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**Research Paper**

# Valorisation of Dune Sand Treated with Lime and Scrap Tyre Rubber Powder as a Road Foundation Material.


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ABSTRACT

The purpose of the work presented in this paper is the treatment of dune sand; which is abundant in the region of Djelfa (Algeria), with different lime and tyre rubber powder in order to valorise them in road construction. Several steps were considered in this research. A method of blend formulation has been proposed which is based on stabilization of the studied sand using a hydraulic binder (lime) and scrap tyre rubber powder with different percentages. For each mixture, the optimum Proctor, shear strength, immediate and immersion CBR index, compressive strength and tensile strength were determined. After that, an analysis of the results was made to examine the influence of treatment agents on the characteristics of the mixtures. The results show that the replacement of lime and tyre rubber powder at optimum content has a positive impact on the physical and mechanical behaviours of the treated dune sand mixtures; increases its compressive and tensile strengths, improves its cohesion and increases its immediate and immersion CBR indexes. The selected optimum formulation has sufficient performances to be used as road material.


## 1 Introduction

The valorisation of local materials (like waste tyre rubber) in road construction remains a topical issue; it is a question of better mastering their behaviour and their implementation in various situations in order to arrive at a characterization which will facilitate their classification and use by the engineers and technicians of road domain. These materials can be used in many civil and non-civil engineering applications such as: lightweight retaining wall backfill, lightweight embankment fill, thermal insulation, insulating backfill to conserve heat inside buildings, road construction, geotechnical works, fuel for electricity production and other applications [1 – 3].


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Waste tyre rubber can be shredded and mixed with different kinds of soils, then reused as a fill material in different areas [4]. The present scrap recycling methods are insufficient to consume the great amount of the waste tyres. This has become a serious issue in the world. More than 26000 tons of scrap tyre rubber is generated each year in Algeria alone [5]. Several techniques of waste tyres recycling are used in the field of civil engineering such as: retaining walls, fibre reinforcing and in the decoration field [6 – 8]. Waste tyre shreds and granulated rubber are used as a geo-material or mixed with soil for the reinforcement of grounds [9, 10].

Rubber reinforces sand properties and keeps its lightweight ability in the same time. It has multiple applications such as: retaining walls by reducing the lateral earth pressures [11 – 14], embankments by reducing the settlements [15 – 17]; providing filter layers for drainage in landfills [18]; and providing damping to foundations and for liquefaction mitigation purposes [19, 20].

The size ratio of rubber to sand has an effect on the behaviour of sand-rubber mixtures. It has been studied in the range of 0.25 [21] to more than 100 [22]. The rubber particles size has a significant effect on the strength and maximum shear modulus [23-25]. Numerical unidimensional compression tests were performed on sand-rubber mixtures by Evans and Valdes [26] in order to study the effects of rubber fraction and size ratios of particles on the force percolation and the strain dependent evolution of strength.

The addition of scrap tyre rubber improves shear strength parameters and reduces unit weight of the sand [27]. Researchers reported that inclusion of 5% rubber content ameliorates compressive strength of clayey soil [28-30]. Amelioration in the friction angle of clayey soil was observed with the inclusion of rubber particles [31-33]. Greatest augmentation in the cohesion and friction angle of clayey soil with the addition of 2% rubber content was reported [34, 35], whereas, the addition of tyre buffing caused a diminution in the friction angle of clayey soil [36].

Different percentages of shredded tyre rubber chips and cement were included in the black cotton soil and Shedi soil. The unconfined and C.B.R tests were applied to the two soils with different rubber ratios. The two soils showed considerable amelioration in strength with the inclusion of 5% rubber content [37].

For the purpose of valorising the use of dune sand as road material (Foundation layers), an interesting idea of combining it with scrap tyre rubber powder and lime in order to improve its geotechnical and mechanical characteristics. This idea can be also beneficial from economical and environmental point of view. Thus the focus of our work is to study the physical and mechanical properties of treated dune sand with different ratios of tyre rubber powder and lime for use in road construction.

## 2 Material and methods

### *2.1 Sand Dune*

The dune sand is found in abundance in the form of dunes in the place named ZAAFRANE, located about 57 km northwest of Djelfa (Algeria) (Figure 1). This type of sand is usually used in construction as concrete and mortar sand.

The chemical analysis of the dune sand was carried out in accordance with (NF EN 1744). The results are presented in Table 1. The studied sand has a siliceous nature; formed in a large quantity of $SiO_2$ (silica), with the presence of some traces of calcium and magnesium species.

The different results of the physical characteristics of the studied sand are summarized in Table 2. The sand presents a continuous particle size distribution ranging from 0 to 0.63 mm (Figure 2). It can clearly be seen that 90% of the dune sand grains are lower than 0.5 mm; this sand can be classified from a granular viewpoint as fine sand [38]. The grading is very tight; nearly 90% of the grains have a dimension ranging between 0.1 mm and 0.5 mm. The sand alone could not have a sufficiently large compactness, and thus inadequate mechanical performances. Which leaves us to conclude that this sand needs therefore to be granularly corrected [39].

