Valuation of Local Materials in Road Construction in Arid Zones

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ABSTRACT

The materials constituting the pavement bodies, until today, have been limited to certain so-called noble materials (rolled sands, aggregates, etc.), but these are in the process of being exhausted under the effect of intensive exploitation and the scarcity of quality quarries. With the objective of preserving the deposits of aggregates in the process of exhaustion for future generations and of exploiting the aeolian sands in abundance in the regions of southern Algeria, we aim to enhance the latter in the body of the roadway mixed with the tuffs, this would imply a reduction in construction costs (use of local aggregates of lower quality available in large quantities, reduction in transport costs). From an environmental point of view, this would limit the impacts with a reduction in CO_2 emissions linked to transport. In this work, we applied a new approach based on the technique of mixtures to valorize and exploit the sand of dunes existing in abundance, with the treatment in hydraulic binders, which allowed us to go up to 20% of sand dunes.

I. Introduction

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, 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, 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.

II. Location of Materials

The materials used in this study are primarily tuffs (basic materials) and dune sand from three regions of the great South of Algeria. As for the tuffs, these are the quarries of Ghardaïa (El-Goléa), Ouargla (N'gouça), and Adrar. The three regions are located in arid Saharan zones, where the average level of annual precipitation is very low (Table 1).

Table 1. Source of study materials

Region	El-Goléa	Ouargla	Adrar
Distance (Km)/Alger	870	750	1410
Climatic zone		IV	
Hygrométrie (mm/an)		H < 100	

III. Characterization of material

III.1. Particle size analysis by sieving

Particle size analysis measures the dimensional distribution by weight of the elements of a material. The test is carried out according to [14].

III.2. Sedimentometric analysis

The fines content (elements less than 80 µm) does not always play a negative role for the material, especially when it comes to siliceous or limestone fines. According to [15], the fine particle content that is necessary for good stability of a material is the lower the coarse it is, and the greater the fine it is. The particle size analysis of this fraction (for the tuffs studied) is made by sedimentation according to [16], which complements the particle size analysis by sieving where it is not possible to use sieves. The principle of this test is based on Stockes' law where the sedimentation rate of particles in suspension in a medium depends on their diameters. Figure 1(a); presents the position of the grain size curves of the tuffs studied, with respect to the tuff 1 (0/40) spindle [17].

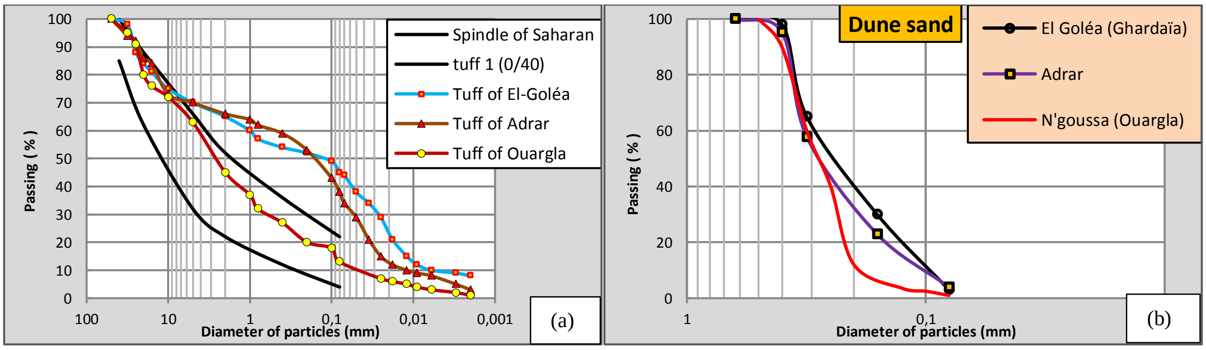


Figure 1. Particle size curves of the tuffs studied

Regarding the grain size distribution of the dunes of the Adrar, El-Goléa and Ouargla regions, it can be seen that the shape of their grain size curves reveals a relatively steep slope which characterizes well-sorted, poorly graded, homometric materials, including the diameter of the larger elements do not exceed 0.4 mm Figure 1(b). These dune sands contain practically no fine elements (maximum 4% for the sand dunes of Adrar).

III.3. Limits of Atterberg

The elements of the soil fraction whose grains have a dimension less than 0.4 mm are characterized by means of the Atterberg limits (liquidity and plasticity limit), as well as the plasticity index according to [18] and [19]. The plasticity index Ip is generally used to characterize the clayness of soils, it is all the more reliable when the proportion by weight of the 0 / 0.4 mm fraction is large [20]. Table 2 summarizes the results of the Atterberg limits.

Table 2. Values of the Atterberg limits of the studiied tuffs

Samples	Tuff			Seuils préconisés	
	El-Goléa	Ouargla	Adrar	CTTP	TRS
WL (%)	28.29	23	30.19	< 40	-
WP (%)	17.92	N.M	19.08	-	-
IP (%)	10.37	/	11.11	< 15	< 13

III.4. Methylene blue test

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 3 summarizes the blue values and the activity coefficients of the samples studied.

Table 3. Values of the VB and CA cofficients of the studied samples

Samples	Tuff		
	El-Goléa	Ouargla	Adrar
VB (0/0.4)	0.69	0.51	0.66
Cd (%)	54	27	59
VB (0/D)	0.37	0.14	0.39
% ≤ 2 µm	8	2	3
CA (%)	4.6	7	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 and El-Goléa, and clean for Ouargla tuff.

III.5. Modified Proctor test

The test is carried out as follows [22]. Its purpose is to determine, for a standardized compaction of a given intensity, the maximum dry density and the corresponding optimum water content. In practice, the maximum density obtained in the Modified Proctor test corresponds to that obtained by modern compactors for the compaction of the materials used in pavement layers at their optimum humidity.

