 Contribution to the valorization of dune sand in road technique

Contribuição para a valorização da areia dunar na técnica rodoviária

Contribución a la valorización de la arena de dunas en la técnica vial

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ABSTRACT
Road construction projects require the use of large quantities of good quality materials, which are not always available in the vicinity of the projects for use in order to create layers of pavement using hydraulic binders for the treatment of soils in place. This soil treatment technique consists of using lime and/or hydraulic binders to improve the soil characteristics. This technique has seen great development over the past twenty years. Soil treatment using products such as lime and/or hydraulic binders and/or cements allows the creation of backfill and subgrade layers. This type of treatment requires a good knowledge of the material to be treated. This is the main reason why we undertook this study, which allows
us not only to valorize local materials through this soil treatment technique and to overcome the shortage of noble materials, on the one hand but also to respond to economic and environmental aspects, on the other hand.


**RESUMO**
Os projetos de construção de estradas exigem a utilização de grandes quantidades de materiais de boa qualidade, que nem sempre estão disponíveis nas proximidades dos projetos, para serem utilizados na criação de camadas de pavimento utilizando ligantes hidráulicos para o tratamento de solos no local. Esta técnica de tratamento do solo consiste na utilização de cal e/ou ligantes hidráulicos para melhorar as características do solo. Esta técnica teve grande desenvolvimento nos últimos vinte anos. O tratamento do solo com produtos como cal e/ou ligantes hidráulicos e/ou cimentos permite a criação de camadas de aterro e subleito. Este tipo de tratamento requer um bom conhecimento do material a ser tratado. Esta é a principal razão pela qual realizamos este estudo, que nos permite não só valorizar materiais locais através desta técnica de tratamento de solos e colmatar a escassez de materiais nobres, por um lado, mas também responder a aspectos económicos e ambientais, por outro. outra mão.


**RESUMEN**
Los proyectos de construcción de carreteras requieren la utilización de grandes cantidades de materiales de buena calidad, que no siempre están disponibles en las proximidades de los proyectos para su uso con el fin de crear capas de pavimento utilizando ligantes hidráulicos para el tratamiento de suelos in situ. Esta técnica de tratamiento de suelos consiste en utilizar cal y/o ligantes hidráulicos para mejorar las características del suelo. Esta técnica ha experimentado un gran desarrollo en los últimos veinte años. El tratamiento de suelos con productos como la cal y/o ligantes hidráulicos y/o cementos permite la creación de capas de relleno y de subrasante. Este tipo de tratamiento requiere un buen conocimiento del material a tratar. Esta es la razón principal por la que emprendimos este estudio, que permite no sólo valorizar los materiales locales mediante esta técnica de tratamiento de suelos y superar la escasez de materiales nobles, por una parte, sino también responder a aspectos económicos y medioambientales, por otra.

**Palabras clave:** Valorización. Tratamiento de Suelos. Arena de Duna. Ligantes Hidráulicos. Capas de Pavimento.
1 INTRODUCTION

As well known, the knowledge of ground stabilization in geotechnics has been well documented recently. Articles and manuals on stabilization techniques are available to students, practicing engineers and consultants in the field of geotechnics. During soil stabilization, the formation of dust due to aggressive binders is not a requirement. For this, soil studies have been carried out to find the solution to this problem. Companies have invested in research and development for several years already, and are notably turning towards soil stabilization techniques using hydraulic binders. This soil treatment technique consists of using lime and/or hydraulic binders to improve the soil characteristics, Rammul et al. (2015). This technique has seen great development over the past twenty years. Soil treatment using products such as lime and/or hydraulic binders and/or cements, Bell (2005) allows the creation of backfill- and subgrade layers. This type of treatment requires a good knowledge of the material to be treated. Road construction requires a large quantity of materials to create not only the road layers but also especially the embankments and the subgrade layers, to create the longitudinal profile. Two methods are used, either by adding aggregates, or by treating the soil in place. The aggregate supply technique requires the use of large quantities of trucks to, on the one hand, dump excess soil and on the other hand, transport aggregates to the site in large quantities. The scarcity of aggregate resources and the nuisance generated by transport have encouraged decision-makers to valorize existing soils through treatment with hydraulic binders. Recently, in Algeria, a very consistent program was launched in terms of road construction. However, such projects require the use of large quantities of good quality materials, Rassul et al. (2016), Talal et al (2019), which are not always available in the vicinity of the projects to create pavement layers with using hydraulic binders to treat the soil in place. This is the reason why it is interesting to promote local materials, Panwar et al. (2016), Almadwi et al. (2018), by a treatment technique. This permits to compensate for the deficit in noble materials, and to respond to economic and environmental concerns, Rou (2004), Giummara (2009). The treatment of soils with hydraulic binders and lime is a process which improves the workability of materials. This treatment technique makes it possible to improve
the physical and mechanical characteristics of soils after compaction. The advantages of this technique are well known in earthworks and are exploited for the construction of road, motorway, railway embankments, industrial platforms, etc. Soil treatment with hydraulic binders has become common practice in the field of road construction. This technique presents technical, economic and environmental advantages, Rou (2004), Giummara (2009). Soil treatment makes it possible to save natural aggregate resources, limit the transport of materials and re-use existing soils, which are often too wet and not very supportive.

