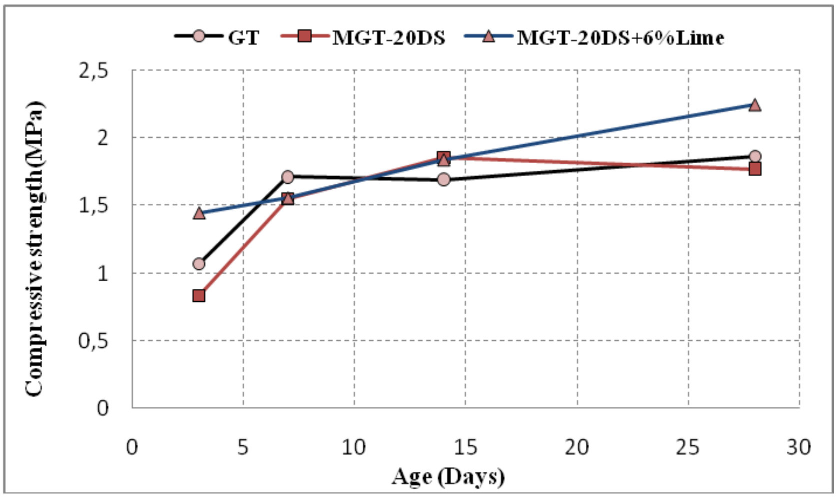


Fig. 11 - Evolution of the compressive strength of MGT-20DS, MGT-20DS treated with 6% lime and GT alone according to the age

4. Conclusion

In the light of results obtained, it is concluded that the idea of combining gypsum tuff and dunes sand appears to be a promising solution to limit the exploitation of non-renewable natural resources such as gypsum tuff which is relatively expensive to extract. Adding up to 20% dunes sand (DS) to gypsum tuff (GT) made it possible to modify the Proctor coordinates by increasing the dry density and decreasing water content; increase the lift (IBI and IBas) of the mixture M GT-20SD, compared to that of GT alone and reduce the compressive strength. The lime treatment of the mixture MGT-20DS led to the improvement of the compressive strength which is significantly higher than that of the untreated mixture as well as that of gypsum tuff alone. This result opens the way to the use of this mixture in Saharan road construction.

Acknowledgement

The authors wish to thank all technical personnel of EVRNZA Laboratory of University of Ouargla and Laboratory of Public Works of the South unit of Ouargla Algeria for kindly assistant.

References

[1] Goual, I., Goual, M. S., Taibi, S., & Abou-Bekr, N. (2011). Behaviour of unsaturated tuff-calcareous sand mixture on drying-wetting and triaxial paths. Geomechanics and Engineering, 3(4), 267–284

[2] Morsli, M. (2007). Contribution à la Valorisation des Tufs d'Encroûtements en Technique Routière Saharienne. Doctoral Thesis, National Polytechnic School, Algeria

[3] Morsli, M., Bali, A., Bensaibi, M., & Gambin, M. (2007). Etude du durcissement d'un tuf d'encroûtement de Hassi-Messaoud (Algérie). Revue Européenne de Génie Civil, 11(9),1219–40

[4] Demdoum, A. (2019). Comportement hydrique et mécanique d'un mélange de bentonite-sable calcaire-tuf: Application à la conception des installations de stockage des déchets (ISD). Doctoral Thesis, Amar Telidji University of Laghouat, Algeria.

[5] Goual, I., Goual, M. S., Taibi, S., & Abou-Bekr, N. (2012). Amélioration des propriétés d'un tuf naturel utilisé en technique routière saharienne par ajout d'un sable calcaire. European Journal of Environmental and Civil Engineering,16(6), 744-763

[6] Goual, I., Goual, M. S., Gueddouda, M. K., & Ferhat, A. (2008). Effect of treatment with lime and cement to the mechanical behavior of calcareous tuffs: For use in pavement layers in the region of Laghouat–Algeria. International Conference on Construction and Building Technology, A(10), 101–11

[7] Goual, I. (2012). Comportement mécanique et hydrique d'un mélange de tuf et de sable calcaire de la région de Laghouat: Application en construction routière. Doctoral Thesis, Abou Bekr Belkaid University of Tlemcen, Algeria

[8] Améraoui, Z. (2002). Les tufs d'encroûtements, utilisation dans la géotechnique routière. Magister Thesis, National Polytechnic School, Algeria

[9] Cherrak, M., Morsli, M., Boutemeur, R. & Bali, A. (2015). Valorization of the Use of Calcareous Tuff and Dune Sand in Saharan Road Design. Journal of Civil Engineering and Architecture, 9, 665-676

[10] Daheur, E. G., Goual, I., Taibi, S., & Mitiche-Kettab, R. (2019). Effect of dune sand incorporation on the physical and mechanical behaviour of tuff (experimental investigation). Geotechnical and Geological Engineering. https://doi.org/10.1007/ s10706-018-0715-4

[11] Khellou, A., Kriker, A., Hafsi, A., Belbarka, K., & Baali, K. (2016). Effect of the addition of by-product ash of date palms on the mechanical characteristics of gypsum-calcareous materials used in road construction. AIP Conference Proceedings 1758, 030005. https://doi.org/10.1063/1.4959401

[12] Akacem, G., Zentar, R., Mekerta, B., Sadok, A. & H. M. (2019). Omar co-valorisation of local materials tuff sand dune sands in construction of roads. Geotechnical and Geological Engineering. DOI 10.1007/s10706-019-01035-4

[13] Morsli, M. & Bali, A. (2009). La Pratique du dimensionnement des chaussées sahariennes. Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering, pp. 805-808

[14] Abdo, J. (2008). Traitement des sols en place aux liants hydrauliques. Actes de la journée valorisation des sols médiocres (In-situ soil treatment with hydraulic binders). Paris

[15] Ben Dhia, M. H. (1998). Quelques particularités de l'utilisation du sable de dune en construction routière en milieu saharien. Bulletin des Laboratoires des Ponts et Chaussées, 213, 33-42

[16] Fredlund, D. G., Rahardjo, H. & Fredlund, M. D. (2012). Unsaturated Soil Mechanics in Engineering Practice, Wiley