Study of the Effect of Adding Dune Sand to Tuff in Saharan Road Construction

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ABSTRACT

The south region of Algeria is characterized by a wide surface, a scattered population and a very small ratio of road length per habitant. To allow the development of agricultural, industrial and touristic activities between different cities in the south of Algeria, it is necessary to maintain and to develop the road infrastructure. However the development of these infrastructures necessitates the use of huge amount of certified aggregates from quarries which is not available in the vicinity of the need. For these raisons, in the framework of sustainable development, a strategy which consists in using local materials like fine sediments (dune sand) and other types of material is engaged. The materials constituting the road layers, until today, have been limited to certain so-called noble materials (gravel, aggregates, etc.), but these are being depleted as a result of the intensive exploitation and the scarcity of quality careers. Gypso-limestone encrustation tuffs, the most used materials in pavements (base course and base course) in the Saharan areas such as southern Algeria, have shown acceptable behavior for many years until these last days, when this type of material begins to present certain limits under the effect of the intensity of the traffic. In order to promote the abundant wind sands in these regions, we are interested in developing the dune sands in the pavement as a mixture with the tuffs. The present work presents a contribution to the study of the behavior of the tuff of the Adrar region (South of Algeria) alone and mixed with the sand dunes in different formulations. The aim is to evaluate the evolution of mechanical properties including resistance to simple compression, the ability to compaction and punching (RBC). The work also discusses the influence of the addition of cement in low levels on the performance of the mixture.

I. Introduction

Tuffs naturally have a high percentage of fines and they have little or no skeleton. Some natural bass are, on the contrary, rich in large elements but totally devoid of fines. In addition, some natural wind or alluvial sands are devoid of fines.

The Sahara covers almost more than three quarters of the Algerian territory. Local materials such as sands are the subject of current research in order to use them in road techniques particularly and in construction, both for economic and environmental reasons. The materials constituting the pavement bodies have been limited to gravels and crushed rocks, the latter having been considered for a long time as the only acceptable materials and which rigorously meet certain geotechnical criteria (hardness, cleanliness, grain size, etc.), whereas Dune sands, due to their poor characteristics, were considered secondary materials.

The calcareous crust tuffs cover approximately an area of 300,000 km^2 of Algeria. They have been used since the 1950 in the construction of thousands of kilometers of economic and access roads in the form of economic substitution aggregates. After the construction of more than 2200 km of road in a desert environment, a Saharan Road Technique (TRS) was developed [1] and [2]. Since then, work has been carried out on these materials and specifications have been proposed [3]. But, in practice, road technicians apply more the criteria recommended by the TRS.

According to the studies already carried out on the tuffs, we can see that they have often weak geotechnical characteristics, in particular their low resistance to shocks and abrasion as well as their sensitivity to water which does not allow consider their use as foundations for high traffic pavements [4-13]. Another technique has been developed and developed for over 30 years. It consists of the association of tuff with other materials, treated or untreated, rich in large elements, but totally devoid of fines (gravel or sand) [9] and [13]. The solution results from the technique of mixing materials which seems to open a new way. It can relate either to a granular correction or to an improvement in the geotechnical and mechanical characteristics of a given material. The second solution is more suitable for Saharan materials.

The association of crust tuffs with these gravel or sands therefore seems quite interesting when we want to improve the grain size of a gravel low in fines or reduce the amount of fines in a tuff rich in fines. According to Fenzy [1] and [2], adding clean sand to fine materials with certain clay content can also improve the compaction characteristics of the mixture.

II. Materials Study

The Adrar tuff is used as the basic material, mixed in varying proportions with dune sand (DS). Identification tests [14-20] are carried out on the mixing sand: very fine (0-0.4 mm), highly homometric and clean (ES = 83%), it has a W_L liquidity limit of around 22 and a non-measurable plasticity limit, practically free of fine elements, with a blue value of 0.10 and maximum dry density of 1.63 kN/m^3 for an optimum water content of 6.3%.

Table 1 shows the and Atterberg limits plasticity of materials study : Tuff and dune sand (DS) of Adrar region.