In this study, the X-ray diffraction (XRD) was used with the random powder method for the bulk sample. The principle crystalline components found in the dune sand were quartz (Q), calcite (C), and illite (I). The diffractometric analyzes illustrated in Figure 3 show that the presence of a high percentage of quartz, and a low percentage of Illite and calcite.

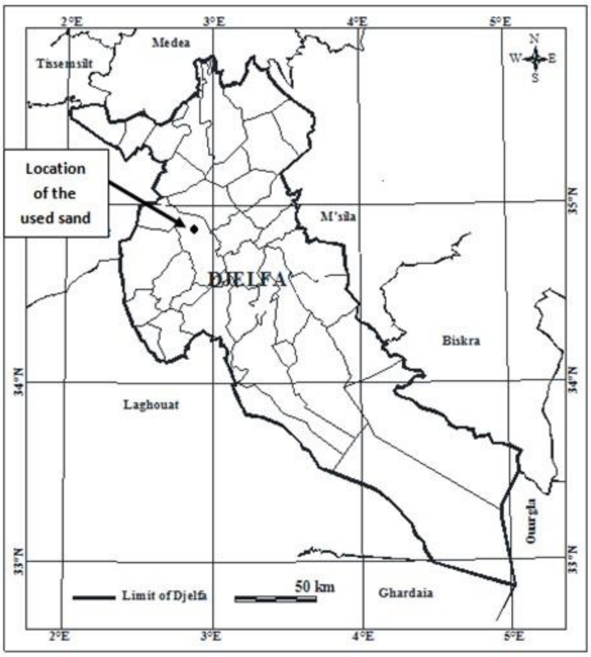


*Fig. 1 –Location map of the studied dune sand*

**Table 1 - Chemical analysis of the studied sand**

| Chemical Composition | (%) |
|---|---|
| $CaCO_3$ | 3.38 |
| $CaSO_4,H_2O$ | / |
| $CO_2$ | 1.48 |
| $Fe_2O_3$, $Al_2O_3$ | 0.71 |
| $H_2O$ | 0.21 |
| NaCl | 0.28 |
| P.F | 1.73 |
| $SiO_2$ | 92.53 |

**Table 2 - Physical properties of Dune Sand**

| Physical characteristics | |
|---|---|
| Bulk density *(g/cm³)* | 1.56 |
| Specific density *(g/cm³)* | 2.45 |
| Optimum water content *(%)* | 11.4 |
| Maximum dry density *(t/m³)* | 1.76 |
| Fineness modulus *(%)* | 0.88 |
| Coefficient of curvature ($C_C$ ) | 1.7 |
| Coefficient of uniformity ($C_U$) | 1.1 |
| Methylene blue for 100*g* | 0.07 |
| Sand equivalent *(%)* | 85 |

*Fig. 2 –Mixtures before compaction*

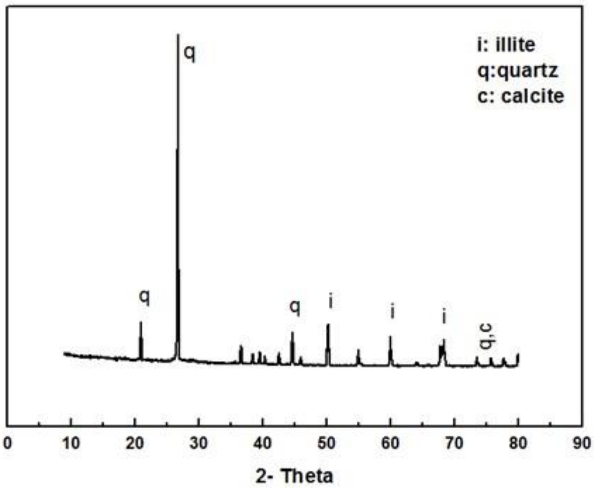


*Fig. 3 –Dune sand mineral analysis*

### *2.2 Lime*

The lime was obtained from Saida located in the northwest of Algeria. Their specific and bulk densities are 2.56 g/cm$^3$ and 0.52 g/cm$^3$ respectively and its Blaine surface specific area is equal to 11053 cm$^2$/g. It is a slaked lime with a low concentration of oxide elements such as $SiO_2$ silicates and $Al_2O_3$ aluminates, and a high concentration of basic elements such as free lime CaO, which gives our binder its aerial appearance. The chemical analysis of the lime was carried out in accordance with (NF EN 1744). The results are presented in Table 3.

**Table 3 - Chemical Composition of Dune Sand**

| **Chemical Composition** | |
|---|---|
| $Al_2O_3$ | < 1% |
| CaO | 67.4% - 73.25% |
| $CO_2$ | < 5% |
| $Fe_2O_3$ | < 2% |
| $K_2O$ + NaO | < 0.4% |
| MgO | < 0.4% |
| $SiO_2$ | < 2.2% |
| $SO_3$ | < 1% |

### *2.3 Tyres rubber powder*

In our study, the size of rubber powder particles ranges from 0.01 mm to 0.8 mm. The average particle size tends towards 0.45 mm. The density of the rubber powder was measured at laboratory temperature to be about 0.83 using helium pycnometer. Rubber powder is also characterized by its low water absorption [18]. Figure 4 shows the used waste tyre rubber powder. Table 4 presents its chemical composition.

