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Evaluation of the Structural Performance of Lime-Stabilized *cubitermes sp* Termite Mound Soil as a Sub-Base Layer for Sustainable Pavements

Louis Ahouet[1,2,3], Sylvain Ndinga Okina[1,2], Adolphe Ekouya[1,2] & Franck Taillandier[4]

[1] Higher Institute of Architecture, Urbanism, Building and Public Works, Denis Sassou Nguesso University, Congo

[2] Higher Polytechnic National School (ENSP), Marien Ngouabi University, Brazzaville, Congo

[3] Building and Publics Works Control Office (BCBTP), Brazzaville, Congo

[4] INARE, Aix Marseille University, RECOVER, Aix -en-Provence, France

Correspondence: Louis Ahouet, Higher Institute of Architecture, Urbanism, Building and Public Works, Denis Sassou Nguesso University, Congo. E-mail: louisahouet2@gmail.com

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Abstract

The scarcity of road materials that can be used directly in the sub-base layer of a road without preparation has led to the use of non-conventional materials. This study describes the feasibility of using hydrated lime-treated *cubitermes sp* termite mound soils for road construction, based on laboratory tests. Tests of Atterberg limits, dry density, CBR, compressive strength, static modulus and measurement of sinking of the material under traffic were carried out with different proportions of lime (0%, 3%, 5%, 6%, 7%, 9%). The results obtained show that the mechanical properties of soil-lime mixtures improve up to the point of lime fixation at 6% and that above 6% lime, the mechanical properties decrease. The traffic simulation at the rut shows that for the 6% lime mix, microcracks appear from 20.000 cycles and that the average settlement is 2 mm. The friction of the grains under the stresses developed by the passage of the wheel reduces the mechanical bonds of the soil-lime mixture. The rigidity of the material leads to the induced slab effect, which gives the material good behavior in hot weather, without strain or rutting. The mechanical connections during the setting of the soil-lime mixture reduce the friction of the grains under the stresses developed by the wheel. Lime welds the fines into much larger, more or less impermeable particles on the surface, which reduces the crumbling of the material by attrition, a major cause of pavement deterioration. The optimal mix can be used as a sub-base layer or wearing course for low-traffic earth roads ($T1 < 300$) and for the treatment of the upper parts of embankments. All these results are consolidated by X-ray diffraction (XRD) and scanning electron microscopy (SEM) analyses.

Keywords: *Cubitermes Sp* termite mound soil, grain size, mechanical properties, deformation, rutting

1. Introduction

The road contributes to the opening up of the hinterland by facilitating exchanges between towns and the countryside. The construction of a road requires the use of good quality materials. Today, certain geometric profiles of road projects are very constraining and require significant earth movements, sometimes in soils that are unsuitable for construction. Sometimes, along the route of the road, the natural deposits of high-quality materials are unevenly distributed or even exhausted. In this case, it is advisable to spare existing materials that do not have the required characteristics to be used without preparation, to support a road, especially as the cost of transporting the materials is high (Ahouet et al., 2019; Georges, 1983; Loubouth et al., 2020). The scarcity of suitable conventional road materials in some parts of sub-Saharan Africa has led to the use of non-conventional materials such as lateritic gravelly or *cubitermes sp* termite mound soils in road construction (Loubouth et al., 2020; Cocks et al., 2015; Molenaara, 2013; Brandl, 1981). The use of *cubitermes sp* termite mound soil as a non-conventional material (recycled or natural) in road construction can be an alternative solution to overcome the shortage of conventional materials on certain roads (Ahouet et al., 2019; Elenga et al., 2019). Indeed, several studies show that the use of local materials preserves non-renewable natural resources, reduces the transport of granular materials, the time of intervention, the nuisances linked to supplies and increases the safety of users and residents (Ahouet et al., 2019; Elenga et al., 2019). Today, sustainable development requires taking into account not only the technical requirements and the direct cost of the works, but also their environmental and social impacts (jobs, lands issues, etc.) (Ahouet et al., 2019; Sinha et al., 1990). Using local material in construction requires to determine its geotechnical characteristics on the one hand and, on the other hand, its interaction with the local environment, i.e., its behaviour in situ. Indeed, some studies report that some local materials, notably lateritic gravels, although not meeting the specifications of European or American standards, have proved to be good in use, whereas some roads built in compliance with these same standards have deteriorated prematurely (Ahouet et al., 2019, Cocks et al., 2015; Toll, 1991). Indeed, these standards were designed taking into account the behaviour of materials in temperate climates (Ahouet et al., 2019). However, few studies have been carried out on the local materials of developing countries, which are likely to be used in the body of the pavement (Ahouet et al., 2019). However, soils that are available in large quantities and do not initially meet standards (clays, clayey silts) and are treated with lime have a wide range of applications in road construction. Lime improves the workability and compactness of soils, facilitates their implementation and gives them sufficient immediate bearing capacity. Lime makes the soil in situ suitable for construction machinery, depending on the water status of the soil at the time of construction (Maubec et al., 2017; Locat et al., 1990; Locat et al., 1996; Little, 1995; Rogers & Glendinning, 2000; Boardman, 2001). Despite the variety of studies on lime-treated soils, very few have been carried out on *cubitermes sp* termite mound soil as a building material (Loubouth et al., 2020; Locat et al., 1990). The subject remains open and is not exhausted. Before accepting the use of *cubitermes sp* termite mound soils in road construction, more studies, laboratory tests and field trials are needed. This research could lead to the development of the technique (implementation of the material) best suited to the economic and natural conditions of the country. Indeed, the behaviour of the soil-lime mixture depends not only on the granularity but also on the mineralogy of the soil. To our knowledge, the application of lime-treated termite mound soils in road construction has not yet been reported. However, some regions of Central Africa have large deposits of *cubitermes sp* termite mound soils that could be used for road construction. The objective of this paper is to optimise the soil-lime mix and to evaluate the mechanical properties and ageing of the material under traffic.