Algeria is known for its sand dunes, which adorn postcards, are tourist destinations, but also which swallow up land and palm groves, and invade certain oases. However, this sand, which occupies almost the entire surface of the Algerian Sahara, is currently not valued for exploitation. Many researchers, in various scientific themes, seek to exploit this clean and abundant material. Its use could be linked to its very high silica content. In civil engineering, this sand is also of great economic and environmental interest for Algeria. Indeed, the increase in demand for construction sand in Algeria, the inability of Algerian quarries to supply fine sand along with the planned cessation of using sea sand, which leads to a major ecological and tourist problem for Algeria, are all reasons for the valorization of this product. We are therefore interested in the valorization of this type of very abundant sand, which can be exploited massively. The range of use of sands in the world is very wide, electronics, Gueddim _et al._ (2007), Gueddim _et al._ (2010), Drissi _et al._ (2020), glassware, Amara _et al._ (2018), Gueddim _et al._ (2009), Gueddim _et al._ (2018), abrasive materials (sandpaper, files, discs, sandblasting, etc. for example.), Zerroug _et al._ (2016), Gueddim _et al._ (2017), Gueddim _et al._ (2016), Gueddim _et al._ (2009). Taking into account its particle size (medium to fine, naturally less than 1mm), Smaida _et al._ (2019), Smaida _et al._ (2022), Smaida _et al._ (2023), its morphology, its cleanliness and its hardness, we focused on its valorization in the layers of the roadways. Numerous studies have been carried out on the use of dune sand in road techniques, Baghdadi _et al._ (1990), Ben Dhia (1998), Ismael _et al._ (2006), Ghrieb _et al._ (2013), Amhadi _et al._ (2019), Smaida _et al._ (2019), Cherfa _et al._ (2021) Smaida _et al._ (2022), Daheur _et al._ (2022), Smaida _et al._ (2023).
2 MATERIALS AND METHODS

2.1 MATERIALS

2.1.1 Dune sand

The sand used is dune sand from Djelfa region located at 300 km south of Algeria. It is a very fine sand, devoid of fine elements whose size is less than 80 µm. More than 90% of its constituents have sizes between 0 and 0.4 mm. Smaida et al. (2019), This abundant material is characterized as a permeable, incoherent soil, low resistance, low bearing capacity, Venkatarama et al. (2007), Haach et al. (2011) and poorly graded grain size. Our studied dune sand is located approximately 57 km northwest of Djelfa at a place named Zaafrane. The mineralogical analysis carried out on the dune sand samples and the particle size analysis are presented in Figure 1(a and b) and the chemical composition is given in Table 1.

![Figure 1. (a) Mineralogical analysis of dune sand; (b) Grain size analysis of dune sand.](source: Authors.)

<table>
<thead>
<tr>
<th></th>
<th>SiO₂</th>
<th>CO₂</th>
<th>Fe₂O₃,Al₂O₃</th>
<th>CaSO₄·H₂O</th>
<th>NaCl</th>
<th>CaCO₃</th>
<th>P.F</th>
<th>H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>According to the chemical analysis summarized in Table 1, our sand is siliceous; formed of a large quantity of SiO₂ (silica), with the presence of some traces of calcium and magnesium species. X-ray analyzes reveal the presence of</td>
<td>93.56%</td>
<td>1.49%</td>
<td>1%</td>
<td>Traces</td>
<td>0.29%</td>
<td>3.39%</td>
<td>1.73%</td>
<td>0.24%</td>
</tr>
</tbody>
</table>

Source: Authors.
quartz with a high percentage, and traces of Illite and Calcite. Note the physical properties of dune sand are summarized in Table 2.