**Table 4 - Chemical composition of the used rubber powder**

| **Chemical Composition** | **(%)** |
|---|---|
| Rubber | 54 |
| Carbon black | 29 |
| Textile | 2 |
| Oxidize zinc | 1 |
| Sulphur | 1 |
| Additives | 13 |

***Fig. 4 –Waste tyre rubber powder used in the experimental study***

## 3 Composition of Mixtures

The study will be devoted to analysing the effect of stabilization, which involves introducing a material to correct the sand defects in terms of granulometric stability, and bearing by the addition of rubber powder and lime.

The additions rubber powder and lime were used as dune sand replacement. In order to study the effect of these additions, the percentage of the added rubber powder ranges from 8 to 20 % with a step of 4 %, and that of the lime from 2 to 5 % with a step of 1 % (the percentages based on the weight of dry mixture). In this experimental work, a formulation with 100% of dune sand was studied in order to compare its performances with those of treated dune sand formulations. Five (05) mixtures are to be studied in this investigation. Figure 4 shows the mixtures studied before the compacting operation.

The mixtures are denoted by M-PS-PL-PRP, where PS represents the percentage of dune sand, PL the percentage of lime, and PRP the percentage of rubber powder, respectively. Details of the proportions of mixtures are given in Table 5.For each mixture, the modified Proctor, the immediate and immersion CBR, the direct shear and the compressive and tensile strength are were tested.

**Table 5 - Mixtures proportions**

| Mixtures | % of dune sand | % of lime | % of rubber powder |
|---|---|---|---|
| M 100-00-00 | 100 | 0 | 0 |
| M 90-02-08 | 90 | 2 | 8 |
| M 85-03-12 | 85 | 3 | 12 |
| M 80-04-16 | 80 | 4 | 16 |
| M 75-05-20 | 75 | 5 | 20 |

## 4 Test results and discussion

### *4.1 Effect of the addition of tyre rubber powder on treated dune sand particle size*

From Figure 5, which shows the particle size distributions of the treated mixtures, we notice a slight shift of the curve to the left is observed; in proportion to the increase in the lime and rubber powder percentage. This displacement indicates an increase in the percentage of fine elements in favour of a decrease of the largest elements especially on the fraction 0.01/0.08mm, and this due to the small size of rubber powder and lime particles compared to dune sand particles.

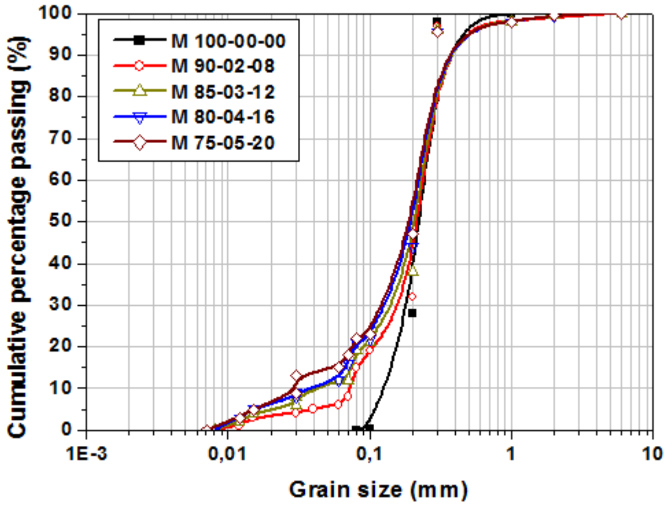


*Fig. 5 –Particle size distribution of the studied mixtures*

### *4.2 Effect of the incorporation of rubber powder and lime on compaction properties*

The studied mixtures are compacted at different moisture by using modified Proctor energy according to ASTM D1557 Standard [40]. A Modified Proctor mould was used to compact five layers, with 55 blows per layer. The curves of Figure 6 show the relationship between water content and dry density for each compacted mixture.

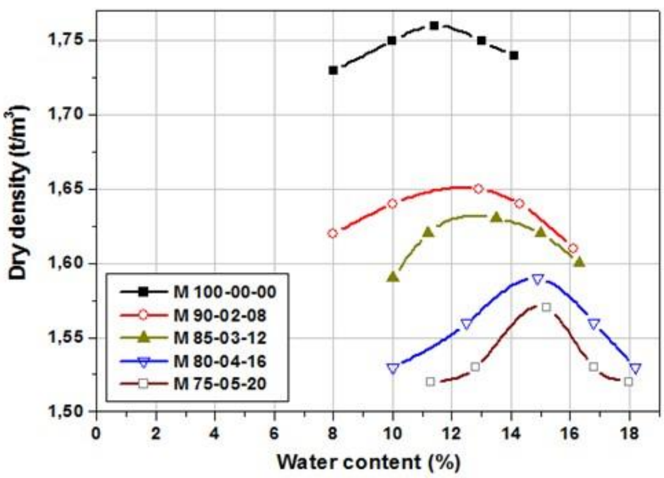


***Fig. 6 –Effect of tyre rubber powder and lime incorporation on Proctor parameters***

The first thing to note is that the curves of treated dune sand mixtures presented slopes steeper than in M 100-00-00 mixture. It can be also noted that the addition of lime and rubber powder has a positive influence on the optimum water content, which increases from a minimum value equal to 11.4% for dune sand alone (M 100-00-00) to a maximum value equal to 15.2% for the mixture M 75-05-20, and this due to the chemical and physical properties of lime which has a high water absorption. The rubber powder does not have a tendency to absorb humidity (maximum 4% its own weight) [8]. Water plays a significant role in the compaction of dune sand and lime-treated sand. At optimum water content, water functions as a lubricating agent among sand particles in order to minimize the friction resistance between soil particles. The amount of water, large or small, makes the compaction difficult, producing a poorly-compacted soil except if the compaction tension is adjusted in accordance [41].