2. Materials and method

2.1 Materials

The soil from the *cubitermes sp* termite mound soil was collected in the Republic of Congo, following the geographical coordinates 150 45' E and 20 29' S. The hydrated lime used was Pascal brand "CL 90-S", purchased in a local market. The mathematical model selected is the one with the highest coefficient of determination R^2 and the lowest Chi sqr (χ^2). Chi sqr (χ^2) - it allows to test the independence between two random variables. The *cubitermes sp* termite mound soil, grey-black in colour and mushroom-shaped, is shown in Figure 1.

Figure 1. *Cubitermes sp* termite mound soil.

2.2 Method

Soil samples from *cubitermes sp* termite mound soil is transported to the laboratory for testing. The tests are carried out after crushing and sieving the soil with a 2 mm sieve. Different tests were carried out to characterize the raw soil and the soil-lime mixtures with lime contents of 3-9%. This was the particle size analysis, the Atterberg limits, dry density (modified Proctor), CBR, compressive strength, static modulus, and measurement of material sinking (rutting). Soil-lime mixtures are obtained by mixing the raw soil with lime contents of 3-9% until a homogeneous mixture is obtained (Figure 2) (NF P94-102-2, 2001).

Figure 2. Mixing the soil-lime mixture

2.3 Grains Size Analysis

For particle separation, two types of tests were performed: by sieving for grains of size ϕ > 80μm, according to (NF P94-056, 1996); and by sedimentation for grains of diameter ϕ ≤ 80μm according to (NF P94-057, 1992). The particle size fraction is deduced from the recommendations of the particle size nomograms, considering clays as particles < 0.002 mm, silts 0.002-0.06 mm and sands 0.06-2 mm.

2.4 Atterberg Limits

The Atterberg limits were determined according to the Casagrande method (NF P 94-051, 1993). The plasticity index characterizes the extent of the water content range in which soils behave plastically. The limits of liquidity (LL) and plasticity (PL) are determined on the fraction of soil (mortar) passing a 0.40 mm sieve. The plasticity index (PI) is expressed by the following relationship:

$$PI = LL - PL \tag{1}$$

2.5 Dry Density

The modified Proctor test is used to determine the optimum moisture content (%) for which compaction leads to a maximum dry density (T/m^3). The maximum dry density is not a direct indication of the mechanical strength of soil. However, for a material that nevertheless has pores, the more interactions there are between the particles, the better the cohesion of soil. The mineralogy and the formation medium influence the water content of soil. The optimum moisture content and maximum dry density were measured by the modified Proctor test, according to (NF P 94-093, 1999).

2.6 The California Bearing Ratio (CBR) - Immediate California Bearing Ratio (ICBR)

The test is used to determine the thickness of sub-base layers, to establish a soil classification and to study trafficability. It gives us one of the essential parameters of geotechnical testing before construction. There are different types of CBR tests to be carried out depending on the type and quality of the soil according to the (NF P 94-078, 1997).

2.7 Compressive strength - Static modulus

To determine the 28-day compressive strength, cylindrical specimens of 10 cm diameter and 20 cm height are manufactured and compacted at the optimum water content of the modified Proctor test for all soil-lime mixtures and cured at an average ambient temperature of 25˚C. For each curing time and soil-lime ratio, six specimens were manufactured and tested for compressive strength according to (NF P98-230-2, 1993). The static modulus was determined from the ratio of the compressive strength to the strain at failure of the material according to the scheme in Figure 3, by formula (2):

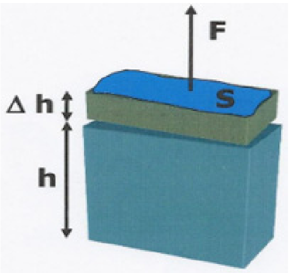

Figure 3. Device for determining compressive strength and static modulus

$$CS\ (MPa) = \frac{F}{S} \tag{2}$$

$$Est(MPa) = \frac{CS}{\frac{\Delta h}{h}} \tag{3}$$

E_{st} – static module; $\Delta h/h$ – strain at failure; CS – compressive strength; F – Force; S – surface

2.8 Measuring the Depth of Settlement of a Material Subjected to Traffic

The test is an adaptation to assess the behaviour of the soil-lime mixture used in the wearing course of earth roads, subject to traffic. The test to measure the sinking of the material is carried out in the laboratory with a rutting machine (EN 12697-22, 2020). Each specimen is tested in the mould used for its manufacture, which is attached to the groove support plate (Figure 4). After this preliminary phase, the first measurements m0j with j varying between 1 and 15 of the specimen profile are carried out according to Figure 5 below.