Table 1. Atterberg limits of materials study

Items	W_L	W_P	I_P
Tuff	30.2	19.1	11.1
Dune sand (DS)	22	N.M	N.M

Like plasticity, we can clearly see that the blue value decreases in favor of an increase in the rate of dune sand. The particle size curves of the studied tuff as well as the mixed dune sand are shown in Figure 1.

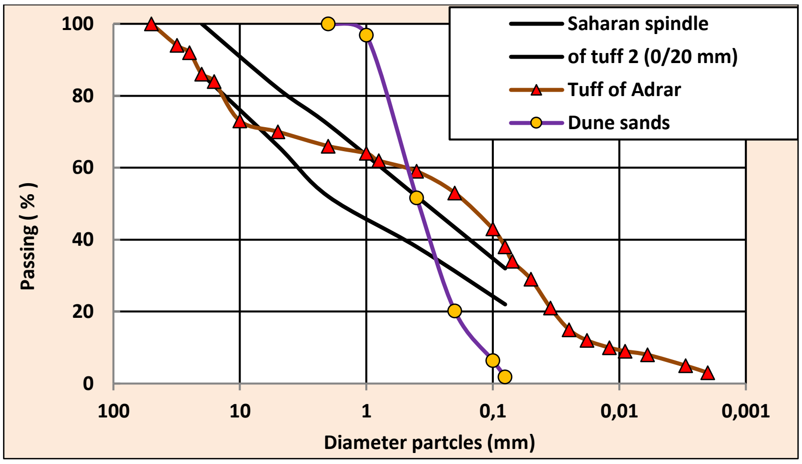

Figure 1. Particle size curves (tuff and dune sand).

The principle of the test consists in constantly maintaining a mixture [sample (0 / d) + water] under stirring, then in introducing increasing amounts of methylene blue in successive doses, until the clay particles are there saturated; an excess then appears which marks the end of the test and which is detected by the task test. The latter consists in forming with a drop of the suspension on standardized filter paper a task which is a deposit of soil colored blue, surrounded by a colorless wetland. Too much blue results in the appearance of a light blue halo in this area. This test is carried out according to [21]. Table 2 summarizes the blue values and the activity coefficients of the tuff studied of Adrar.

Table 2. Values of the VB and CA cofficients of the Adrar tuff studied

Tuff	Tuff of Adrar
VB (0/0.4)	0.66
Cd (%)	59
VB (0/D)	0.39
% ≤ 2 µm	3
CA (%)	13

Concerning the degree of pollution, and if we adopt the classification of [9] retained for the sands with crusting tuffs, we find that the samples studied are: slightly polluted for the tuff of Adrar.

III. Bihavior tests

The tests frequently used to know the behavior of road materials are: The Modified Proctor Test [22]; the CBR test [23] and the simple compressive strength test.

III.1. Modified Proctor

This test is used when the material is intended to be used as a pavement layer. The various authors who have carried out tests of this type agree on the following findings [3] and [5].

- Optimal OPM densities are generally between 1.7 and 2 kN/m^3; values less than 1.6 kN/m^3 denote an alteration of the crusting, and too fine a limestone material;
- The optimal water contents are very variable, but in general high, and between 8 and 15%, they can reach or exceed 20% at times;
- The lowest densities correspond to the highest water contents;
- The OPM curves are relatively flat for non-plastic tuffs (Ip < 5); the optimum density can be influenced by the variation of the water content;
- The presence of clay (Ip > 10) leads to sharp curves, the density drops when one deviates from the optimum water content.

Figure 2 shows the variation of the dry density of tuff from the Adrar region (Berbaa tuff) as a function of water content.