The compaction test results demonstrate that addition of rubber powder and lime to the dune sand results in a decreased maximum dry density which is primarily due to the lower density of the inclusions especially the tire rubber powder. This observation was already reported by several authors [31, 42], which revealed that while the optimum water content stays unchanged, the maximum dry unit weight of the mixture deceases by about 3.0 $kN/m^3$ with the inclusion of 20% of the rubber's weight. Bekhiti et al 2019 studied influence of scrap tyre rubber fibre and cement on maximum dry density (MDD) and concluded an increase in tyre rubber fibre content causes a decrease in dry density [43].The correction of the used dune sand with 20% rubber powder and 5% lime (M 75-05-20) causes a reduction in maximum dry density about 11%.

### *4.3 C.B.R tests*

The California bearing ratio (CBR) is used to assess the load-bearing capacity of a natural or compacted soil, by estimating its resistance to punching. The CBR Index is a ratio between the values of the forces corresponding to penetrations of 2.5 and 5 mm to those obtained on a reference material.

The treated dune sand mixtures are compacted by using modified Proctor energy according to ASTM D1557 Standard [40]. The studied mixtures are prepared at their optimal water content. The compacting operation is done in 5 layers, by different compaction energy; 10, 25 and 55 shots per layer.

The C.B.R. index was determined according to ASTM D1883 Standard [44], immediately after compaction (immediate CBR index) and after four days immersion (CBR index after immersion).The test consists of determining the value of the CBR at 95% of the Optimum Modified Proctor (OMP); in compaction curve, the OMP is the point corresponding to the maximum dry density, this density is achieved at a water content known as the optimum water content.

### *4.3.1 Immediate CBR index*

Figures 7 display the evolution of the pressure of studied formulations by different compaction energy (10, 25 and 55 shots) as a function of penetration. It can be observed that, when the compaction energy varies from 10 to 55 shots, the pressure improves significantly; the increase rates are about 66.7%, 21%, 26%, 93.4% and 38% for 0%,10%, 15%, 20% and 25% of additions (lime and rubber powder) respectively, which indicate the importance of the compaction operation for the improvement of punching resistance.

At penetration equal to 12.5 mm, the pressure for the mixture without additions, varied from 16.5, 22.5 and 27.5 kg/cm$^2$, for 10, 25, 55 shots respectively, and increased to a maximum values of 31, 35 and 37.5 kg/cm$^2$, for the mixture with 2% lime and 8% rubber powder, and then decreased beyond this point.