Figure 4. Compaction and adjustment of the material surface (BBPAC compactor)

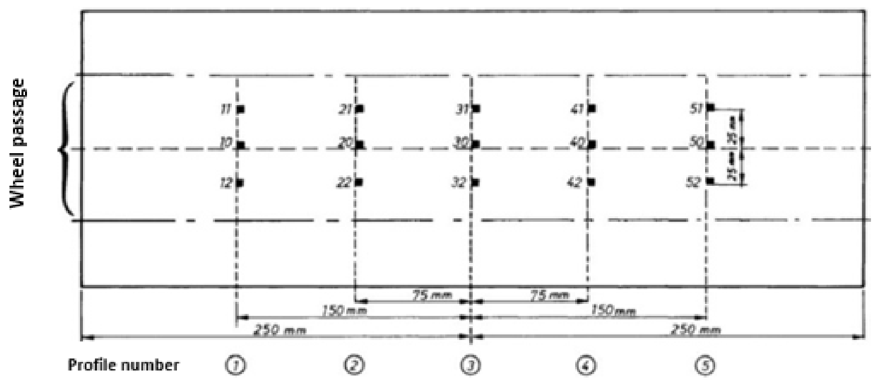

Figure 5. Location of measuring points

The final adjustment of the material after partial compaction is done by manual shaving over the entire width to be adjusted by the operator, which provides an additional 3 cm of processed material. Final compaction takes place immediately after the final adjustment, in order to provide the additional energy needed to achieve the desired compaction quality according to the weight of the material. Then, after 28 days, the material is subjected to simulated traffic (wheel hammering on the material) for several cycles until signs of fatigue appear, manifested as micro-cracks (Figure 6). The test is interrupted to measure the sinking (rutting) of the material. The ruler is placed successively at five selected points on the top surface of the specimen to measure the indentation of the material at the point of passage of the wheel (Figures 5-6). The sinking measurements are taken at five different points and the average is calculated (Figure 5-6).

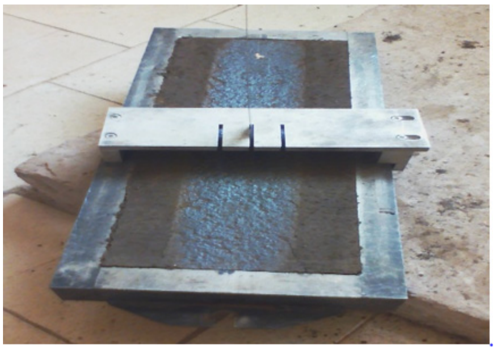

Figure 6. Measuring the sinkage after several passes of the wheel

A traffic simulation carried out in the laboratory in a room with an ambient temperature of 30°C.

3. Results

3.1 Identification and Classification of Raw Soil and Soil-Lime Mixtures

Figure 7 shows the distribution of grains in the raw soil.

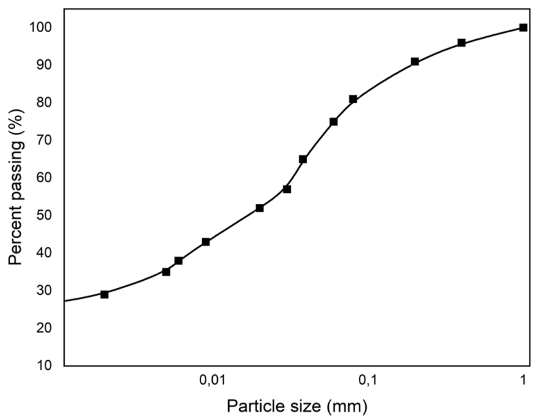

Figure 7. Grain size of raw soil

Figure 7 shows the grains size distribution of raw soil. The clay, silt, sand contents, deduced from the particle size curve and the Atterberg limits are reported in Table 2.

Table 2. Particle size fractions, Atterberg limits and soil classification

Designation	Clay (%)	Silt (%)	Sand (%)	LL (%)	PL (%)	PI (%)	Classification	
							AASHTO	USCS
Soil	29.45	45.12	25.43	36.20	18.44	17.76	A-6	Clayey silt

From Table 2: Size fractions (sand, silt, clay), LL (%) - liquidity limit, PL (%) - plasticity limit, PI (%) - plasticity index.

Figure 7 shows the evolution of the clay, silt and sand size fractions of the raw soil and the 3-9% lime mixtures.

