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Influence of the Granular Class of Crushed Granites on the Litho-Stabilization of Samo Laterites (South-East of Côte d'Ivoire)

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Abstract

Most of the laterites found in Ivory Coast do not meet the technical conditions to be used in their natural state for the design of road foundations. Also, to meet the growing needs for road materials, various amendments are made to them, including litho-stabilization. Thus, this study proposes to understand the influence of the granular class of natural aggregates on the performance of laterites. To achieve this objective, different proportions of crushed granites of class 0/5, 0/15 and 5/15 have been incorporated into the soils of southern Côte d'Ivoire, especially in Samo. This modified soil has been subjected to mechanical tests such as the modified Proctor and CBR test. The results obtained show that the dry densities of the incorporated laterites containing crushed granites increase with the content of natural aggregates and decrease with the increase in the water content. Likewise, the CBR bearing indices at 95% of the Modified Optimum Proctor of the different compositions (laterites + crushed granites) increase with the proportion of aggregates. The addition of coarse aggregates to the laterites therefore promotes the establishment of a framework which improves its bearing capacity. From 20% to 30% crushed granites respectively of class 0/15; 0/5 and 5/15, the values of the CBR obtained are greater than those of 30% therefore these modified soils can be used as a foundation layer for traffic of T1, T2 and T3 type. Likewise, the laterites' mixtures with at least 40% crushed granites of class 0/15 and 0/5 can also be used for the foundation and base layers.

Keywords

Laterite, Litho-Stabilization, Natural Aggregate, Coarse Aggregate, CBR, Modified Proctor, Incorporated Laterites

1. Introduction

Since 1976, in many parts of the world and particularly in tropical regions, road construction has required the manipulation of a large volume of soils and rocks, specifically laterites. The problem of the choice and the implementation in road engineering of this raw material, depends strongly on the climatic conditions and the criteria of dimensioning required by the standard. However, a soil just like a lateritic gravel is a continuum of grains of size in very variable proportions and for it to be used in construction, it must respect a well-defined specification according to the type of traffic (CBR ≥ 30%, dry density ≥ 1.9, percentage of fine ≤ 35% and plasticity index ≤ 25%) [1]. Unfortunately, it is not always easy to find laterites capable of guaranteeing the performance and durability of base and foundation layers. Thus, stabilizing products (cement and lime) are added to give them the mechanical properties required by the standard [2]. This amendment technique with Portland cement, although having given some technical satisfaction, remains in the current context of very costly global economic crises for developing countries in general and for Côte d'Ivoire in particular. One kilometer of road is estimated at 300 million XOF. Alongside these products, local materials (crushed rock) are also used and this method is known as litho-stabilization.

Litho-stabilization is a technique that consists of improving the performance of lateritic soils used as roadbeds by adding a quantity of granular materials (crushed sand or granite). The paternity of this technique used today in many countries in sub-Saharan Africa is recognized in Burkina Faso where it was for the first time the subject of study thanks to the research work of Pierre LOMPO who described the methods of the use of litho stabilization in Burkina Faso in his book "The materials used in road construction in Upper Volta: A non-traditional material (the Lithostab)" published in Paris in 1980. In addition, [3] [4] [5] [6] complete these studies by improving the geotechnical characteristics of this type of soil with aggregates. Indeed, the mixing of laterites with granular materials such as sand or crushed materials improves their properties in order to make them usable in road construction. Remember that the geotechnical and mechanical characteristics of lateritic soils are strongly conditioned by the texture, that is to say the mode of intermingling of the grains which constitute them as well as the mode of attack of the iron oxides. In other words, lateritic soils containing large quantities of coarse elements offer better bearing capacity than those which do not contain any. Natural crushed granites by their solid mechanical aspect and their great abundance on the Ivorian territory constitute a favorable asset not only from the economic point of view but also from the environmental point of view. The objective of this study is to understand the influence of the incorporation of natural aggregates of different granular class on the performance of lateritic soil. This article first presents the different raw materials (laterite and crushed granite) that will be used in this study. Then, in a second step, the formulation of the different mixtures will be exposed as well as the method of elaboration of the test specimens. Finally in a third step, the method of processing the data collected will be treated.