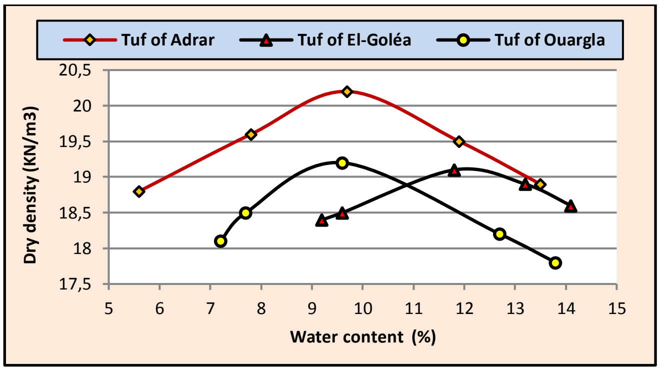


Figure 2. Variation of the dry density as a function of the compaction water content

The Modified Proctor curves in figure 2 show the variation of the dry density γd as a function of the water content ω of the tuff samples studied. We can therefore determine the optimum water content ω_{opt} and the maximum dry density γd max for each material.

III.6. CBR test

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 4.

Table 4. Characteristics of compaction and bearing of the tufs studied

Test	Modified Proctor		Lift
Sample of tuf	W_{opt} (%)	γ_{dmax} (kN/m^3)	I CBR (Immdiatly)
Adrar	9.7	20.2	27.5
El-Goléa	11.8	19.2	20
Ouargla	9.5	19.2	19

IV. Study of the tuf-sand mixture

In this part of this work, we present the study of tuff - sand mixtures of dunes of the regions of Adrar, El-Goléa and Ouargla 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 binders: cement and lime in low levels on the performance of mixtures.

V. Search for an 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] and [11-13]. 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 in the three regions. Simple compression tests at different ages were performed on specimens of different mixtures compacted at Modified Proctor Optimum (OPM). The study approach is made according to the following flowchart, figure 3.

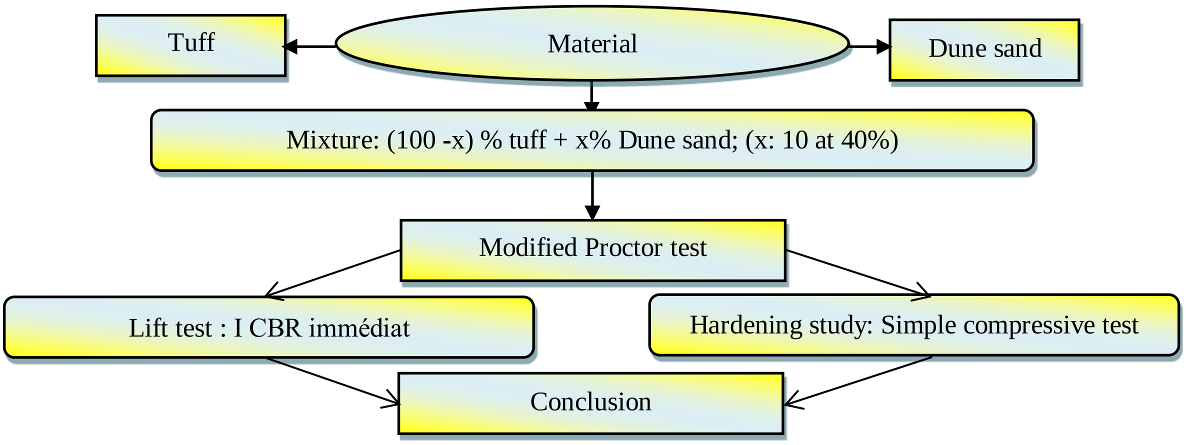


Figure 3. Flowchart for the search for an optimal formulation

V.1. Cleanliness and plasticity

The Atterberg limit and methylene blue value tests were performed on samples of each tuff material from the three regions mixed with proportions of dune sand (DS) from the corresponding region at rates of 10; 20; 30 and 40%. Tables 5, 6 and 7 show the contribution of the incorporation of dune sand into the base material on cleanliness and plasticity.

Table 5. Cleanliness and Plasticity of Mixtures – Adrar

Formulation		Tuf	Tuf + 10% DS	Tuf + 20% DS	Tuf + 30% DS	Tuf + 40% DS
Vb (0/D)		0.39	0.35	0.31	0.26	0.22
Limits	W_L	30.19	25.19	22.27	17.78	15.63
	W_P	19.08	17.61	16.89	N.M	N.M
	I_P	11,11	7.58	5.38	/	/

Table 6. Cleanliness and Plasticity of Mixtures – El-Golea

Formulation		Tuf	Tuf + 10% DS	Tuf + 20% DS	Tuf + 30% DS	Tuf + 40% DS
Vb (0/D)		0.37	0.33	0.29	0.25	0.21
Limits	W_L	28.29	23.61	20.87	16.67	14.65
	W_P	17.92	16.52	16.38	N.M	N.M
	I_P	10.92	7.09	4.29	/	/

Table 7. Cleanliness and Plasticity of Mixtures – Ouargla

		Tuf	Tuf + 10% DS	Tuf + 20% DS	Tuf + 30% DS	Tuf + 40% DS
Vb (0/D)		0.14	0.11	0.09	0.07	0.06
Limits	W_L	23	21.36	18.54	16.93	14.31
	W_P	N.M	N.M	N.M	N.M	N.M
	I_P	/	/	/	/	/

According to the results given by the preceding tables, it is noted, for the tuffs of the Adrar and El-Goléa regions that the plasticity index decreases respectively by 50 and 60% for an addition of 20% of dune sand, and becomes unmeasurable at 30%. Tuff from the Ouargla region shows no plasticity. As with plasticity, we can clearly see that the blue value decreases in favor of an increase in the rate of dune sand.

V.2. Mixtures Modified Proctor test

These tests were carried out according to standard NF P 94-093 for mixtures of tuffs with sand from dunes from the three regions. Figures 4, 5 and 6 show the variation in dry density as a function of the water content of the mixtures of the three regions studied, for the different rates of addition of dune sand.