<table>
<thead>
<tr>
<th>Physical properties of dune sand.</th>
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</thead>
<tbody>
<tr>
<td><strong>Apparent density (g/cm³)</strong></td>
</tr>
<tr>
<td><strong>Absolute density (g/cm³)</strong></td>
</tr>
<tr>
<td><strong>Proportions (%)</strong></td>
</tr>
<tr>
<td><strong>Fineness modulus</strong></td>
</tr>
<tr>
<td><strong>(0 / D)</strong></td>
</tr>
<tr>
<td><strong>% Passing ≥ 80 μm</strong></td>
</tr>
<tr>
<td><strong>% Passing ≥ 2 mm</strong></td>
</tr>
<tr>
<td><strong>Coefficient of gradation Cu</strong></td>
</tr>
<tr>
<td><strong>Coefficient of curvature Cc</strong></td>
</tr>
</tbody>
</table>

Source: Authors.

2.1.2 Cement

Chemical analysis of cement using a scanning electron microscope (SEM) carried out in the M'sila cement factory laboratory gave the results summarized in Table 3.

<table>
<thead>
<tr>
<th>Chemical analysis of cement.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
</tr>
<tr>
<td>19.70%</td>
</tr>
</tbody>
</table>

Source: Authors.

2.1.3 Lime

The lime used in the present study comes from the west of Algeria. It is a slaked lime which has a low concentration of oxides such as SiO₂ (silicate) < 2.2% and MgO (aluminate) <0.4% and a high concentration of basic elements such as CaO (free lime) < 67.4% and 73.25%, with more than 90% passing through 80μm sieve. Its absolute density is 2.559 g / cm³, and its specific surface area is 11053 cm² / g. Table 4 summarizes the chemical composition of the lime.

<table>
<thead>
<tr>
<th>Chemical composition of lime.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
</tr>
<tr>
<td>&gt;67.4%</td>
</tr>
</tbody>
</table>

Source: Authors.
2.2 METHODS

The study focuses on the effect of the addition of mass substituents, which are lime and cement on the mechanical behavior of the studied sand. The different mixtures, which have been developed in this direction contains lime percentages of 4%, 6% and 8% and cement percentages of 5%, 7% and 9%. Note that these percentages were chosen according to the recommendations of the standards applied to road networks (GTR, 2000). The aim of compaction is to increase the in-place density of a soil, reduce its deformation rate and improve its bearing capacity. Proctor standard compaction tests were carried out according to standard NF P94-093 to determine the maximum dry density (MDD) and the optimum water content (OMC). All mixtures were statically compacted to optimum Proctor before placement in the rectilinear shear box. The test mode is conditioned by a rapid speed of 1 mm/min corresponding to an unconsolidated undrained (UU) test according to standard NF P 94-071-1. It should be mentioned that the optimal moisture content results were also used for the preparation of CBR and resistance tests on studied soil samples. Then, the CBR tests, shear strength, compressive strength and tensile strength were carried out in accordance with the standards NF P 94-078, NF P 94-071-1, standard EN 13286-53 and standard EN 13286-42, respectively, on the soil samples studied.

3 RESULTS AND DISCUSSIONS

3.1 THE EFFECT OF STABILIZERS ON THE PARAMETERS OF THE STANDARD PROCTOR COMPACTION TESTS

The obtained results are represented in Figures (3.a, 3.b). One can see that the different additions have the tendency to shift the coordinates of the Proctor optimum (optimal water content $W_{OPM}$ and maximum dry density towards the right, by increasing the maximum dry density (MDD) and optimal water content (OMC) (Figure 2.a and 4.b). This trend of increasing the optimal water content becomes clearer for the case of cement mixtures. The densification of this material allowed us to note a dry density systematically higher than that of
formulations based on cement. Lime mixtures result in an increase in dry density from 1.72 g/cm$^3$ to 1.81 g/cm$^3$. The optimum water content varies in the range of 5% to 7.8%. For cement-based formulations, the optimal water content varies in the range of 5% to 9.9% for a dry density between 1.72 g/cm$^3$ and 1.82 g/cm$^3$. This behavior of the different mixtures is due to the increase in the rate of fine elements and their replacement by particles, which facilitate the movement of dune sand particles by making them denser.