2. Material and Methods

2.1. Raw Materials

In this study, the raw materials used are the lateritic soils of Samo, a locality located in the South East of the Ivory Coast, and granite crushed stone all both mentioned respectively on **Figure 1** and **Figure 2**.

The granite crushed was collected at the CADERAC Career located in Ayamé (South East of the Ivory Coast). Three granular classes were retained: 0/5, 5/15 and 0/15. These raw materials have been the subject of geotechnical characterization tests and have been used to make road base layers.

2.2. Experimental Methods

2.2.1. Development of Laterite-Crushed Granite Formulations

The different formulations of crushed granite laterite mixtures are given in **Table 1**.

For each formulation, the laterite soil in its natural state is mixed with the granite crushed stone until it becomes visibly homogeneous. These formulations were subjected to geotechnical tests used in road engineering, namely; particle size analysis, Atterberg limits, Proctor test and CBR test.

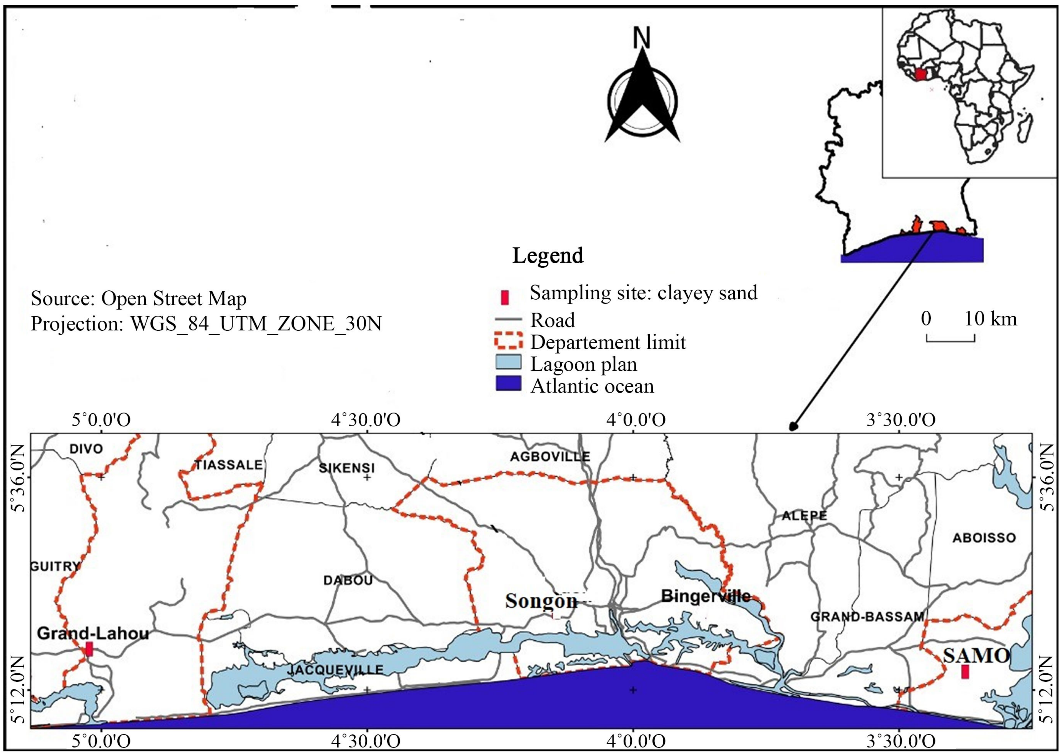


Figure 1. Geographical location of the sampling sites.