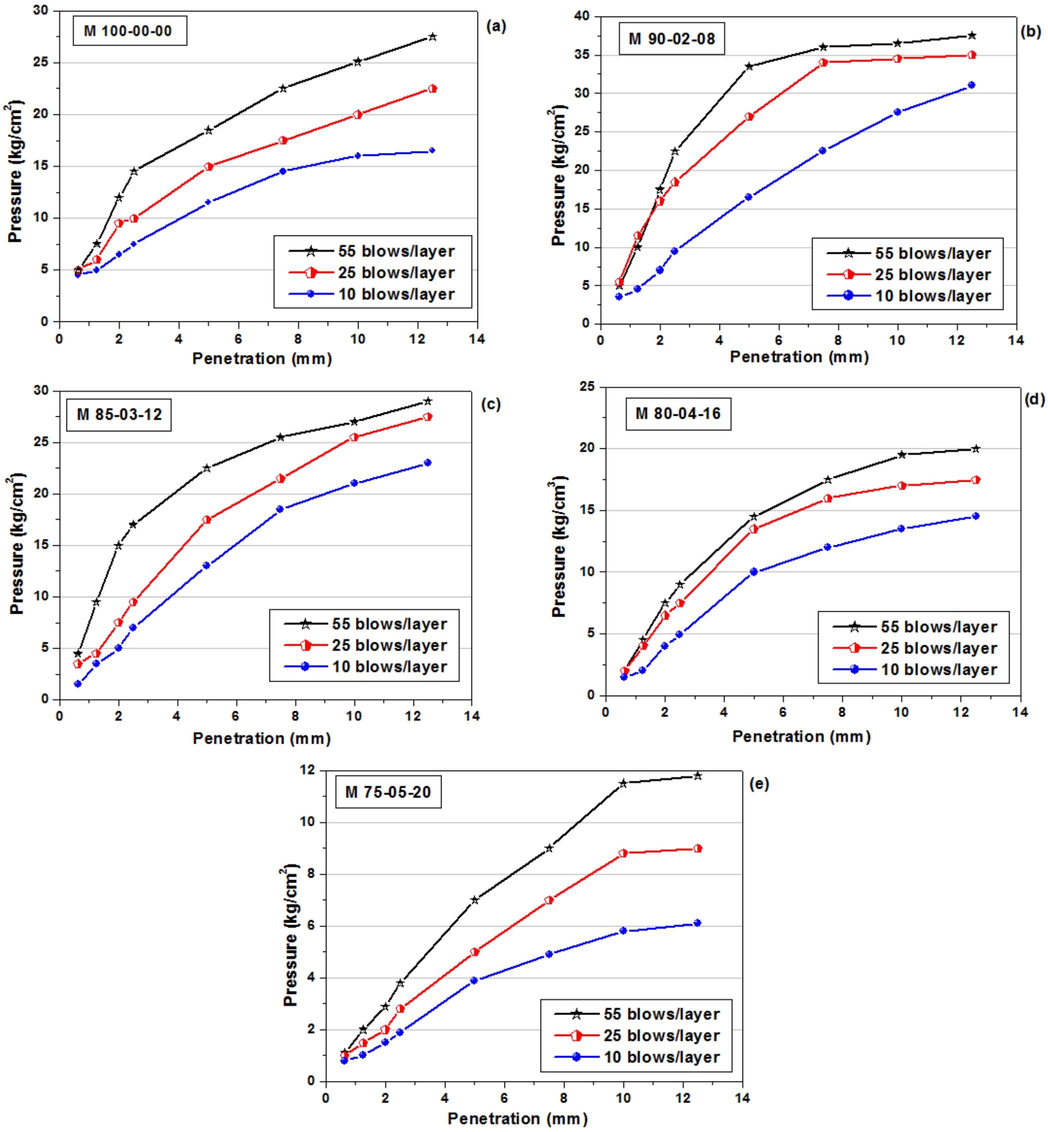


***Fig. 7 –Immediate CBR curves of the studied mixtures (a) M 100-00-00, (b) M 90-02-08 (c), M 85-03-12, (d) M 80-04-16, (e) M 75-05-20***

Figure 8 displays immediate CBR index at 95% of the Optimum Modified Proctor (OMP) results of studied mixtures as a function of rubber and lime amounts. The results show that, for 2% lime and 8% rubber powder, there is an augmentation in the immediate C.B.R index, and then graduated diminution with increasing rubber powder and lime percentages. The incorporation of lime and rubber powder can give maximum improvement in immediate C.B.R index of the order of 67%. This improvement value vividly demonstrates the effectiveness of used additions in improving the immediate C.B.R index, and therefore the bearing capacity of the treated dune sand.

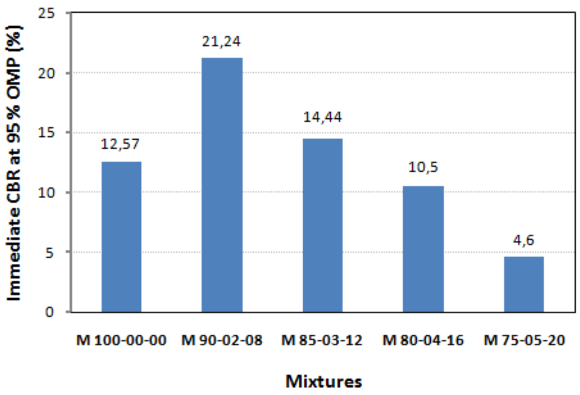


*Fig. 8 –Evolution of immediate CBR at 95 % OMP*

### *4.3.2 CBR index after immersion*

CBR index test after immersion is the same as the previous test, except that in this case, the penetration is done after four days of immersion. The Figures 9 represent the pressure obtained as a function of penetration for the various mixtures, in different compaction energy; 10 blows 25 blows and 55 blows per layer.