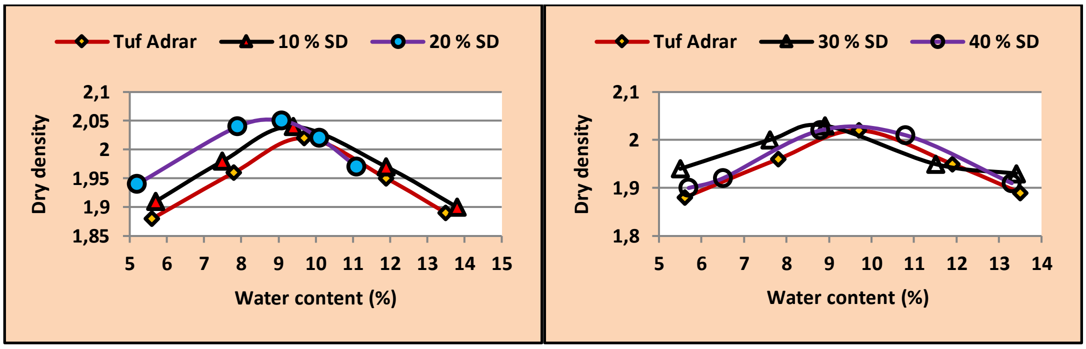


Figure 4. Modified Proctor curves of the various tuff / sand mixtures of dunes in the Adrar region

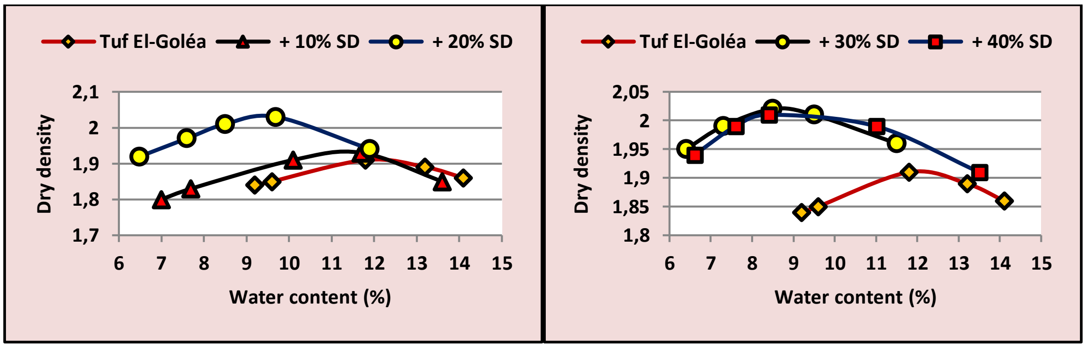


Figure 5. Modified Proctor curves of the various tuff/sand dune mixtures in the El- Goléa region

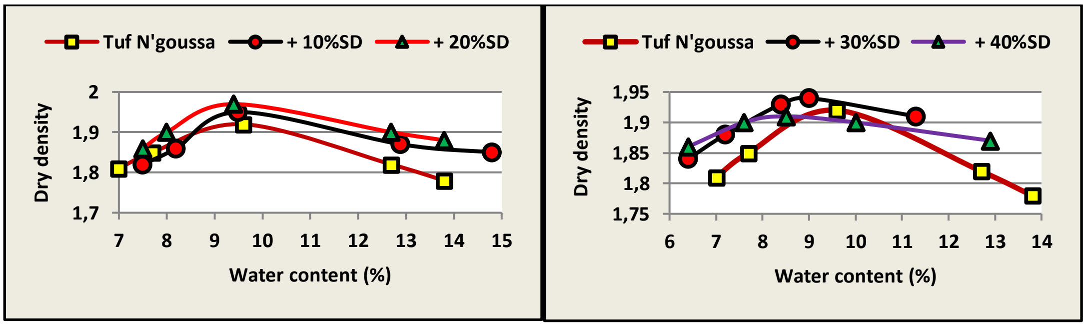


Figure 6. Modified Proctor curves of the various tuff/sand dune mixtures in the Ouargla region

The results show that the incorporation of sand from dunes to the tuffs of the different regions studied tends to improve the optimal compaction characteristics of the mixtures compared to the tuffs 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 three regions 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 8 lists the values of dry density and water content corresponding to the Modified Proctor optimum for the different mixtures.

Table 8. 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
El-Goléa	W_{OPM} (%)	11.8	11.5	9.7	8.5	8.4
	γ_{dmax}	1.91	1.93	2.03	2.02	2.01
	I CBR	20	24	28	32	29
Ouargla	W_{OPM} (%)	9.6	9.5	9.4	9.0	8.5
	γ_{dmax}	1.92	1.95	1.97	1.94	1.91
	I CBR	19	25	30	28	26

Figure 7 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 8, the influence of the rate of dune sand incorporated on the maximum dry density is more significant for the tuf of the El-Goléa region than for the two other tufs of Adrar and Ouargla. In fact, the improvement in the maximum dry density of El-Goléa tuff reaches 11%; in contrast, the increase is only 3% and 5% respectively for the Adrar and Ouargla tuffs. Note that all these improvements are for an addition of sand of 20%.

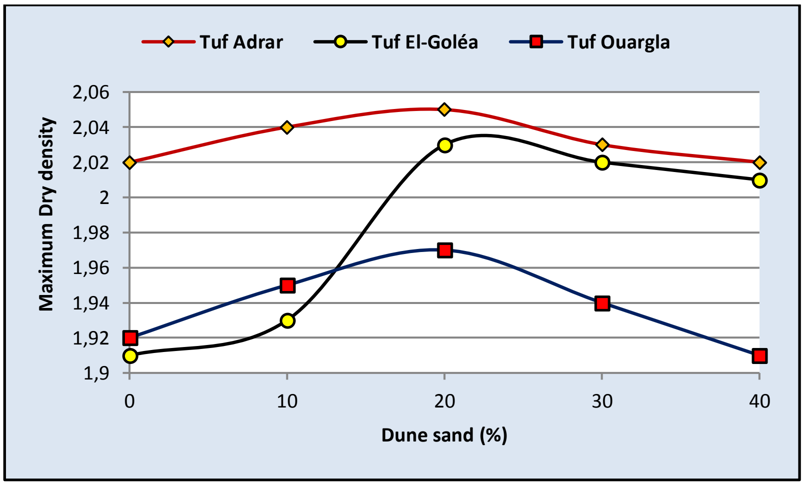


Figure 7. Influence of dune sand on the maximum dry density of the various tuff/dune sand mixtures in the three regions studied

V.3. Simple compressive test

This is an empirical test, first introduced for local materials by [6]. It is carried out on all Saharan materials on the 5 mm fraction. Compaction with the OPM is carried out in a press and the demoulded specimens (5 cm in diameter and 10 cm in height) are dried, either in an oven at 45 ° C for 48 hours, or stored in the open air. The study of simple compression is only carried out on the tuff / sand mixture of dunes in the Adrar region.