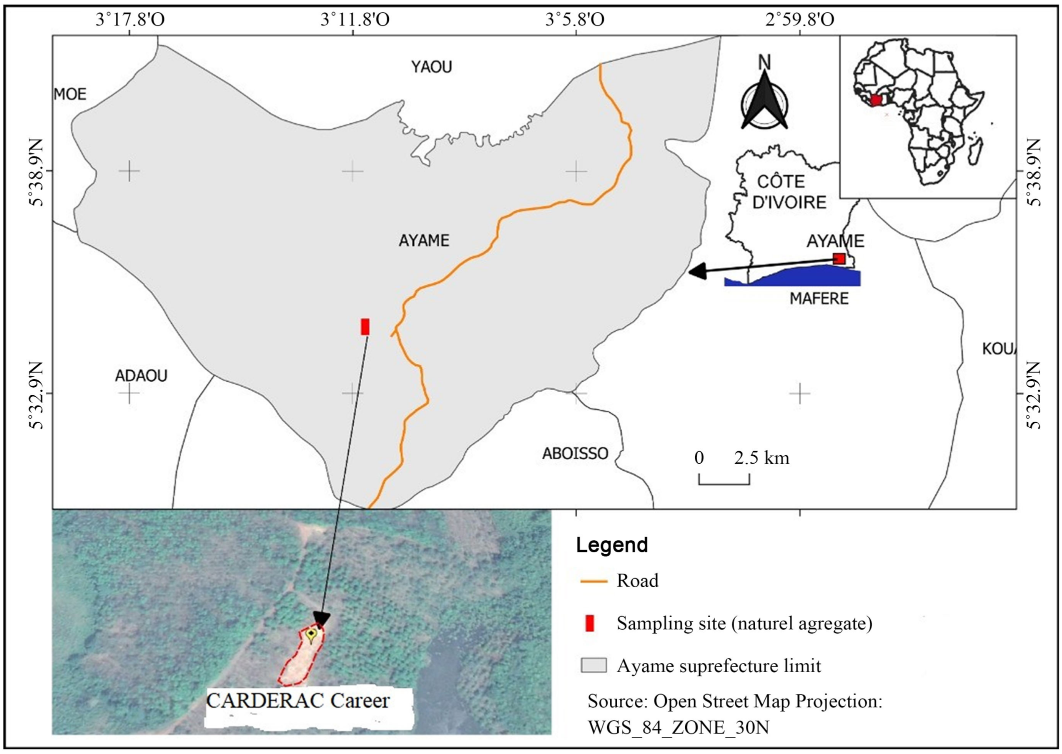


Figure 2. Sampling site for the crushed.

Table 1. Ranges of formulations.

Proportion of lateritic soil	Proportion of granite crushed	Samo formulation index		
		0/5	5/15	0/15
100	0		S	
85	15	$S_{15-0/5}$	$S_{15-5/15}$	$S_{15-0/15}$
80	20	$S_{20-0/5}$	$S_{20-5/15}$	$S_{20-0/15}$
70	30	$S_{30-0/5}$	$S_{30-5/15}$	$S_{30-0/15}$
60	40	$S_{40-0/5}$	$S_{40-5/15}$	$S_{40-0/15}$

2.2.2. Test Techniques

Granite crushed was subjected to tests Particle size analysis, Los Angeles and Micro Deval test while Particle size analysis, Atterberg limits, Proctor and the CBR test were carried out on lateritic soils and the various formulations.

1) Particle size analysis

Particle size analysis is used to determine the distribution of the grains of a material according to their size. Two techniques are conventionally used: sieving and sedimentometry.

The sieving was carried out by dry process for the granite crushed stone and for the lateritic soils and the various formulations according to the [7] standards. This analysis was supplemented by sedimentometry for lateritic soils and the various formulations according to the [8] standards.

2) Los Angeles and Micro-Deval test

The test consists of measuring the mass m of elements less than 1.6 mm, produced by the fragmentation of the material tested (diameters between 4 and 47 mm) and which is subjected to the shocks of standardized balls, in the cylinder of the Los Angeles machine in 500 rotations. It is the subject of the French standard [9]. The Los Angeles coefficient is calculated from the passing through a 1.6 mm sieve, measured at the end of the test. The Micro-Deval test measures the combined resistance to fragmentation by impact and wear by reciprocal friction of the elements of an aggregate.

3) Atterberg limits or consistency test

The Atterberg limits consist of the liquid limit, the plastic limit and the plasticity index. The plasticity limit and the liquidity limit correspond to the water contents which separate the solid state from the plastic state and the plastic state from the liquid state of the soil, respectively. They are determined according to the method proposed by standard [10]. The plasticity index is equivalent to the extent of the plastic domain. It is calculated from the formula:

$$IP = WL - WP \quad (1)$$

IP = plasticity index;

WL = liquid limit;

WP = plasticity limit.