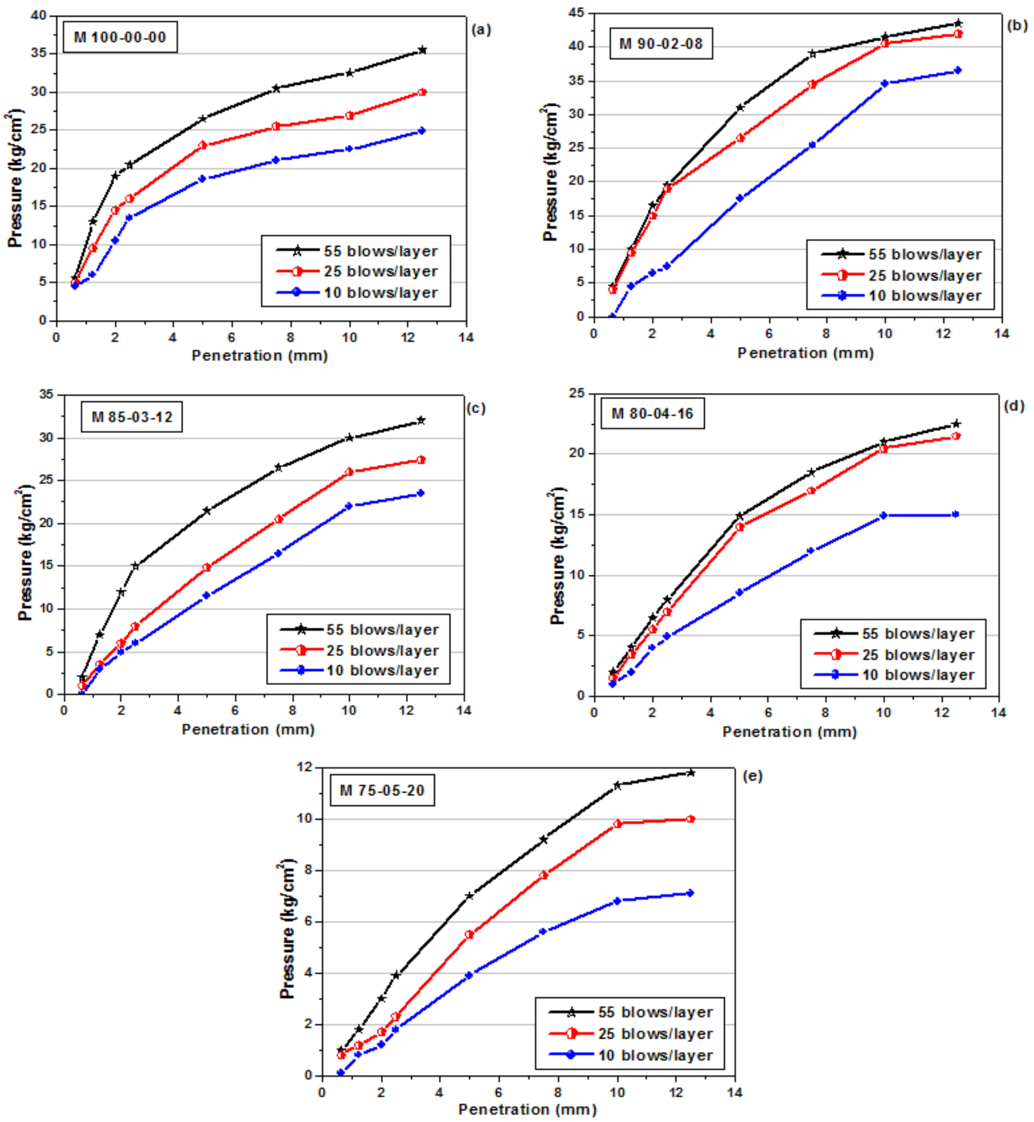


*Fig. 9 –CBR after immersion curves of the studied mixtures (a) M 100-00-00, (b) M 90-02-08 (c), M 85-03-12, (d) M 80-04-16, (e) M 75-05-20*

The same observation mentioned in the case of the immediate CBR index can be noticed; the inclusion of 2% lime and 8% rubber powder caused a maximum increase in the CBR index after immersion, but increasing rubber powder and lime above these percentages caused a reduction in this parameter.

We see from Figure 10 that CBR index after immersion at 95 % OMP grows from 18.47% for dune sand without treatment to 30.5% for the mixture M 90-02-08, and then decreases with inclusion of increasing percentages of rubber powder and lime until a minimum value of 9.18% for the mixture M 75-05-20. The increase in CBR index for replacement rate 2% lime and 8% rubber is linked to the decrease of voids volume within the treated dune sand (filling effect); which explains the effectiveness of the used additions (lime and rubber powder) to improve the compactness of the compacted mixtures.

The results shown in Figures 8 and 10 demonstrate the beneficial effect of the immersion on the CBR index; where we find the values of the CBR index after immersion are greater than those of the immediate CBR index(for the mixture M 90-02-08, we note an improvement of over 40%). On the other hand we notice that the progressive incorporation of lime and rubber powder induces the same type of evolution of the immediate and after immersion CBR indexes.

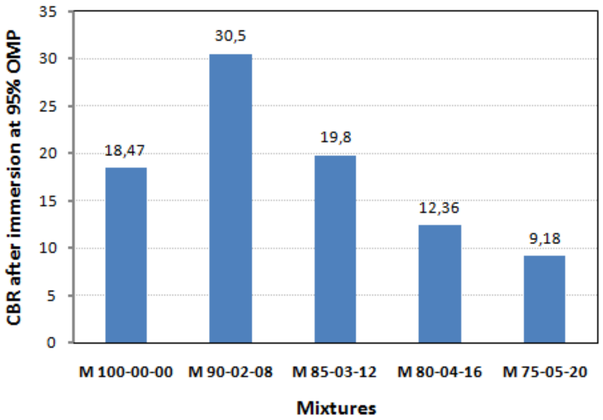


*Fig. 10 –Evolution of CBR after immersion at 95 % OMP*

### *4.4 Direct Shear Test*

The direct shear test was performed according to ASTM D 3080 Standard. This test aims at the evaluation of the mechanical characteristics of the soil by proceeding to the rectilinear shear of a sample under constant load. The shear test makes it possible to *determine* the angle friction φ, the cohesion C and the maximum shear strength $\tau_{max}$ at the rupture moment.

The soil sample to be studied is placed between two half-boxes which can move with respect to each other. The shearing machine is equipped with a piston makes it possible to exert a stress normal to the shear plane. The lower half-box is driven horizontally with a constant speed. The shear force was measured by means of a ring attached to the upper half box.