The equipment consists mainly of a hydraulic press and elements for making the test specimens (mold, countermould, lower piston, spacer, upper piston, and release cylinder), Figure 8.

The material is mixed manually or using a mixer; the cylindrical-shaped specimens (Ø = 5cm; h = 10cm) are made statically at the water content Wopt and the density γd max. The making of a test specimen goes through several stages, Figure 9:

• Place the mold on the spaced lower piston using a spacer, pour the prepared amount of wet material into it and place the upper piston;

• Static compaction of the test piece until the two pistons are closed;

• demolding of the test specimen, using the counter-mold and the demolding cylinder.

Figure 8. Test specimen mold for simple compression testing

Figure 9. Steps for making cylindrical specimens for simple compression testing

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

The resistance of the compacted tuff specimens to compression is measured at ages: 0; 7; 14; and 30 days. The specimens - tuff / sand dunes from the Adrar region - were subjected to a compressive force applied parallel to the axis of the cylinder, Figure 10.

Figure 10. Test piece of tuff / sand dune mixture subjected to the compression test.

For tuff from the Adrar region, and with the different dune sand rates, the crushing results of the specimens at different ages are shown in Figure 11.

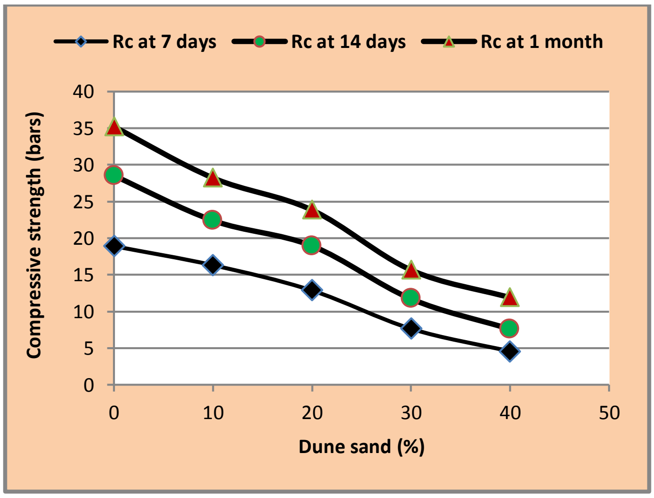


Figure 11. Compressive strength of tuff / sand mixtures from dunes in the Adrar region

Regarding the tuff of the Adrar region, and referring to the results in figure 11, 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, and 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 the cohesion between the fines of the tuff and the siliceous grains of the sand of the dunes of the Adrar region is not up to the level of improving the compressive strength compared to that of the tuff alone.

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).

VI. Treatment of the TSD mixture with hydraulic binders

Mechanical improvement processes are sometimes insufficient for pavement materials to achieve the required load-bearing capacity. It is then necessary to consider their treatment with hydraulic or hydrocarbon binders, whether with a view to bringing them an immediate improvement, even temporary, to allow their implementation in the backfill body under satisfactory conditions, or to considerably increase their medium and long-term mechanical characteristics for use as pavement layer materials. It is therefore necessary, before undertaking a soil treatment study, to set the target objective beforehand.
The treatment of the tuff / dune sand mixture with a binder has a dual objective:
• On the one hand, make the mixture insensitive to water;
• On the other hand, improve its mechanical performance in order to allow it to be used for paving with heavy traffic.
In this study, we planned to study the treatments of the TSD mixture with hydraulic binders such as cement and lime in order to observe the evolution of the mechanical characteristics with the age of the treated mixture;
The analysis of the change in immediate stability as well as mechanical performance as a function of age is carried out by the following tests: Modified Proctor, CBR index, simple compression and indirect traction (traction by splitting) on test specimens of density and water content, during preparation, close to those of the respective optimum of each formula (TSD + binder). The binder contents used are: 3% (cement, lime and mixed) and 6% (cement, lime and mixed). The case of mixed treatment is done on an equal footing between cement and lime, so the treatment with 3% mixed results from 1.5% of each binder, just like the treatment with 6% mixed involves 3% cement with 3% lime . The formulation study is carried out according to the steps schematized by the following flowchart, Figure 12. The incorporation of binders into soils has a rapid effect on the rheological behavior of the material which results in immediate stability and a long term effect which results in the improvement of the mechanical characteristics of the treated material.