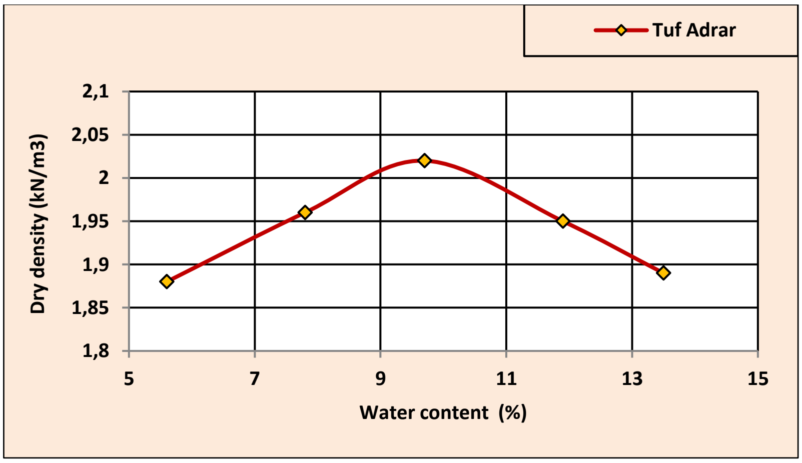

Figure 2. Modified Proctor curve for tuff of Adrar

III.2. CBR test

The CBR puncture test is often performed on crust tuffs, as its result is retained in the specifications of many countries. The test is carried out either immediately after compaction or after four days of immersion.
The immediate CBR results vary greatly depending on the characteristics of the tuff studied; the CBR index being higher the more the material has a hard skeleton and the grain size curve is regular. The maximum indices are most often reached for water content slightly lower than W_{OPM}. For calcareous crust tuffs used as pavement structures, the values of the CBR index vary between 50 and 150 [3]and [9].
The CBR index after immersion drops more or less from the immediate index depending on the presence of clay. The values of the CBR index after immersion are generally between 30 and 10 [4].
The coefficient most generally used to give a thickness to a pavement body is the CBR index. This empirical index is determined by a laboratory test. Done according to [23], it makes it possible to estimate the bearing capacity of the compacted soil at a given humidity. It is based on the resistance to soil penetration by a standardized punch. The soil specimen is compacted in the CBR mold. The compaction and lift results are summarized in Table 3.

Table 3. Characteristics of compaction and bearing of the Adrar tuff

Test	Modified Proctor		Lift
Sample of tuf	W_{opt} (%)	γ_{dmax} (kN/m^3)	I CBR (Immdiatly)
Adrar	9.7	20.2	27.5

III.3. Simple compression test

The elements of the soil fraction whose grains have a dimension less than 0.4 mm are characterized by means of This is an empirical test, first introduced for local materials by Fenzy [1], [2]. It is carried out on all Saharan materials on the 5 mm fraction. Compaction with the OPM is carried out in the press and the demolded specimens (5 cm in diameter and 10 cm in height) are dried, either in an oven at 60 °C for 48 hours, or stored in the open air.
The equipment consists essentially of a hydraulic press and elements for making the test specimens (mold, counter-mold, lower piston, spacer, upper piston, and demolding cylinder) - figure 3

Figure 3. Elements for making cylindrical specimens test

The material is mixed manually or using a mixer, the cylindrical specimens (Ø = 5 cm; h = 10 cm) are statically prepared at the water content Wopt and the density $\gamma_{d\,max}$.
We prepare respectively:

- quantity of dry material (W_d),

$$Wd = \gamma_{dmax} \pi \emptyset^2 \frac{h}{4} \quad (1)$$

- amount of water (W_w),

$$Ww = \gamma_{dmax} \pi \emptyset^2 \frac{h}{4} W_{opt} \quad (2)$$

- and quantity of wet material (W).

$$W = \gamma_{dmax} \pi \emptyset^2 \frac{h}{4} (W_{opt} + 1) \quad (3)$$

The making of a test specimen goes through several stages, figure 4 [8] and [10 –13].

Figure 4. Steps for making cylindrical test pieces for simple compression testing

IV. Tuff-sand mixture

In this part of this work, we present the study of tuff - sand mixtures of dunes of the region of Adrar according to different formulations. The aim is to assess the variation in mechanical performance, including resistance to simple compression, shear, compaction ability and CBR punching. The study is also interested in the influence of treatment with hydraulic binder: cement in low levels on the performance of mixtures.

V. Optimal formulation

The geotechnical characteristics of the tuffs are poor with respect to the regulations in force, but the latter have the particular property of hardening with age [6-9]. To improve the compactness, we opted for a correction of the particle size by substituting a fraction of (x %) of tuff by adding dune sand, with (x %) varying from 10 to 40. In order to find the optimum composition of the mixture, compaction and bearing tests were carried out on the different mixtures of tuffs and dune sands [24-32]. Simple compression tests at different ages were performed on specimens of different mixtures compacted at Modified Proctor Optimum (OPM).