Figure 2. (a) Modified Proctor of lime mixtures; (b) Modified Proctor of cement mixtures.

Source: Authors.

3.2 THE EFFECT OF STABILIZERS ON THE CBR TESTS

To determine the CBR values at 95% of the optimum consists of punching into the CBR mold specimens made at different compaction energies (10 blows per layer, 25 c/c, 55 c/c), and at water content corresponding to the optimum of the modified Proctor test. The aim being to obtain 3 castings with clearly different compactnesses (these compactnesses are respectively of the order of 90%, 95% and 100% of the maximum dry density of the modified Proctor). The material is then introduced according to the process of the modified Proctor test in 5 successive layers of equal thickness which will each be compacted with the same modified Proctor lady according to different compaction energies which are generally 10, 25 and 55 strokes per layer.

According to the curves which represent the pressure of the piston as a function of its depression (Figure 3 (a and b)), we determine the CBR index for each compaction energy. This makes it possible to represent the variation of the dry density as a function of the CBR index [$\gamma_d = f(ICBR)$] (Figure 4 (a and b)).
final CBR index, determined graphically, is that which corresponds to 95% of the maximum dry density of the modified Proctor test. Figure 5 illustrates the variation of CBR at 95% for lime mixtures and cement mixtures.

Figure 3. (a) Variation of pressure according to the penetration (Unsoaked case); (b) Variation of pressure according to the penetration (Soaked case).

Source: Authors.

Figure 4. (a) Variation of dry density according to the CBR Unsoaked index; (b) Variation of dry density according to the CBR soaked index.

Source: Authors.

Figure 5. (a) Variation of CBR index (unsoaked and soaked) according to the percentage of Lime; (b) Variation of CBR index (unsoaked and soaked) according to the percentage of Cement.

Source: Authors.
Figure (5.a) shows that lime improves the immediate bearing capacity from 8.28 to 13.45% for 4% lime. Beyond this value, we note a slight decrease to 12.32% for 8% lime. At the same time, in immersion, the lift improves from 6.45% to 12.10% for 6% lime then it drops to 9.5% for 8% lime. Just like lime, cement (Figure 5.b) showed a very significant increase in immersion lift of up to 162% in the case of 9% cement. This is obviously due to the cement setting. Unlike the lift in immersion, the immediate lift of cement shows values close to the values of lime where we note 26.5% for 5% cement then it drops to 21% for 9% cement.

3.3 THE EFFECT OF STABILIZERS ON THE SHEAR STRESS TESTS

The test is intended to evaluate the mechanical characteristics of a soil, that is to say the cohesion $C$, the friction angle $\Phi$ and the shear resistance $\tau_{\text{max}}$ at the moment of rupture. The cohesion of a soil is the property, that makes it possible to oppose the sliding of the grains which compose it and to resist a shear force, that is to say to oppose the sliding of a layer, this allowing exposure to the danger of landslides to be limited.

The used test to determine the parameters is the unconsolidated undrained direct shear test (U.U) according to standard NF P 94-071-1. The samples of the dune sand-lime, dune sand-cement mixtures were placed between two half-boxes, which can move relative to each other. In addition, a piston makes it possible to exert a stress normal to the shear plane. The samples of the sand-binder mixtures are sheared at their compaction water contents. The normal stresses used for these tests are:

$$\sigma_1 = 100 \text{ kPa}; \sigma_2 = 200 \text{ kPa}; \sigma_3 = 300 \text{ kPa}.\quad (1)$$

The shear speed used is 1 mm/min.

The mechanical parameters of the mixtures are obtained by drawing the Coulomb lines (intrinsic curves) in an orthonormal reference frame, which presents, on the abscissa the vertical stresses ($\sigma_i$) and on the ordinate the maximum shear stresses ($\tau_{\text{max}}$). The slopes of these lines represent the tangents of the internal friction angles $\Phi$ of the sand-binder mixtures, on the one hand. On
the other hand, the cohesions $C$ are obtained by the intersection of these lines with the ordinate axis. The values of the angle of friction and cohesion are obtained analytically according to Coulomb’s law:

$$\tau = C + \sigma\tan(\Phi)$$  \hspace{1cm} (2)

Figure 6 (a and b) shows the intrinsic curves of the dune sand-lime and dune sand-cement mixtures. Figures 7 and 8 present the variations of the cohesion of the mixtures and the variation of the friction angle depending on the binders added, respectively.