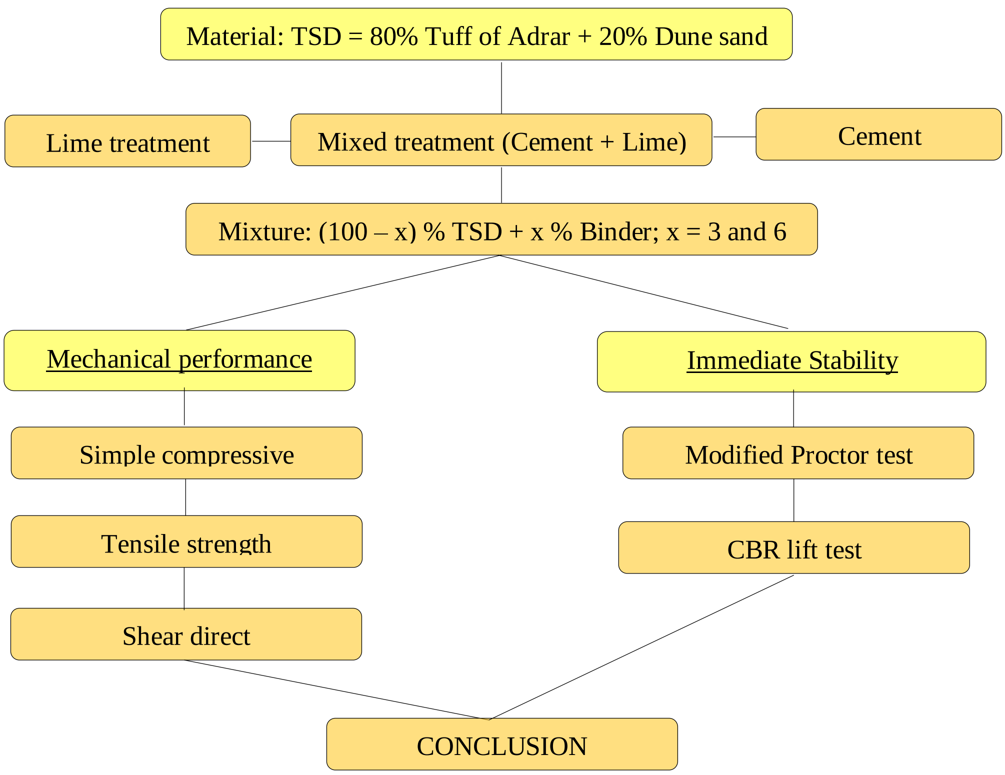


Figure 12. Flowchart of the study of the treatment of tuff / sand dune mixtures

VI.1. Compaction test

The "Modified Proctor" compaction test is performed according to [22]. Several samples of the mixture (tuff - sand - binder) are prepared and increased water contents are added to them, in order to determine each time the dry density and the corresponding compaction water content. The curve representing the variation of (γ_d) as a function of (W %) allows us to deduce the maximum dry density (γ_{dmax}) and the optimum water content (W_{opm}%) for each mixture.

The treatment of soils with hydraulic binders influences the compaction characteristics of the mixtures, namely the maximum dry density and the corresponding optimum water content. The effect of treating the TSD mixture with cement, lime and cement with lime is shown in Figure 13.
Changes in compaction characteristics are significant for 3% binder, whether for cement, lime or mixed treatment, while there is little variation when the binder content increases to 6%.

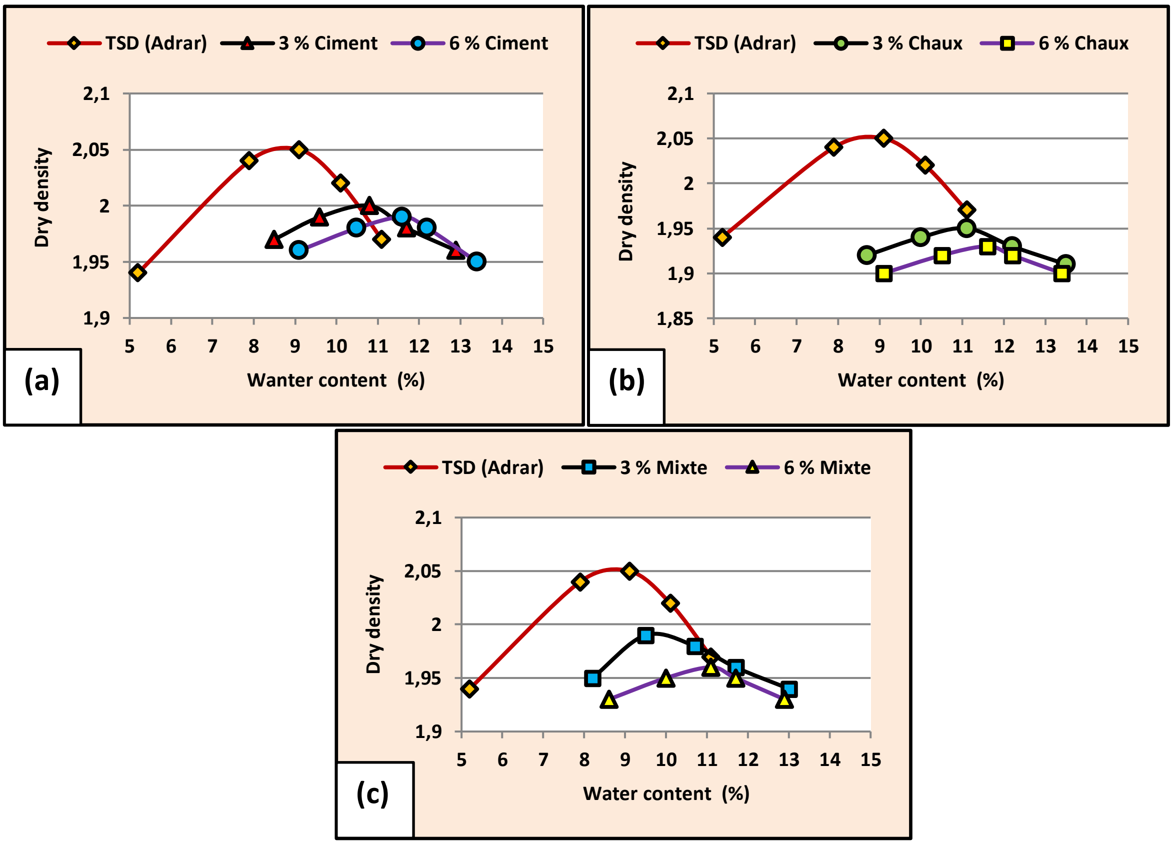


Figure 13. Proctor curves of the TSD mixture treated with (a) cement, (b) with lime and (c) cement with lime

VI.2. Bearning test

Immediately after compaction with the parameters of the optimum Modified Proctor, the immediate CBR index is determined according to [23]. The test is carried out at different compaction energies (12 strokes per layer, 25 c / c, 55 c / c).