4) Proctor test

The Proctor compaction characteristics of a material are determined from the modified Proctor test. The principle of the test consists of humidifying a material with several water contents and compacting it, for each of the water contents, according to [11] and conventional energy. For each of the water content values considered, the dry density of the material is determined and the curve of the variations in this density is plotted as a function of the water content. In general, this curve, called the Proctor curve, presents a maximum value of the density of the dry material which is obtained for a particular value of the water content. These two values are called the optimum modified Proctor compaction characteristics. Samples collected from study sites were compacted in Proctor molds.

5) CBR test

The load brought by the tire on the pavement punctures the base soil. This punching is smaller the greater the thickness of the pavement. The principle of the CBR test is therefore to reproduce this phenomenon by compacting the material under the conditions of the Proctor test in a CBR module then by measuring the forces to be applied to a cylindrical punch to make it penetrate at a constant speed in a test tube of this material. The reference standard is the French standard [12].

3. Results and Discussion

3.1. Characteristic of the Granite Crushed Stone

Figure 3 shows the results of the particle size analysis carried out on the granite crushed stone. It shows that the crushed granite used can be divided into three granular classes: Class 0/5, class 0/15 and class 5/15. The proportions of sand and gravel of these different classes of aggregate are given in the table.

According to standard [13], the granite crushes used gave after characterization, proportions of sand, proportions of gravel, values of the micro-Deval and Los Angeles test (resistance to wear and impact) less than or equal to 40 and 13 respectively, Allowable value for T1-T3 type traffic and less than or equal to 30 and 12 respectively, admissible value for T4-T5 type traffic [14].

Table 2 shows that the three classes of crushed granites mainly contain gravel for classes 0/15 and 5/15 (55% and 98% respectively) and sand for class 0/5 (90%). The 0/5 crushed is finer than the 0/15 crushed which itself is finer than the 5/15. This is confirmed by the diameters of 50% of the passers-by (D_{50}) which shows that the 0/5 aggregate is the finest followed by the 0/15 aggregate and the 5/15 aggregate which is coarser. Moreover, the table also shows that the Cu of crushed grade 0/15 is higher than that of crushed class 0/5 which is higher than that of crushed class 5/15. The particle size distribution of class 0/15 crushed stone is more spread out than that of the other two classes. In addition, this table also shows that the crushed class 0/15 has a higher Cc (Cc = 2.57) than that of the crushed 5/15 (Cc = 1) which itself is greater than that of the crushed 0/5 (Cc = 0.79). Class 0/5 aggregates are poorly graded while class 5/15 aggregates have a very narrow grain size. Their fineness modulus according to the [15] [16], are respectively 2.82 for 0/5 gravel, 5.16 for 0/15 gravel then 6.14 for 5/15. According to this same standard, when the 0/5 gravel fineness modulus is between 2.8 and 3.2, the sand is mostly coarse-grained. Likewise, when the modulus is greater than 3.2, sand should be avoided. We deduce that gravel of class 0/15 and 5/15 are avoided fine, while sand B is coarse.