VI. Results analysis

VI.1.Effect of incorporation of dune sand on cleanliness and plasticity

In this work, Adrar tuff is used as the basic material, mixed in varying proportions with dune sand (DS) ranging from 10% to 40%; we can see the effect on the geotechnical characteristics. Table 4 shows the contribution of incorporating dune sand into the base material, in terms of cleanliness and plasticity.

Table 4. Cleanliness and plasticity of mixtures Atterberg limits

Items	VBs	W_L	W_P	I_P
Tuff	0.39	30.2	19.1	11.1
+10% DS	0.35	25.2	17.6	7.6
+20% DS	0.31	22.3	16.9	5.4
+30% DS	0.26	17.8	N.M	N.M
+40% DS	0.22	15.6	N.M	N.M

We see that the plasticity index drops by 50% for an addition of 20% dune sand, and becomes non-measurable at 30%.
Like plasticity, we can clearly see that the blue value decreases in favor of an increase in the rate of dune sand.

VI.2. Effect of Incorporation of Dune Sand on Dry Density

Figures 5, 6, 7 and 8 shows the variation in dry density as a function of the water content of the mixtures of the Adrar tuff studied, for the different rates of addition of dune sand. These tests were carried out according to standard NF P 94-093 for mixtures of tuff with sand from dunes from the Adrar region.

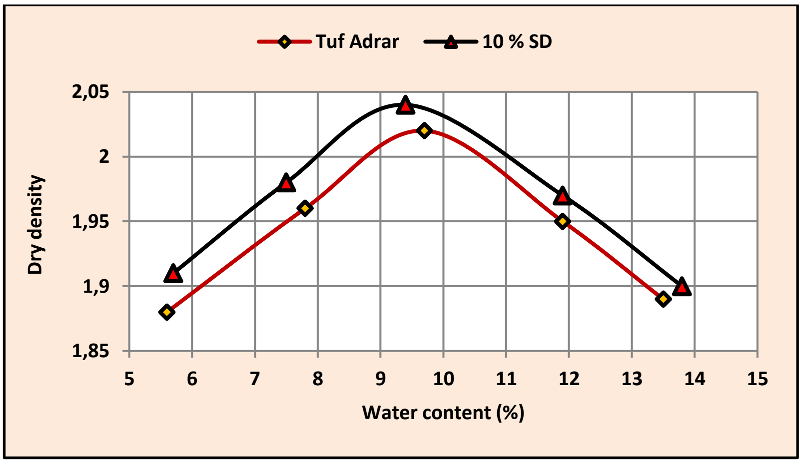

Figure 5. Modified Proctor curves of the tuff / sand mixtures of dunes (10%) in the Adrar region

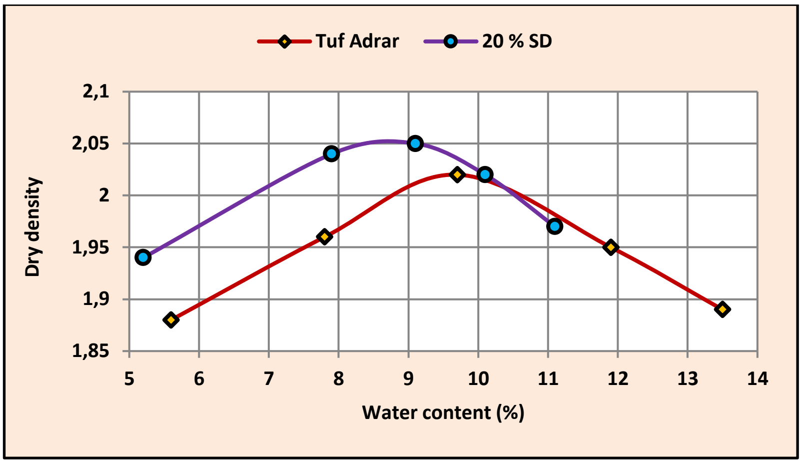

Figure 6. Modified Proctor curves of the tuff / sand mixtures of dunes (20%) in the Adrar region