VI.3. Simple Compression Test

The simple compression test is often used as an index to quantify the improvement of treated soils. This essay has already been seen in the first part of this work.

VI.4. Tensile Test

For the tensile test, there are several loading modes making it possible to subject a specimen to a tensile stress (direct traction, traction by bending and traction by splitting) and, given that the pavements are stressed by compressive forces leading to indirect traction, the test closest to this phenomenon is the tensile test by splitting (Brazilian test).

VI.5. Direct box shear test

The direct box shear test allows us to follow the improvement of the shear parameters (cohesion and internal friction angle) of the mixtures treated according to the age of conservation, the nature of the treatment binder and its content. Figure 14 shows the different phases of making test specimens to be analyzed by the direct box shear test.

Figure 14. Stages of making samples for box shear test

The effect of treatment on immediate lift is characterized by an increase in the CBR number of the mixtures related in proportion to the binder content, Figure 15.

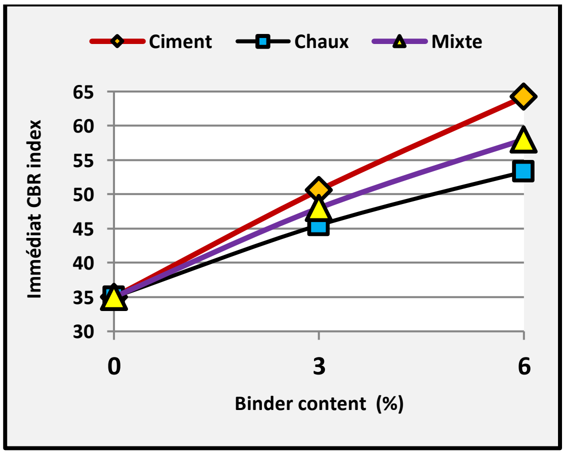


Figure 15. Influence of the binder content on the immediate CBR index

From the lift results, it can be seen that the immediate CBR index shows a gain over the untreated TSD mixture of 85, 50 and 65% respectively for a 6% cement, lime and mixed treatment.
Figure 16 shows the evolution of the compressive strength of the TSD mixture treated with 3 and 6% binder (cement, lime and mixed), at different storage ages in the open air. It is noted that the treatment gave a significant increase in the resistance to simple compression. These increases are linked to the storage age, the type of binder and its content.

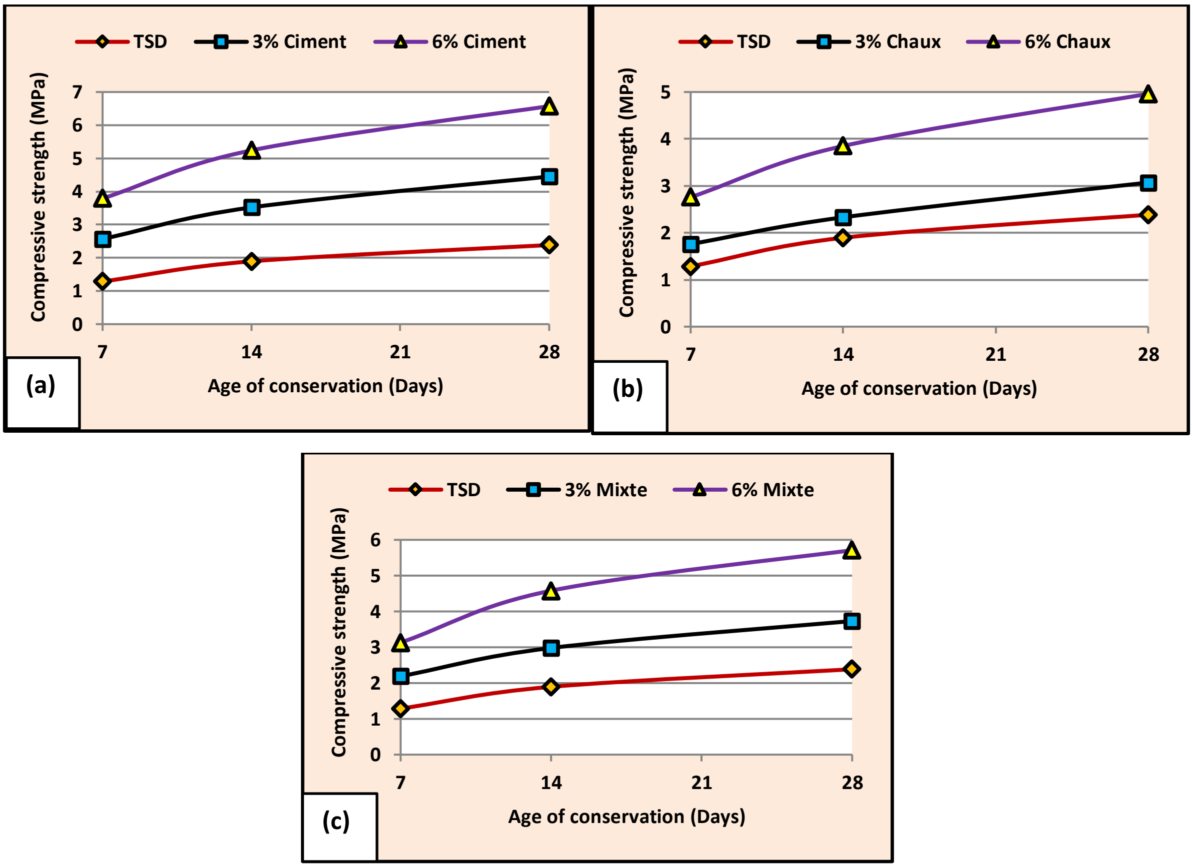


Figure 16. Variation of the compressive strength of the TSD mixture treated with (a) cement, (b) with lime and (c) cement with lime, depending on the age of conservation

The effect of the hydraulic binder treatment of the TSD (Adrar region tuff with dune sand) mixture on the tensile strength is shown in Figure 17.