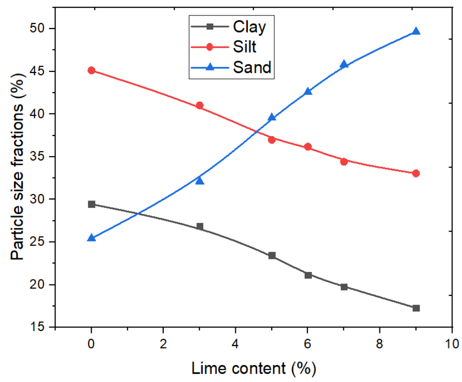

Figure 8. Evolution of clay, silt and sand fractions as a function of lime content

The particle size changes resulting from the pozzolanic reaction are polynomial fit:

$$Y = C + AX + BX^2 \quad (4)$$

Clay (%) = 29.74454 - 1.12137X - 0.03423X^2, R^2 = 0.975

C = ±0.68934, A = ±0.3206, B = ±0.03458

Silt (%) = 45.35157 - 1.83305X - 0.04821X^2, R^2 = 0.982

C = ±0.57924, A = ±0.2694, B = ±0.02906

Sand (%) = 24.9126 + 2.93973X - 0.01254X^2, R^2 = 0.983

C = ±1.1441, A = ±0.53211, B = ±0.0574

R^2 – coefficient of determination, X - lime content

Figure 8 shows the changes in the particle size fractions of clay, silt and sand after the addition of lime. Lime changes the particle size by decreasing the clay and silt fractions, compensated by an increase in the sand fraction. The changes in particle size alter the nature of the raw soil and the behavior of the mixtures, leading to improved use properties.

Figure 8 shows the evolution of the activity of raw and mixed soils as a function of the specific surface area.

3.2 Mechanical Behaviour of the Compacted Material

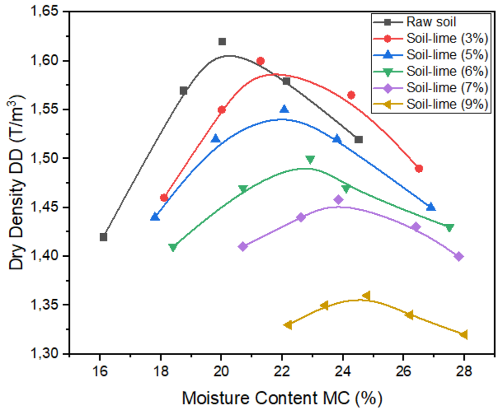

Figure 9. Evolution of the dry density as a function of the optimal moisture content

The addition of lime leads to a decrease in the maximum dry density and an increase in the optimum moisture content due to the pozzolanic reaction and the improved compaction properties of the material (Jacques Locat et al., 1990; Locat et al., 1996; Little, 1995; Rogers, 2000; Boardman, 2001; CEBTP, 1984).

Figure 10 shows the evolution of the plasticity index as a function of the lime content.

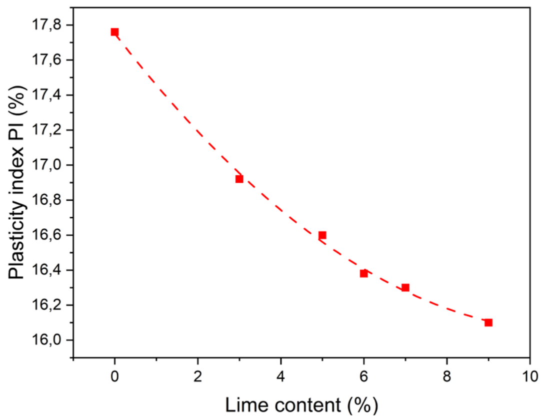

Figure 10. Evolution of the plasticity index as a function of lime addition

The raw soil has a plasticity index PI (17.76%), the mixtures with 6% and 9% lime have plasticity index of 16.38% and 16.1% respectively. The PI (17.76-16.1%) decreases by 9.35%. All PI values are below 30%, which is the maximum allowed for pavement sub base layer materials (Zhu et al., 2019).

Figure 11 shows the raw soil sample after compaction by tyre pounding (rutting machine).

Figure 11. *Cubitermes sp* termite mound soil after compaction

Raw soil and 3-9% soil-lime mixtures are compacted to optimum moisture contents to achieve maximum dry density. The material is then subjected to several passes of the wheel in order to determine the number of cycles that cause the deformation (rutting) of the material leading to sinking (Figure 11). For raw soil, from 6.000 cycles onwards, micro-cracks appear on the surface of the material at the point of the wheel passage. The average sinkage measured is 9 mm, that is, the raw soil is coherent. For the 3% lime mixture, micro-cracks appear on the surface of specimen from 10.000 cycles. The average sinkage of the material measured at the point of passage of the wheel is 7 mm. For the 6% lime mixture, microcracks appear from 20.000 cycles and the average sinkage is 2 mm. At 9% lime, the specimen shows microcracks from 16.000 cycles onwards with an average sinkage of 6 mm.

From 3-28 days, the lime content has no significant effect on the rate of improvement of soil. Indeed, evolution Indeed all curves of the compressive strength are on the whole parallel (Figure 12).