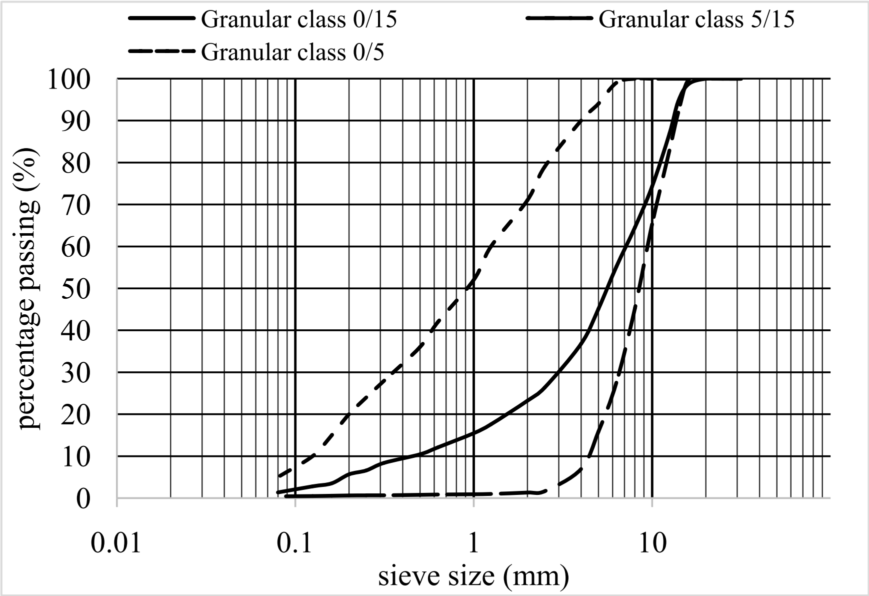


Figure 3. Particle size analysis of granite crushed stone.

Table 2. Summary of the results of the GC particle size analysis.

	Granular class		
Granular class Granite crush	0/5	0/15	5/15
Gravel 2 mm ≤ Φ	30	98	77
Sands (0.08 mm ≤ Φ <2 mm	65	1.32	21.68
Silt	5	0.4	1.32
Clay	0	0	0
Cu	12.73	2	14
Cc	0.79	1	2.57
Mf	2.82	6.14	5.16
LA coefficient (class 10/14)		28	
MDV coefficient (class 10/14)		5	

3.2. Properties of the Lateritic Soils of Samo

According to [14] and [17], the materials used as a base layer must have dry densities greater than 2 and a CBR index ≥ 80 and those used as a foundation layer must have dry densities greater than 1.90 with a CBR index ≥ 30 as signified in **Table 3** for the geotechnical characteristics of the lateritic soil of Samo.

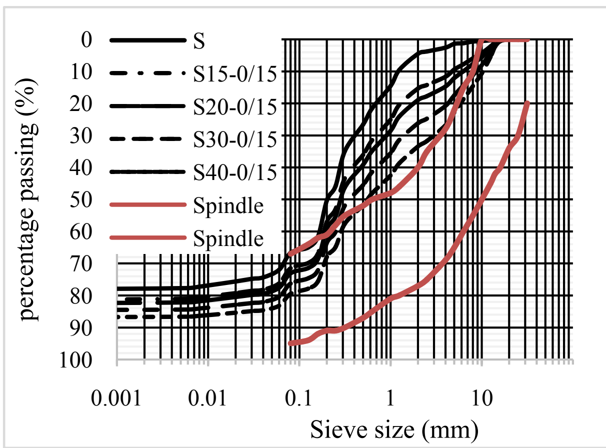
In view of this table, it appears that lateritic soils have a particle size distribution that is not suited to the recommendations of the [15] on the criterion of acceptability of materials. This is linked to the Atterberg limits which are far above the values required by the standard and finally the lift and compaction characteristics are below the values required by the standard. This soil can therefore not be used in the base layer of the road in its natural state. To make it conform to the specifications of the foundation and base layers, this soil was associated with different classes of crushed granite of an almost heterometric nature whose particles have dimensions between 0 and 15 mm to study the influence of the contribution of granites crushed on the geotechnical properties of the lateritic soil several tests were made on the various mixtures. These include particle size analysis, Atterberg limits, compaction and lift tests. And then we analyzed the variation in properties depending on the rate of addition of crushed granites in the lateritic soil. Regarding the particle size analysis, it shows that the lateritic soil of Samo contains a proportion of fine elements less than 35% and a proportion of coarse elements greater than 60%, a uniform and poorly graded particle size [18].