Figure 6. (a) Intrinsic curves of lime mixtures; (b) Intrinsic curves of cement mixtures.

Source: Authors.

Figure 7. Evolution of the cohesion according to the binders added.

Source: Authors.
The dune sand-lime and dune sand-cement mixtures show an increase in cohesion ranging from 2 kPa to 81 kPa for 6% lime and 46 kPa for 5% cement. Beyond these contents, there is a slight drop in cohesion, which becomes around 24 kPa for 8% lime and 15 kPa for 9% cement. The role of cement, however, is to consolidate the skeleton of the sand by welding the grains together, thanks to the setting of the binder; on the other hand, the dune sand-cement mixture loses flexibility and risks cracking quickly under traffic. However, it is necessary to adopt a cement dosage, which improves the bearing capacity without giving too much rigidity to the mixture after setting.

Unlike cohesion, the friction angle shows a decrease to 32° for 5% cement and to 21° for 6% lime followed by an increase to 40° for 9% cement and to 27° for 8% lime. It is clear that all the studied dosages of hydraulic binders show a growth in cohesion inversely proportional to the angle of friction.

3.4 THE EFFECT OF STABILIZERS ON COMPRESSIVE AND TENSILE STRENGTH TESTS

The series of cylindrical test pieces with dimensions φ=100mm, H=100mm was prepared according to standard 13286-53 for the different mixtures. The mixture is placed in a single layer in a double piston mold then statically compacted, to the dry density and optimal water content of Proctor modified according to standard EN 13286-41. After preparation according to standard EN
13286-53, the specimens were stored dry in bags at a temperature of 20±2 °C until the date of the test. These tests were carried out at the ages of 7, 14, 28, 60 and 90 days for the different mixtures. The tensile tests were carried out on cylindrical specimens of the same dimensions in accordance with standard EN 13286-42 by measuring the indirect tensile strength, but the specimens were compacted and preserved in the same way until the date of the test (at 90 days).

Figure 9 (a and b) illustrates the changes in compressive strength at different curing times and at different binder percentages.

![Figure 9](image-url)  
Source: Authors.

The compressive strength as a function of curing time shows a moderate growth up to 265.59 kPa for a curing duration of 90 days (Figure 9.a) for 8% lime mixture. It is clear from the results that lime does not act as a good stabilizer on sandy material since only the role of grain size corrector is predominant. For the case of cement (Figure 9.b), the results are greater than those obtained with lime and go up to 2734.25 kPa and 2973.41 kPa respectively for mixtures with 7% and 9% cement for a curing duration of 28 days and at 3425.26 kPa and 3845.68 kPa for a cure duration of 90 days. This lets us notice that the increase in compressive strength is less significant from 28 days to 90 days, which explains the rapid hydration of the cement for the first period (28 days).

Figure 10 (a and b) illustrates the evolution of the tensile strength depending on the binders added.
The tensile strength generally increases with the percentage of binder added. According to Figure 10.a, lime has low values before 8% lime, value for which the resistance becomes more significant. For the case of cement, we notice an increase in the tensile strength up to the respective values of 398.23 kPa and 538.75 kPa corresponding to the percentages of 7% and 9% respectively for a curing duration of 28 days. It is clear that cement mixtures give better tensile strength compared to those obtained with lime mixtures.

4 CONCLUSION

In order to valorize dune sand, taking into account the environmental and economic aspects, the work focused on materials formulation techniques by adding hydraulic binders: lime and cement. The objectives targeted in this work was to study the influence of the incorporation of fine fractions (hydraulic binders) on the improvement of the mechanical characteristics of treated dune sand. The results that the use of hydraulic binders and lime improves very significantly the mechanical characteristics of this treated material. The main conclusions are:

- hydraulic binders (lime and cement) have a very positive effect on the mechanical performance of dune sand-based mixtures for pavement bases;
- lime is less effective in improving mechanical characteristics than cement;
- lime as a stabilizer is more suitable for fine soils (silt and clay) than for grainy soils (sand). It acts as a grain size corrector rather than a stabilizer;
- the addition of increasing quantities of hydraulic binder demonstrated a trend towards a permanent increase in the optimal water content;
• the use of hydraulic binders improves the tested mechanical performance (tensile and compressive strength).

In perspective we hope to continue our work to determine other correctors leading potentially to improved mechanical properties of dune sand.

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