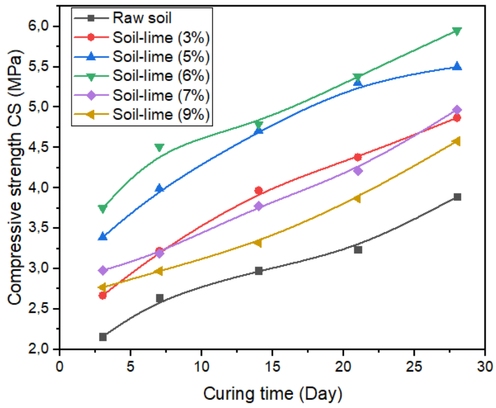

Figure 12. Evolution of the compressive strengths of soil-lime mixtures as a function of curing time

The evolution of the compressive strength with curing time is linear (Figure 12). The improvement in compressive strength with curing time is related to the pozzolanic reactions occurring in the soil-lime mixture. However, the similarity in the shape of the curve of the raw soil and the soil-lime mixtures indicates that the pozzolanic reaction may not be the main cause of this improvement up to 28 days. Indeed, this improvement with curing time can be attributed mainly to the drying process.

Figure 13 shows the compressive strength and strain at failure as function of lime addition and soil compaction.

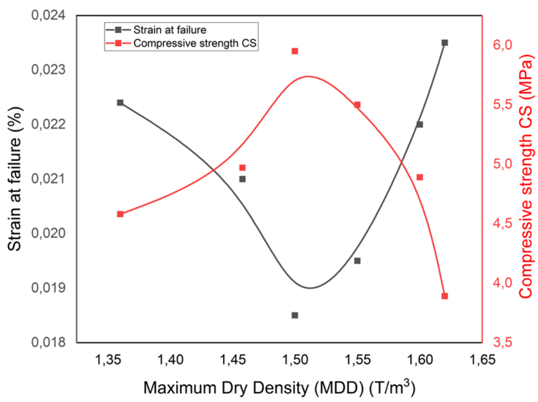

Figure 13. Compressive strength and strain at failure as a function of maximum dry density

Figure 13 shows the negative correlation between strain at failure and compressive strength as a function of compaction and lime content. For a relatively thin lime-treated pavement layer placed on a deformable substrate, the pavement structure will undergo an imposed deformation. Indeed, for lime contents of 3-6%, the strain at failure decreases by 21.28%, the compressive strength increases by 52.96% and the dry density decreases by 7.41%. For lime contents of 6-9%, strain at failure increases by 21.08%, compressive strength decreases by 23.03% and dry density decreases by 10%. It is therefore necessary to use the stiffer soil-lime mixture for a pavement layer to limit cracking caused by structural deformation due to traffic.

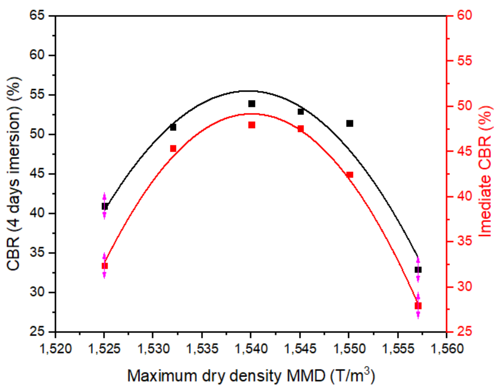

Figure 14. Correlation of immediate ICBR and CBR at 4 days of immersion

According to Figure 14, the immediate ICBR and CBR at 4 days of immersion are highly correlated and their optimum is obtained at 6% lime, i.e., 48% and 54% respectively (Zhu et al., 2019; Thi Thanh Hang Nguyen, 2015). The curing time seems to be the cause of the difference between ICBR and CBR. The evolution of CBR and ICBR is a polynomial fit:

$$Y = C + AX + BX^2 \quad (5)$$

For the CBR at 4 days immersion:

$$C = -166340.61123 \pm 22314.07876$$

$$A = 216142.82229 \pm 28965.36588$$

$$B = -70190.50229 \pm 9399.43341$$

Coefficient of determination $R^2 = 0.951$

For immediate ICBR

$$C = -173133.72914 \pm 8914.08922$$

$$A = 224907.06582 \pm 11571.1556$$

$$B = -73019.8834 \pm 3754.91137$$

Coefficient of determination $R^2 = 0.992$

Figure 15 shows the correlation between the CBR and the static modulus of raw soil and the soil-lime mixtures as a function of lime content.

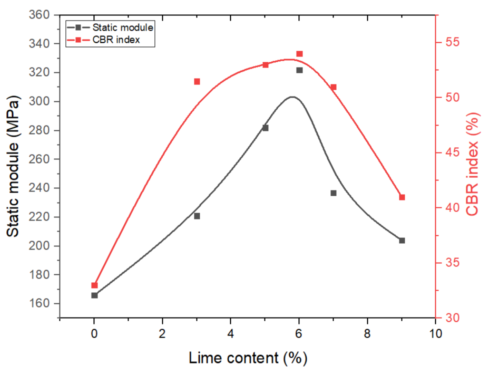

Figure 15. Correlation between static modulus and CBR index as a function of lime content

The static modulus Est and CBR increase with the addition of lime from 3-6% and from 6-9% lime, both properties do not improve anymore, they decrease. The reorganisation of the material's microstructure may be responsible for the decrease in static modulus Est and CBR above 6% (lime fixation point).