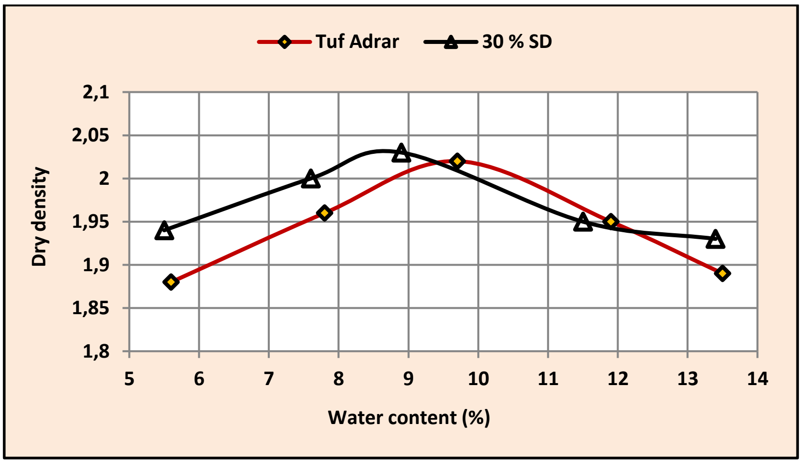

Figure 7. Modified Proctor curves of the tuff / sand mixtures of dunes (30%) in the Adrar region

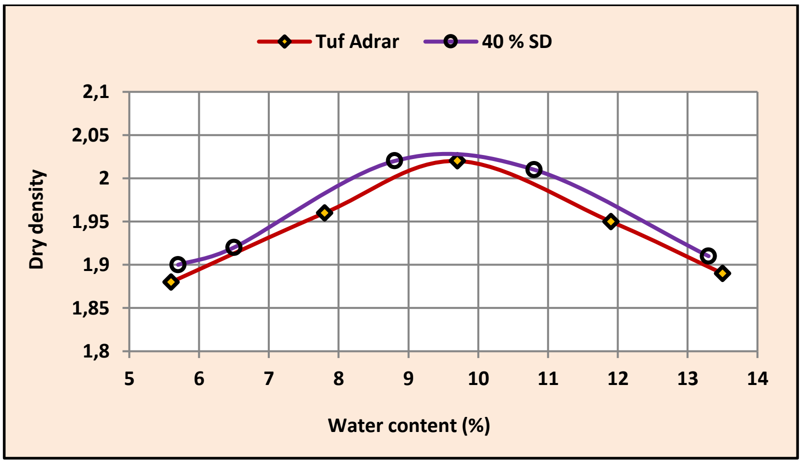

Figure 8. Modified Proctor curves of the tuff / sand mixtures of dunes (40%) in the Adrar region

The results show that the incorporation of sand from dunes to the tuffs of the Adrar tuff region studied tends to improve the optimal compaction characteristics of the mixtures compared to the tuff alone. According to the graphs, the dry density visibly improves when the sand content of the mixture increases up to 20%, then it decreases slightly at rates above 20%. This fact can be explained by the fact that at first the dune sand improves the density up to the point where the amount of fine particles of the tuff just manages to fill the voids between the grains of sand, but, once this threshold exceeded, voids accumulate and density is reduced.
After examining these different curves, we can draw the following observations:
• These curves flatten more and more with the increase in the percentage of sand dunes;
• The incorporation of dune sand in the tuffs of the Adrar tuff region studied improves the dry density OPM compared to the base materials, and this up to the rate of 20% of addition of dune sand; beyond this rate, the dry density drops slightly, while remaining higher than that of tuffs alone;
• Regarding the OPM water content, it is reduced with the addition of dune sand, which leads to a valuable saving of water, especially in desert environments;
• The flattening of the Proctor curves with the addition of the dune sand is an indication of the reduced plasticity of the mixtures, which would reduce the harmfulness of the fine clay.
Table 5 lists the values of dry density and water content corresponding to the Modified Proctor optimum for the different mixtures.

Table 5. Optimal characteristics Modified Proctor and bearning of various mixtures

Mixtures		Tuf	Tuf + 10% DS	Tuf + 20% DS	Tuf + 30% DS	Tuf + 40% DS
Adrar	W_{OPM} (%)	9.7	9.4	9.1	8.9	8.8
	γ_{dmax}	2.02	2.04	2.05	2.03	2.02
	I CBR	27.5	31	35	34	29

Figure 9 shows the influence of the addition of dune sand on the optimal compaction characteristics (W_{OPM} and corresponding γ_{dmax}) depending on the rate of sand incorporated. According to Figure 7, the influence of the rate of dune sand incorporated on the maximum dry density. In fact, the improvement in the maximum dry density of Adrar tuff is only 3%. Note that improvement is for an addition of sand of 20%.