The treatment improves the tentile strength of the TSD mixture and it can always be seen that the addition of cement gives better strengths compared to the mixed treatment, which itself is in turn better than the treatment with lime alone.
For a content of 6% cement, the test pieces stored in the open air for 28 days have a tensile strength of about 10 bars; In general, we find that the tensile performance is average and does not exceed 1 Mpa.
The direct shear test was carried out with the Casagrande box on 6 × 6 × 3 cm^3 test pieces of the TSD mixture (80% Adrar tuff + 20% dune sand), treated with 3 and 6% hydraulic binder (cement , lime and mixed), stored in the open air for 7, 14 and 28 days. The results showed a considerable improvement in cohesion compared to the untreated blend, Figure 18.

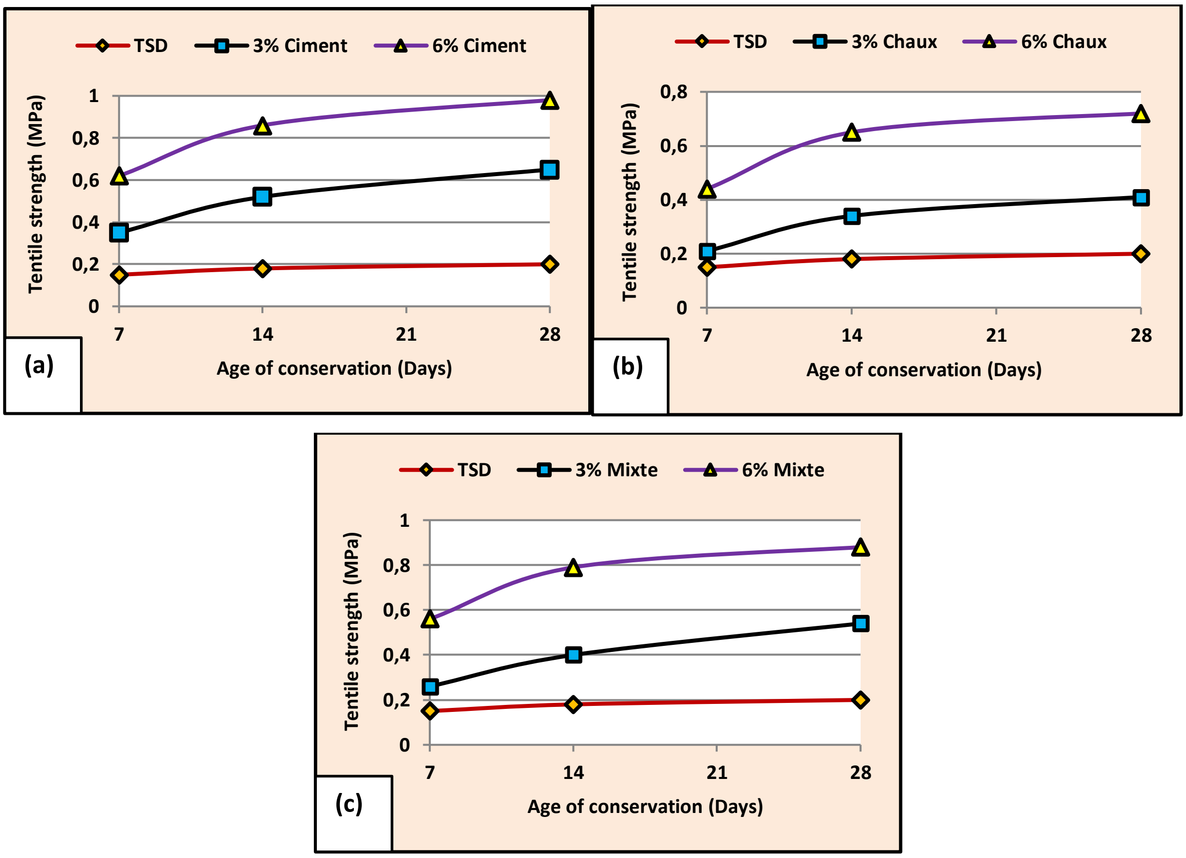
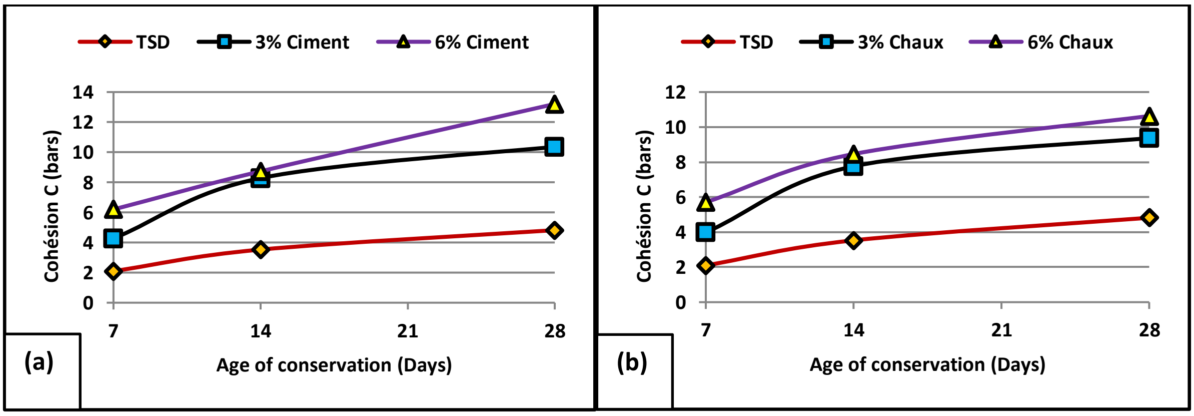


Figure 17. Variation of the tentile strength of the TSD mixture treated with (a) cement (b) lime (c) mixed, depending on the age of conservation.