Figure 16 shows the fit that best simulates the relationship between static modulus and CBR, as a function of the coefficient of determination and Chi-Sqr.

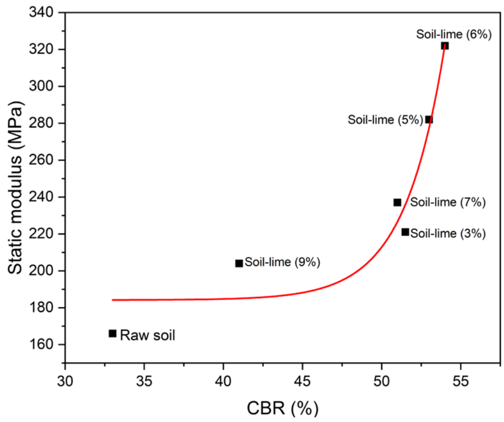

Figure 16. Correlation between static modulus E_{st} and CBR

According to Figure 16, the static modulus Est and the CBR are correlated and the relationship found between the two parameters corresponds to the ExpDec1:

$$E_{St} = A_1 * exp\left(-\frac{CBR}{t_1}\right) + Y_0 \quad (6)$$

$$Y_0 = 184.16783 \pm 13.54243$$

$$A_1 = 7.89399E - 8 \pm 5.62245E - 7$$

$$t_1 = -2.53691 \pm 0.84989$$

Chi-Sqr (χ^2) = 347.2306

$R^2 = 0.888$

E_{st} - static modulus, CBR - California Bearing Ratio, R^2 - coefficient of determination, Chi-sqr (χ^2) - it allows to test the independence between two random variables.

However, as the *Cubitermes sp* termite mound soil is homogeneous, the static modulus and CBR index can be adopted by the following relationship (Georges Jeuffroy, 1983):

$$E_{St} = K * CBR \quad (7)$$

E_{st} – static modulus, K – coefficient of soil, CBR – California Bearing Ratio

The raw soil and the 3-9% soil-lime mixtures have a CBR (33-54%) > 10%. Knowing the static modulus Est (MPa) and the CBR (%), the K coefficient of the raw soil and the 3-9% soil-lime mixtures are respectively K (5, 4.29, 5.32, 5.96, 4.65, 4.98), i.e., an average of K (5.033) (Georges, 1983). The recommended average of K (5) for any soil with a CBR > 10 (Georges, 1983).

Figure 17 shows the uses of raw soil and 3-9% soil-lime mixtures in road construction.

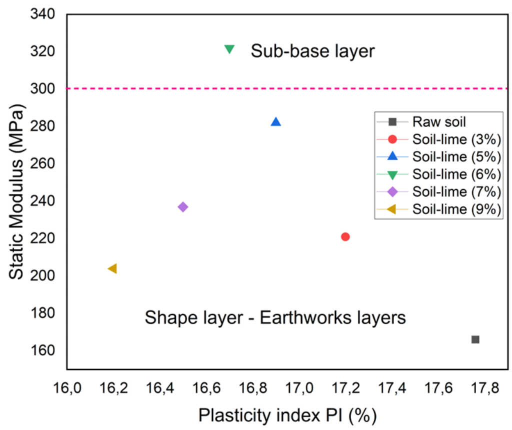

Figure 17. Use of raw soil and mixtures in road construction

According to Figure 17, the static modulus is (166-322 MPa) for raw soil and mixes with 3-9% lime. Mixtures with 3-6% lime can be adopted for the sub-base layer of pavements, the wearing course of low-traffic earth roads or for the stabilisation of car platforms and parking areas (CEBTP, 1984). Raw soil and mixtures with 7-9% lime can be used for backfilling and stabilisation of the upper parts of earthworks respectively.

3.4 Observation of the microstructure of raw soil and mixtures by Scanning Electron Microscopy (SEM)

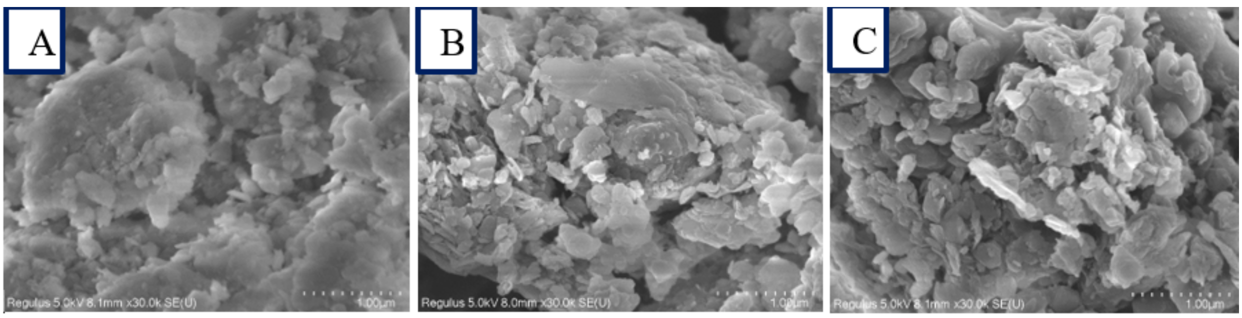

Figure 18. Observation of raw soil and soil-lime mixture (6% and 9%), magnification x 30