#### *4.4.1 Effect of the addition of rubber powder and lime on Shear Strength*

The treated dune sand mixtures (dune sand, rubber powder and lime) were prepared at the optimum water content according to the shear test procedure. Figure 11 shows a photograph of the test sample of the mixture M 90-02-08 in shear box before direct shearing.

*Fig. 11 –Test sample of the mixture M 90-02-08 in shear box before direct shearing*

The results of cohesion and friction angle are shown in Figures 12 and 13 respectively. The inclusion of lime and rubber powder as partial replacements of dune sand leads to a continuous increase in the cohesion; which confirms the above results and gives the importance of adding rubber powder and lime for the improvement of the mechanical properties. Conversely, there is a decrease in friction angle with the increase of rubber powder and lime percentages.

The cohesion value is about 0.02 bar for the mixture without treatment (M 90-02-08), whereas for the treated samples the values are of the order of 0.42 bar, 0.44 bar, 0.79 bar and 0.97 bar for incorporation rates of 10%, 15% ,20%, and 25% respectively (Figure 12). The friction angle is gradually decreases with the incorporation rate from 36.65° for the mixture based on dune sand, to 19.60° for the mixture containing 20% rubber powder and 5% lime. A reduction in friction angle of soil with the inclusion of tyre buffing was reported by Özkul and Baykal [36] which coincides with our results.

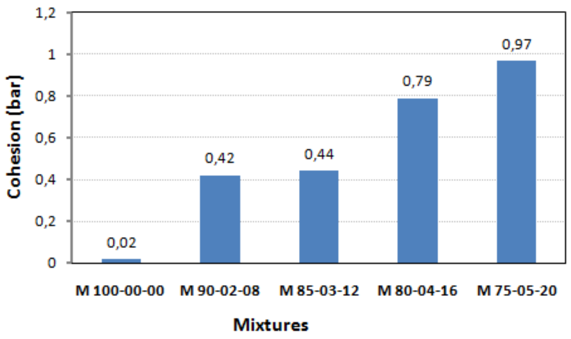


*Fig. 12 –Evolution in cohesion of studied mixtures*

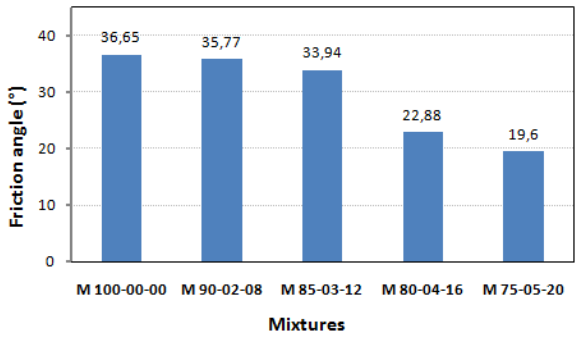


*Fig. 13 –Variation of the friction angle of studied mixtures*

### *4.5 Compressive and Tensile Strength tests*

The studied mixtures were prepared at the optimum water content. The samples were prepared at optimum water content and maximum dry density using a modified proctor mould. After moulding, the obtained samples were covered with a plastic film then kept inside the laboratory at ambient temperature 20± 2 °C for curing periods of 7, 14, 28 and 60 days.

For the compressive strength, each cured sample was placed between the platens of the press, then we applied the load in a continuous manner at a regular speed of 0.05 mm/s until the sample was entirely broken (Figure 14).

*Fig. 14 – Compressive strength test*

The maximum loads supported by different cured samples at the breaking moment were recorded in Table 6.

The tensile strength is the ability of the samples to resist the destruction under the traction force, which is difficult to measure directly. A diametral compression test was performed to each cured sample in order to determine the indirect tensile strength, which can be used to deduce the direct tensile strength. The maximum values of tensile strengths deduced for different cured samples were recorded in Table 6.

The compressive and tensile strength tests were carried out in accordance with the standards NF EN 13286-41 and NF EN 13286-42 respectively.

**Table 6 - Compressive and tensile strengths results**

| Mixtures | Compressive strength *(kg/cm²)* | | | | Tensile strength *(kg/cm²)* | | | |
|---|---|---|---|---|---|---|---|---|
| | 7-day | 14-day | 28-day | 60-day | 7-day | 14-day | 28-day | 60-day |
| M100-00-00 | 1.2 | 2 | 2.6 | 3 | 0.1 | 0.2 | 0.3 | 0.4 |
| M 90-02-08 | 3.2 | 4.2 | 5.5 | 6.2 | 0.6 | 1.5 | 1.8 | 2.2 |
| M 85-03-12 | 2.4 | 3.3 | 4.2 | 4.8 | 0.5 | 1.1 | 1.5 | 1.6 |
| M 80-04-16 | 1.8 | 2.5 | 3.1 | 3.8 | 0.4 | 0.8 | 1.1 | 1.2 |
| M 75-05-20 | 1.2 | 1.5 | 2.2 | 2.7 | 0.3 | 0.5 | 0.5 | 0.9 |

### *4.5.1 Effect lime and rubber powder incorporation on compressive strength*

As seen from the Figure 15, by increasing of the replacement rate of the lime and rubber powder, the compressive strength of the treated dune sand samples increased until a certain optimum and then decreased. The increase in this characteristic for replacement rate of 2% lime and 8% rubber is linked to the decrease of voids volume within the mixture, due to the addition of the fine particles; which explains the effectiveness of the used additions to improve the compactness and therefore the resistance to the compressive strength. For the 60-day cure time samples, the compressive strength increases from 3 kg/cm² for the mixture without additions (M 100-00-00) to 6.2 kg/cm² for the optimum formulation (M 90-02-08), then decreases with increasing lime and rubber incorporation until 2.7 kg/cm² for the mixture M 75-05-20.