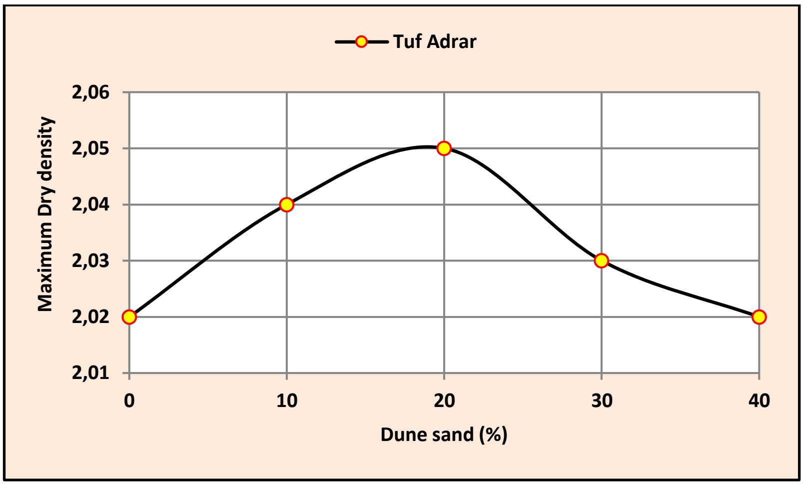

Figure 9. Effect of dune sand on the maximum dry density of the various tuff/dune sand mixtures in Adrar region

VI.3. Effect of addition of dune sand on the bearning capacity

The results of punching tests performed on the different formulations are shown in Figure 10, where the effect of the addition of sand on the immediate CBR index can be seen.

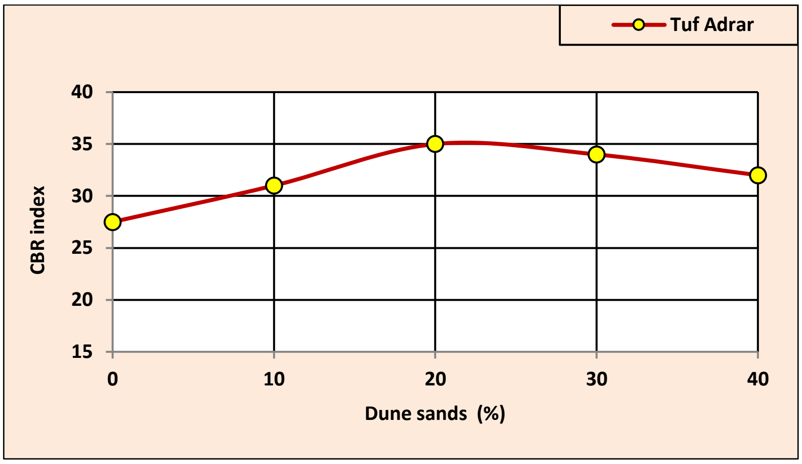

Figure 10. Effect of the incorporation of dune sand on the bearing capacity of the various mixtures

The incorporation of dune sand clearly improves the bearing capacity of the mixes.

VI.4. Evolution of compressive strength as a function of age

We measure the resistance of the compacted tuff specimens to compression at ages: (0; 7; 14; and 28 days), the specimens - tuff from the Adrar region - were subjected to a compressive force applied parallel to the axis of the cylinder, figure 11.

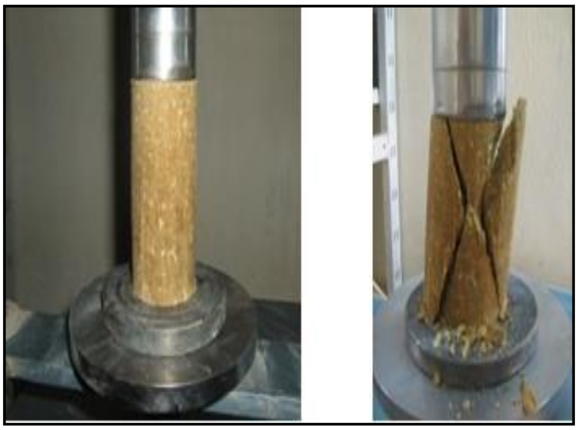

Figure 11. Tuff / sand dune mixture specimen subjected to the compression test.