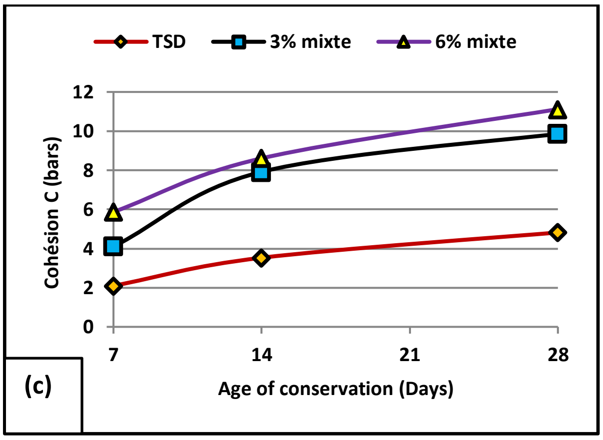


Figure 18. Evolution of the Cohesion of the treated TSD mixture (a) cement (b) lime (c) mixed, depending on the age of conservation.

For cohesion, we see that the treatment at 3 and 6% cement gives a significant improvement for an age of 28 days of storage in the open air; in fact, the cohesion drops from 4.8 bars to reach 10.4 and 13.2 bars respectively, which means an increase of about two to three times the cohesion of the untreated TSD mixture.
Likewise for the internal friction angle φ, the treatment at 3 and 6% cement provides a gain which varies respectively from 10 to 13 degrees compared to the untreated TSD mixture at the age of 28 days. The mixed treatment with lime at 3 and 6% binder also gives an improvement in the internal friction angle of the order of 9 to 11 degrees, figure 19.

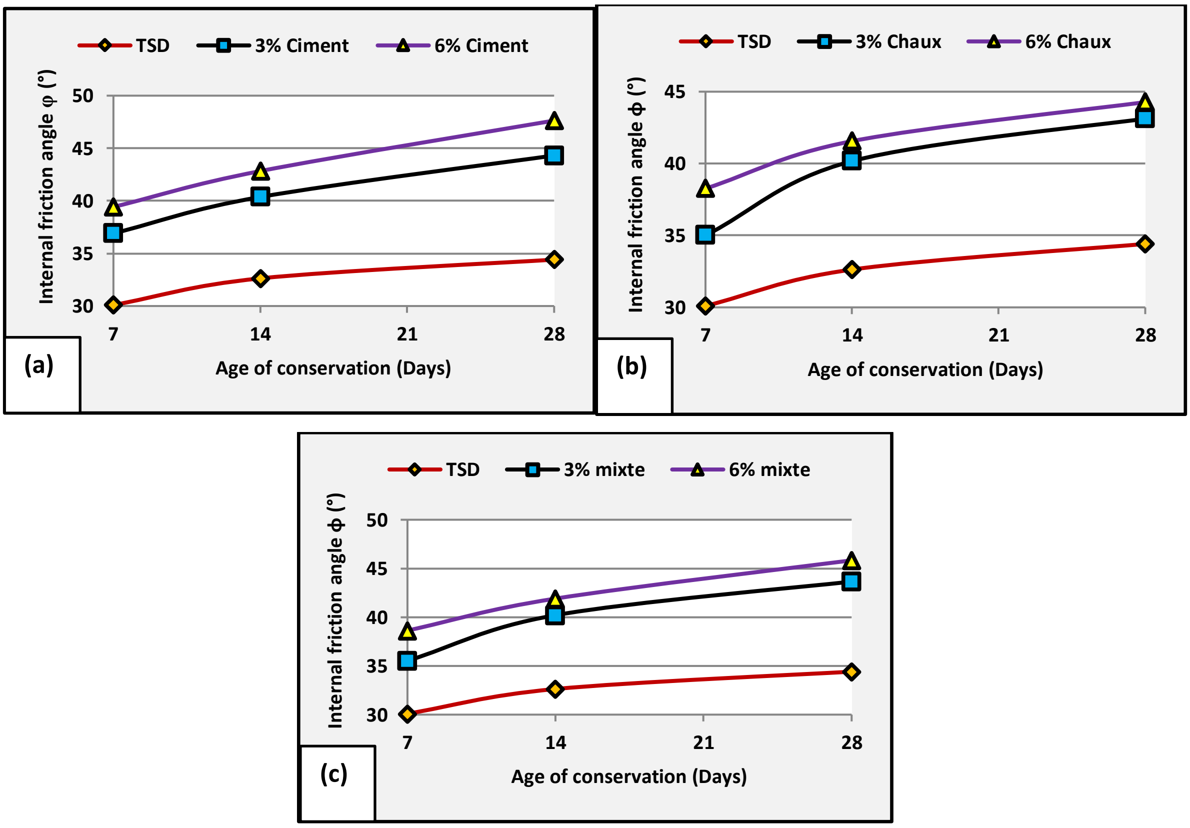


Figure 19. Evolution of the internal friction angle φ of the treated TSD mixture (a) cement (b) lime (c) mixed, depending on the age of conservation.

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.

The treatment with hydraulic binders led to a coordinate shift of the Modified Proctor Optimum by increasing the optimum water content and reducing the maximum dry density. The influence of the treatment on the TSD mixture (tuff with dune sand) is linked to the nature and the content of the binder used: the cement improves the immediate stability and the mechanical performances better than the mixed treatment, which is itself better than lime alone. For a rate of 6% of cement, the gain in the immediate CBR index reaches 85% compared to the untreated TSD mixture.

For a treatment of 3% cement, the improvement in simple compression achieved after 28 days a gain of 85% compared to the untreated TSD mixture. With 6% cement, the simple compressive strength is 6.5 MPa, almost double that of the untreated material.

The tensile strength of the treated TSD mixture also improves, but without exceeding, after 28 days, 10 bars for a treatment of 6% cement.

For an age of 28 days, the mechanical characteristics of shear, cohesion and internal friction angle, also improve considerably by the effect of the treatment. The cohesion of the TSD mixture treated with 3 and 6% cement shows an increase of 6 and 9 bars respectively compared to the untreated mixture.

In the Saharan regions, as everywhere else, there is a great interest in minimizing the transport of materials and water as much as possible. 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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