From Figure 18 (A), observation of the compacted raw soil shows the elementary particles covered with agglomerated clay minerals and forming continuous bridges between the soil grains. The grains are in contact with each other and leave macropores between them. The aggregations of clay particles are at the origin of an intra-aggregate microporosity.

From Figure 18 (B), the textural morphology of the soil treated with 6% lime makes it difficult to distinguish clay minerals on the surface of the grains. Newly formed and potentially crystallized minerals are observed on the surface of the bound soil grains. The new minerals are cementitious products that fill the natural inter-aggregate pores. The pore volume is smaller than that of the raw soil. The result shows that the pore volumes of the 6% lime treated sample are slightly higher than the corresponding raw soil sample. This is explained by the lower compaction density after treatment due to the increased sand content.

From Figure 18 (C), the textural morphology of the 9% lime mixture shows that the aggregate agglomerations fill the artificial inter-aggregate macropores and decrease the pore volume by cementing the grains of the 9% lime mixture. The change in microstructure was attributed to the reorganization of the clay particles induced by the flocculation phenomenon. This phenomenon evolves with the curing time and the lime dosage. Indeed, the soil treated with 9% lime Figure 18(C) is more active in Ac (0.988) than the one in Fig. 18(B) with an Ac activity (0.775).

The mixtures in Figures 18 (B) and 18 (C), compared to the raw soil in Figure 18 (A), have a denser internal structure. Indeed, the structure of the mixtures includes agglomerations of soil aggregates formed as a result of the flocculation phenomenon and dispersed aggregates of clay particles.

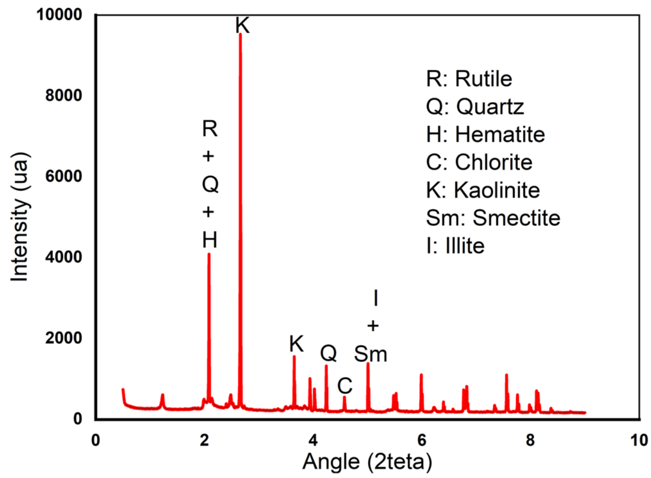

Figure 19. X-ray diffractogram of *cubitermes sp* termite mound soil

The diffractogram analysis indicates that quartz is present in the sample in minimal quantities. The most represented clay minerals in the soil of the *cubitermes sp* termite mound soil is kaolinite, illite, chlorite and smectites or rutile-quartz-hematite intermediate layers. Chlorite is also present, but in smaller quantities.

3.5 Implementation of Hydrated Lime Treatment of cubitermes sp Termite Mound Soils

The scarcity of road materials has made it possible to use the *cubitermes sp* termite mound soil for the first time in the construction of the wearing course of an earth road. A description of the methodology for the implementation of the in-situ soil-lime treatment is presented below.

Figure 20. Implementation of the soil-lime treatment the *Cubitermes sp* termite mound soil

The treatment of soil with lime consists of preparing the mixture in the following steps:

- Preparation of the surface by levelling to the desired elevation and according to the coast requested by the topographical study;
- Placement of *Cubitermes sp* termite mound soils with an average diameter of 30 cm and a height of 30 to 50 cm on the prepared platform;
- Run the tyre compactor several times to crush mounds of *Cubitermes sp* termite mound soils. The number of passes of the machine required for this operation will be determined in situ according to the density in place;
- Scarification of compacted material with a ripper;

- Application of lime in one or more passes and at the required rate;
- Soil-lime mixture in situ. During this operation, the mixture must have a moisture content of at least 3%, higher than the optimum moisture content of the modified Proctor. It is therefore necessary to provide for humidification at this stage;
- Close the stabilized surface by lightly compacting and leave to cure for 48 hours;
- Scarify and knead the compacted material so that all agglomerates pass through the 50 mm sieve. During this second mixing operation, the water content should be kept close to the modified Proctor optimum.;
- Final compaction with a multi-tyre compactor up to 90% of the modified Proctor;
- Allow to cure for at least seven (7) days before opening to traffic;
- Impregnate with fluidised bitumen to retain moisture in the material.