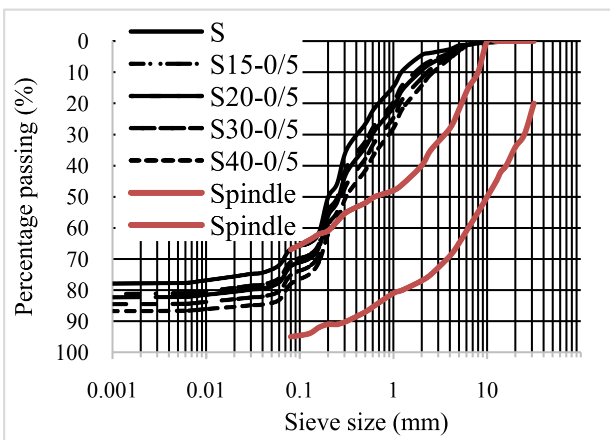
3.2.1. Change in Grain Size

By observing **Figure 4** we can say that the influence of natural aggregates on the geotechnical properties of soils is also manifested by the variation in physical characteristics such as than the grain size which is much more influenced by the contribution of natural aggregates. This variation depends on the soil. The percentage of fines (passing through a 0.08 mm sieve) decreased 13.4%, 13.77% and 14.4% for the lateritic soils of Samo in the 40% crushed mixture. Still in this same mixture of 40%, the percentage of sand varied from 49.42%, 29.72% and 23.592% in the lateritic soil of Samo. The representation of the grain size curves of the lateritic + crushed soil mixtures whose CBR index values are greater than 30 (foundation layer) and 60 (base layer) respectively on the spindles proposed by the dimensioning catalog for coastal pavements. Taking into account the granulometric requirements of [19] for this lateritic soil entering the spindles leads us to conclude that: only the mixtures of laterites with 40% of crushed stone enter the major part into the spindle.

Table 3. Criterion of acceptability of materials in road technology.

Soil type	Particle size analysis			Modified Proctor		CBR index	Atterberg limits		
	<80 µm	<2 mm	<10 mm	WOPM (%)	γopm (t/m^3)	95%	WL	WP	IP
Samo	34	96	100	14.32	1.89	20	46.2	23.2	23
	Base layer condition			$\gamma_d \geq 1.9$		CBR ≥ 30	15 ≤ IP ≤ 25		
	Base layer condition			$\gamma_d \geq 2$		CBR ≥ 80	IP ≤ 15		





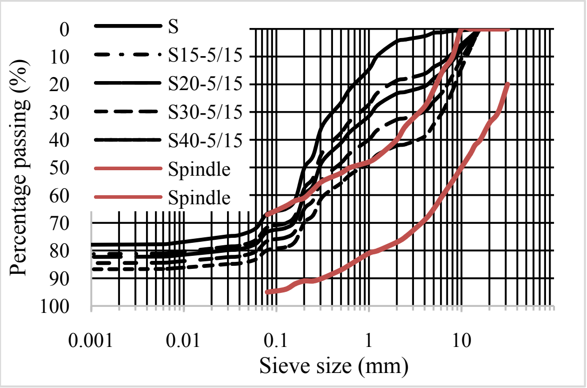


Figure 4. Granulometric curve of the lateritic soil mixtures of Samo + crushed with granite.

3.2.2. Variation of the Atterberg Limit According to the Mixtures

For the case of the Atterberg limits, we noticed that according to the results obtained, the plasticity index (PI) gradually falls from 23.5% and from 19.3% in the natural lateritic soils of Samo to 15.63% in the 40% crushed mixture. Thus, the plasticity index (PI) has dropped considerably in the natural lateritic soil.

3.2.3. Modification of the Proctor Optimum

After the various tests of Proctor, we observe an increase in density of the lateritic soil with each proportion of the mixture (**Figure 5**). For the lateritic soil of Samo, it varies from 1.89 t/m^3 in the natural state to 2.1 t/m^3 on the other hand, the optimum water content Proctor (Wopt) does not follow this order of variation but rather evolves in the opposite direction to the growth of the dry densities, that is to say changes in the decreasing direction of the dry densities.

From the curves, the optimum water content and the corresponding dry density were determined. These values have shown on all the given formulations, the dry density at the Proctor optimum is higher and higher while the optimum water contents are lower and lower as the quantity of aggregate is increased. This can be explained by the fact that lateritic soils are materials whose geotechnical and mechanical performance is particulary dependent on its particle size composition, as well as its microstructural aspect and the arrangement of mineral phases within the microstructure [19]. According to [20] and [15] the materials used as a base layer must have dry densities greater than 2 and those used as a base layer must have dry densities greater than 1.90. Thus, the Samo mixtures with 30% crushed granite of class 0/5 or 0/15 or 5/15.