1) Compressive strength (Untreated material)

For tuff from the Adrar region, and with the different dune sand content, the crushing results of the specimens at different ages are shown in Figure 12.

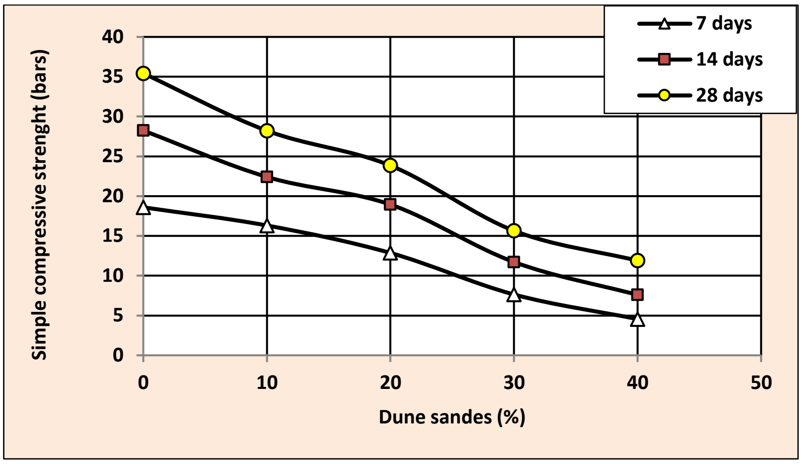

Figure 12. Compressive strength of tuff / sand mixtures from dunes in the Adrar region

Regarding the tuff of the Adrar region, and referring to the results of figure 12, it can be seen that the addition of dune sand to the tuff caused a deterioration of the resistance which caused a decrease of more than 60 % of the compressive strength of tuff alone.

Therefore we can conclude - and in the absence of any treatment - that Berbaa tuff behaves much better on its own.

This can be explained by the fact that there is no cohesion between the fines of the tuff and the siliceous grains of the sand used.

The experiment of adding sand from dunes to the tuff of the Adrar region gave poor results in simple compressive strength; in fact, tuff alone gave better resistance than for the tuff / sand dune mixture for all the rates tested and for all the storage times.
To make up for this decrease in compressive strength, we will begin a study of the stabilization of the mixture of the Adrar tuff / sand dune region by hydraulic binders such as cement and lime, and see the possible contributions of the point from the point of view of mechanical performance.
The admixture of the Adrar region tuff / sand with a 20% rate of dune sand, the subject of the following study, will be referred to as TSD (tuff / dune sand).

2) Compressive strength (Cement treated material)

For the treatment, we chose to treat the tuff alone and the optimal mixture (tuff + 20% dune sand) at 2% and 4% cement. The crushing results of the test pieces at different ages are shown in Figures 13 and 14 respectively.

For the treatment of the base material alone, and from the results found, it can be seen that an addition of 2% to 4% of cement improves the compressive strength respectively from 5 bars to 20 bars for Berbaa tuff.

This allows us to say that if we opt for a cement treatment, we choose to do it at 4% for the tuff of the Adrar region.

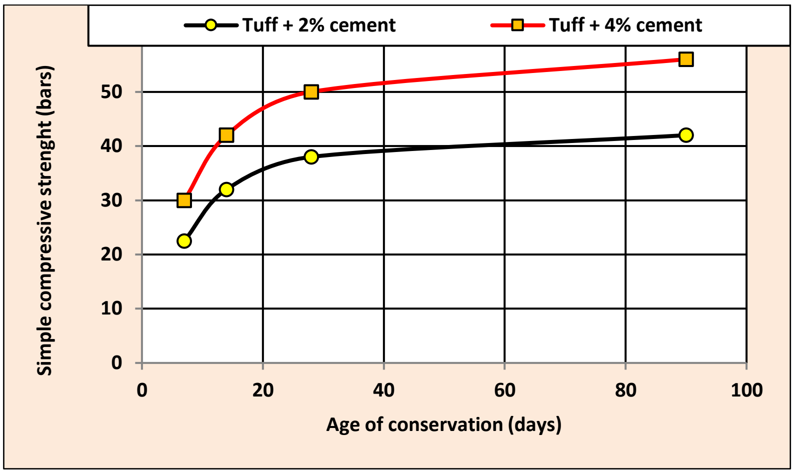

Figure 13. Compressive strength of tuff from the Adrar region treated with cement