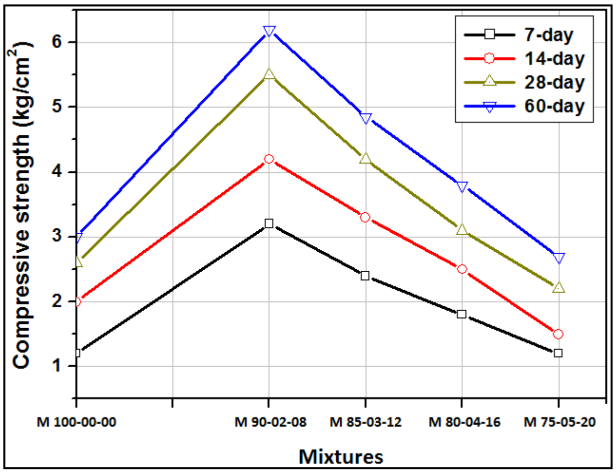


*Fig. 15 –Evolution of compressive strength according to lime and rubber incorporation*

We can also observe the beneficial effect of the cure time on the compressive strength. The cure promotes hydration which has the effect of clogging the existing capillary pores and reinforcing the inter-granular bonds. As an example, the compressive strength for the mixture M 90-02-08 augmented from 3.2 kg/cm² for 7-day cure time to 6.2 kg/cm² for 60-day cure time (an increase of 93.7%).

### *4.5.2 Effect lime and rubber powder incorporation on tensile strength*

Similarly to the compressive strength test, the maximum value of tensile strength was observed with the mixture M 90-02-08. Beyond total incorporation of 10%, the dune sand replacements by used additions have a negative influence on this mechanical characteristic (Figure 16).

For 60-day cure time samples, the tensile strength is about 2.2 kg/cm² for the optimum formulation (M 90-02-08), whereas for treatment at total incorporation of 15%, 20% and 25%, the tensile strength is of 1.6 kg/cm², 1.2 kg/cm² and 0.9 kg/cm² respectively.

All mixtures showed an improvement in tensile strengths with augmentation of cure time. As an example, the tensile strength for the mixture M 90-02-08 augmented from 0.6 kg/cm$^2$ for 7-day cure time to 2.2 kg/cm$^2$ for 60-day cure time.

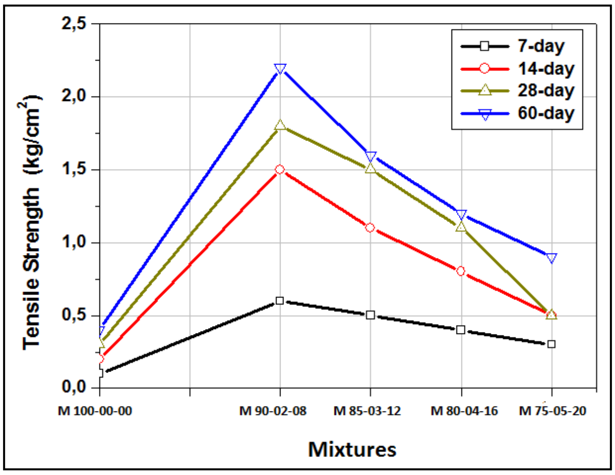


*Fig. 16 –Evolution of tensile strength according to lime and rubber incorporation*

## 5 Conclusion

As mentioned earlier, this study was conducted to assess the possibility of using waste rubber powder and lime as a partial replacement of dune sand and of valorising them in roadway foundations. From the results of present study, the following conclusions were drawn:

The dry density of treated dune sand mixtures has lower values than that without addition, which is 1.57 t/m$^3$ for the mixture M 75-05-20 and 1.76 t/m$^3$ for M 100-00-00. The water content increases from 11.4% for dune sand alone to 15.2 % for the mixture M 75-05-20.The optimum water content increases while the maximum dry density decreases with the inclusion of the powder and lime contents. The dry density decreases due to the light weight of the tire rubber powder, while the optimum water increases due to excess water absorption by lime.

The correction of dune sand with 8% rubber powder and 2% lime can give very good improvements in the CBR index and CBR at 95% of OMP for both immediate and immersion; indicating an increase in the bearing capacity of the roadway surfaces. The inclusion of increasing percentages rubber powder and lime caused an improvement in shear strengths, which is reflected by the increase in cohesion and a decrease in the friction angle.

The optimum rubber powder and lime content played a significant role in improving the tensile and compressive strengths. Also cure time has a beneficial effect on compressive and tensile strengths by promoting hydration which has the effect of clogging the existing capillary pores and reinforcing the inter-granular bonds. The advantages of using local materials like the waste rubber are indeed economic advantages (cost and transport) which are very important fact.

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