Become usable for road foundation layers. For this lateritic soil, the minimum proportion of granite crushed material to be added with a view to their use as a foundation and base layer seems to be independent of the initial properties of the lateritic soil.

3.2.4. Load-Bearing Capacity of Laterite-Crushed Granite Mixtures

The measurements of the load-bearing or punching resistance of laterite-crushed granite mixtures are given in **Figure 6**.

With regard to the lift factor, the CBR increased considerably (**Figure 6**). From 20 (at 95% of the OPM) at 68 in the mixture of 40% crushed 0/15. In the context of this study, we retain that the CBR at 95% of the OPM (foundation layer). But it has been noticed that in most mixtures with more than 15% crushed we note a CBR greater than 30. This is due to a good distribution of the particle size during the quartering operation. Samo contains more sand and is less sensitive to water, which is why when we add the granite crushed elements to it, we note after compacting higher and higher dry densities requiring lower water contents.

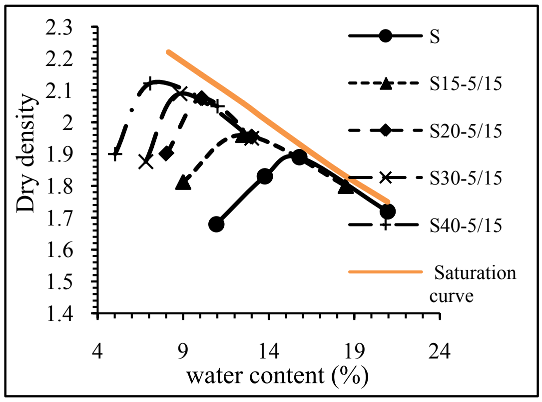
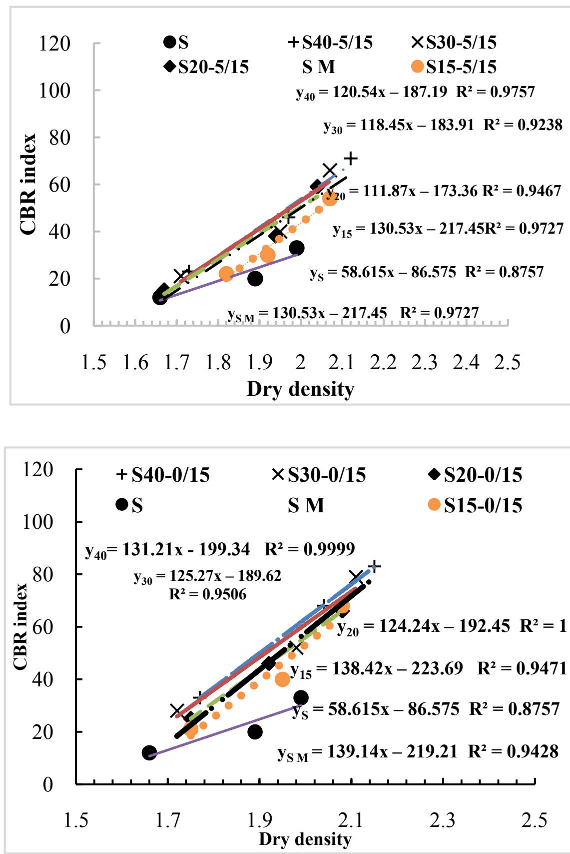


Figure 5. Modified proctor curve of samo soils containing different classes of granite crush.