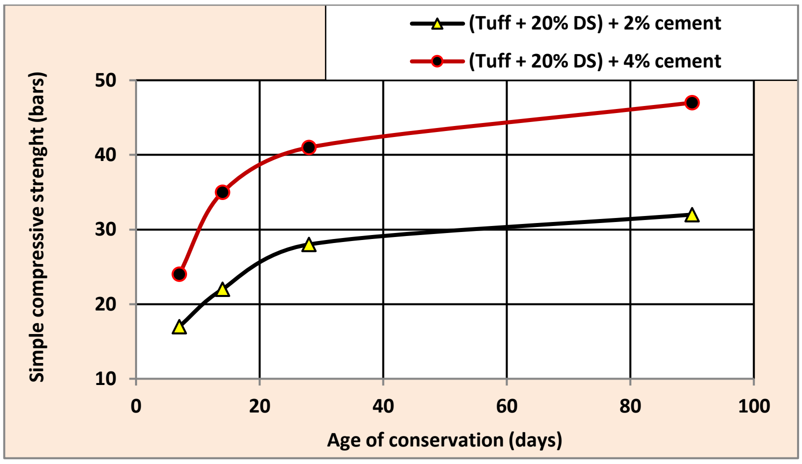

Figure 14. Compressive strength of the mixture (tuff + 20% sand of dunes) treated with cement.

Regarding the treatment of the tuff and dune sand mixture (20%), and in the light of the results obtained with the addition of 2 to 4% of cement, it is noted that the gain in compressive strength and respectively 7 to 20 bars for tuff from the Berbaa quarry.

VII. Conclusion

The study in this work focused on the influence of the addition of sand from dunes on the geotechnical and mechanical characteristics of the tuff of the regions of Adrar, El Goléa and Ouargla. The aim was to test the possibilities of improving the characteristics of the two types of local materials in these three regions, namely tuff and dune sand, through an economic stabilization technique aimed at upgrading the two materials in road construction.

The tuff / dune sand (TSD) mixture with a formulation of 80% tuff + 20% dune sand has given good results, especially with regard to cleanliness, plasticity and the characteristics of compaction and immediate bearing capacity. The weak point in this formulation lies in the deterioration of the compressive strength. To compensate for this decrease, we opted for a treatment of this mixture with hydraulic binders.

We can retain from all these studies on the use of dune sand that up to about 20% of addition of sand, the material obtained has geotechnical characteristics comparable to those of the base material, if not better.

The dry density improves as the sand content of the mixture increases to a threshold of 20%. It then decreases slightly to arrive at the value relating to sand alone.

The incorporation of dune sand clearly improves the bearing capacity of the mixes and a decrease in cohesion is recorded when the percentage of dune sand increases.

As for plasticity, it decreases in favor of a marked improvement in cleanliness. At different storage ages, the incorporation of dune sand causes a decrease in the compressive strength of the mixtures, (Berbaa tuff from the Adrar region has shown to resist better on its own).

For the treatment of tuff alone, and based on the results found, a rate of 4% cement can be applied.

The treatment of the tuff and dune sand mixture has shown that with an addition of 20% sand, the rate of 4% cement gives good improvements, it remains to be justified from an economic point of view.

The incorporation of dune sand in road materials and the use of salt (or sea) water in compaction operations are suitable solutions to achieve this objective because the results found during the studies are encouraging.

The valorization of these local materials (tuff and sand of dunes) is of great interest both from an economic point of view and from an environmental point of view. Indeed, it should make it possible to reduce the transport distance of aggregates, this would limit the impacts with a drop in CO_2 emissions linked to transport, and limit the use of aggregates from other regions.

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