4. Discussion

The discussion focuses on changes in the particle size of the soil-lime mixtures (Figure 7) and their particle size fraction (Figure 8), which result in improved behavior and usability of the material at lime contents of 3-6%. Above 6% lime, the mechanical properties decrease.

Figure 8 shows the changes in the size fractions of clay, silt and sand. Lime changed the grain size by decreasing the clay and silt fraction, compensated by the increase of the sand fraction by 97.25%.

According to Figure 9, the increase in sand content (Figure 8) results in the flattening of the Proctor curves, the decrease of the maximum dry density and the shift of the Proctor curves of the soil-lime mixtures towards the higher moisture contents (Locat et al., 1990; Locat et al., 1996; Little, 1995; Rogers, 2000; Boardman, 2001; Zhu et al., 2019).

According to Figure 10, the plasticity index PI (17.76-16.1%) decreases with the addition of lime by 3-9%, a decrease of 9.35%. With a lime content of 6%, the plasticity index of PI (16.6%) is higher than the lower limit of 10% but lower than the upper limit of 30%. The plasticity index remains within the permissible limits for road construction for sub base layers materials (CEBTP, 1984).

According to Figure 11, from the raw soil to the 6% mix, settlement decreases from 9 mm to 2 mm, a decrease of 77.77%, and from 6-9% lime, settlement increases from 2 mm to 6 mm, an increase of 200%. In other words, for lime contents ranging from 0% (raw soil) to 6%, the mechanical characteristics improve and rutting decreases from 9 to 2 mm. From 6 to 9% lime, the mechanical characteristics of the material decrease and rutting increases from 2 to 7 mm. The lime content of 6% is considered as the lime point. A traffic simulation carried out in the laboratory (Figure 4-6) gave conclusive results. The material will perform well in hot weather, without deformation or rutting, due to the stiffness of the material and the induced slab effect (Figure 12-14).

According to Figure (11-14), the use of lime-treated soil in a pavement layer ensures good load distribution on the structure's support (Cocks et al., 2015; Little, 1995). The mechanical bonding during the setting of the soil-lime mixture reduces the friction of the grains under the stresses developed by the traffic. Wear particles generating plastic fines are slowed down. Clay fines resulting from internal friction of the material are neutralized by the lime during setting. The lime welds the fines into much larger, more or less impermeable particles on the surface, which reduces the crumbling of the material by attrition, a major cause of pavement deterioration. It is necessary to use the soil-lime mixture on a stiffer platform to limit cracking's.

According to Figure 12, from 3 to 28 days of curing, the compressive strengths CS (2.16 -5.95 MPa) of the raw soil and the resulting soil-lime mixtures are higher than the range of compressive strengths of cohesive soils reported by Bruce (2001).

A correlation best simulates the fit when the coefficient of determination is high and its Chi-Sqr is lowest. From Figure 16, since the value χ^2 (347.2306) is very high, despite the coefficient of determination R^2 (0.888), the relationship (6) cannot be accepted. The correlations (5) allow the prediction of the CBR or the ICBR.

According to Figure (17), the static modulus of the 6% lime mix is 322 MPa, higher than the minimum 300 MPa recommended for light traffic sub-grad layer (CEBTP, 1984).

Before the large-scale use of lime-treated *Cubitermes sp* termite mound soils, a 15 km test board was constructed (Figure 22).

6. Conclusion

The objective of this test board will be to monitor the behaviour of the treated layer material in relation to the evolution of traffic and climatic variations (dry season - rainy season) and the effect of temperature. With the aim of using this material on a very large scale. This work characterizes the *Cubitermes sp* termite mound soil properties (class A_6 clayey silt) and the soil-lime mixtures that were used to determine their range of action in road construction. The *Cubitermes sp* termite mound soil is kaolinite, illite, chlorite and smectites or rutile-quartz-hematite intermediate layers. The results of the laboratory and scanning electron microscopy (SEM) tests show that the lime content and drying time significantly influenced the geotechnical properties and microstructure of the soil-lime mixtures. Increasing the lime content from 3-6% resulted in an increase in the optimum moisture content for compaction, sand size fraction, maximum compressive strength, static modulus, ICBR and CBR. However, the plasticity index, silt fractions, clay fractions, dry density, swelling capacity and water absorption decreased. The sinking of soil-lime mixtures decreases at lime contents of 3-6% and above 6% lime, the sinking increases. The 6% lime content is the point of lime fixation, above which the mechanical properties do not improve, but decrease. These results show that the geotechnical properties of the lime-treated *Cubitermes sp* termite mound soil are affected by the microstructural organisation of the soil itself. Material treated with 6% lime can be used in pavements sub-base layers, as a wearing course for low traffic earth roads or for the stabilization of vehicle parking platforms. Raw soil and mixtures containing 3-9% lime can be used to improve the bearing capacity of the upper part of earthworks.

Declaration of Conflicting Interests

The authors declare no conflicts of interest regarding the publication of this paper.

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