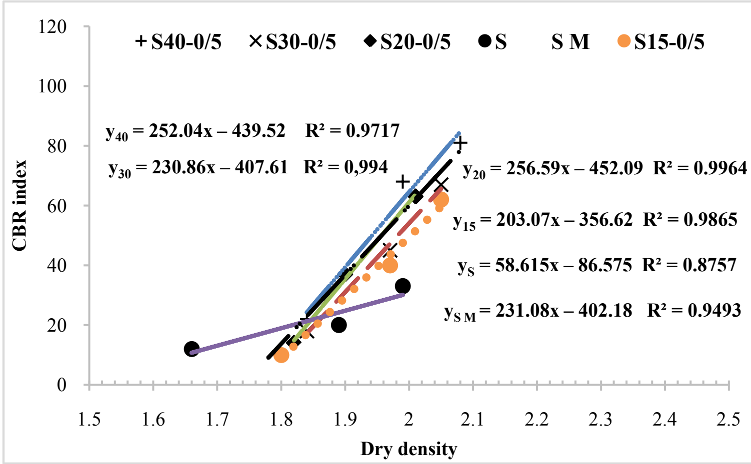


Figure 6. Variation of CBR lift after immersion as a function of the dry density of the mixture of Samo soil and granite crushed.

To reach the optimum from its results it appears that laterites are soils sensitive to water and therefore capable of changing characteristics when different soil states pass in the presence of water. This sensitivity to water is such that for certain mixtures soaked for 4 days, the lift is considerably reduced; the effect being less for laterites compacted at the optimum water content. Indeed, similar results have been obtained by [21]. It highlights the influence of the contribution of crushed granites of class 0/31.5 in natural lateritic gravels of type G3. These results clearly show that the impute of 20%, 25%, 30%, 35% and 40% of granite crushed led these soils to reach the load capacities required by the standard. This increase remains greater than that obtained by Issiakou on the lateritic gravelly of Dosso in Niger with 15% of lateritic nodules of the 0/5 mm class. In fact, with this nodule content, the CBR index of the lateritic gravel has gone from 14% to 43%. It should also be noted that with another laterite loan, this same author for a nodule content of 10%, obtained an increase in the CBR index from only 22% to 32%. On the other hand, the result obtained here is much better than that obtained by [22]. In its studies report that the identification tests (particle size analysis and Atterberg limits) and lift (modified Proctor and CBR) were carried out on several mixtures silty sand and class 0/31.5 (10%, 15%, 20% and 30% crushed). The percentage of fines (passing through a 0.08 mm sieve) has fallen from 26.43% in silty sand to 15.80% in the 20% mixture, thus the plasticity index also drops from 10.45 to 8, 30. An analysis of the change in the dry density of the litho-stabilized silty sand showed that the satisfactory dry density is achieved for an improvement to 20% crushed. The analysis of the variation in the bearing capacity of the stabilized silty sand as a function of the basaltic crushed stone has shown that this is sufficient for a 20% improvement in crushed material for the foundation layer. In addition, other authors such as [23]. Working on litho-stabilization of gravelly laterite with coconut shells obtained, for a shell concentration of 20%, an optimal value of the CBR index, at 95% of the Optimum

Proctor which is 48%. The CBR index therefore fell from 38% for natural soil (without hull) to 48% with soil containing 20% hulls. Then it fell to 11% for soil containing 30% hull. Results obtained by [5] on the correction of laterites in Senegal by incorporation of sand of granular class 0/5. This study shows that the lift increases for some lateritic gravels and decreases for others. He completes by saying that the Grain size curves of the soils, after adding the sand, fall into the grain size ranges according to [14].

4. Conclusion

The analysis of the physical properties of the Samo soils shows that these soils cannot be used in their natural state as materials for the realization of road bed taking into account the classification standards, because the soil sought must be gravelly with little plastic. In order to use them as pavement base layers, their geotechnical properties must be noted by making them efficient. They must therefore be treated. But what treatment and in what proportion for what type of soil? The addition of crushed granite to the laterites modifies the geotechnical properties of the treated soils and makes them suitable for certain road uses. The laterites of southern Ivory Coast studied in this article react to the addition of crushed stone by a modification of their grain size curve, a decrease in their plasticity index, a modification of their Proctor optimum (modified) and an evolution of opposite direction of their CBR index. This development conditions their use as a foundation layer or base layer according to the criteria established by the literature. With regard to the CBR index and the IP, the 40% mixtures meet specifications for the base layers of T1 and T2 traffic while other mixtures are authorized for the base layer of T3 and Traffic.

Conflicts of Interest

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

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