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IMPROVEMENT OF LATERITIC GRAVELLY SOILS IN ROAD CONSTRUCTION: PARTIAL SUBSTITUTION OF CEMENT BY GRANITE POWDER

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Abstract: This study focuses on the lateritic gravels of N'DOUCI whose physical properties do not meet the specifications for their use as a road base. Thus, for its use in road construction, a partial substitution of cement by granite powder has been made. Several tests (particle size analysis, chemical analysis, CBR and proctor tests, Atterberg limits, etc.) were carried out to verify the geotechnical and mechanical characteristics of the new material. This study showed that the addition of granite powder in place of cement improved the material properties, i.e. optimum dry density, CBR. The results show that the optimum dry density is 1.95% with a moisture content of 12%. Overall, the results obtained are satisfactory and show that a quantity of 2% cement for 6% granite powder is required for a base course material in road construction. However, it would be useful to use the proportions of 4% cement to 4% granite powder.

Keywords: lateritic gravel, substitution, granite powder, material.

1. Introduction

In Côte d'Ivoire, road is one of the main levers for socio-economic development and also a factor of regional and sub-regional integration. The Ivorian road network, a tool for the collection and evacuation of commodities from production areas to marketing and export centres, is clearly degraded due to a lack of maintenance (Boad, 2015). In fact, given the stresses of the high overloads of heavy vehicles that our roads are subjected to, its behaviour is significantly deregulated and as a result we are witnessing premature deterioration of our pavements, which until now have behaved normally (Tapsoba, 2012).

Given the impact of the effect of road infrastructure on economic development, it is desirable to have good quality, durable roads. The quality of a road results from the quality of the materials. Materials are designed to meet specific needs, and to do so they must meet a number of requirements. The first of these requirements is the criterion of safety with regard to its short-term use and its durability over time to satisfy all the tasks assigned to it during its state of service (Koné, 2013). One road material that deserves special attention is lateritic gravel. Today these materials, which are mixtures of aggregates and earth, are the most widely used for paving road structures. They are the most commonly used materials for paving road structures. The use of these lateritic gravels in road construction most often requires treatment with Portland cement. Clinker, which is the basic raw material of cement, is used in its manufacture, resulting in the emission of greenhouse gases that pollute the environment. In order to overcome this problem, it is envisaged to use other materials in partial substitution of cement in order to considerably reduce the quantity of cement used in road construction. Hence the objective of this article, which deals with the amendment of gravelly lateritic soils in road construction: partial substitution of cement by granite powder.

2. MATERIALS AND METHODS

2. 1- Raw materials

The raw material used in this study consists of lateritic gravelly soil, Portland cement and granite powder.

2. 1-1- Gravelly lateritic soil

The gravelly lateritic soil was collected in the sub-prefecture of N'Douci, Tiassalé department in the Agnéby-Tiassa region. The coordinates of the borrow area are 5°52'37.2" N / 4°44'9.599" W. It is a region located in the south of Côte d'Ivoire, about 113 km from Abidjan via the northern highway **(Figure 1).**

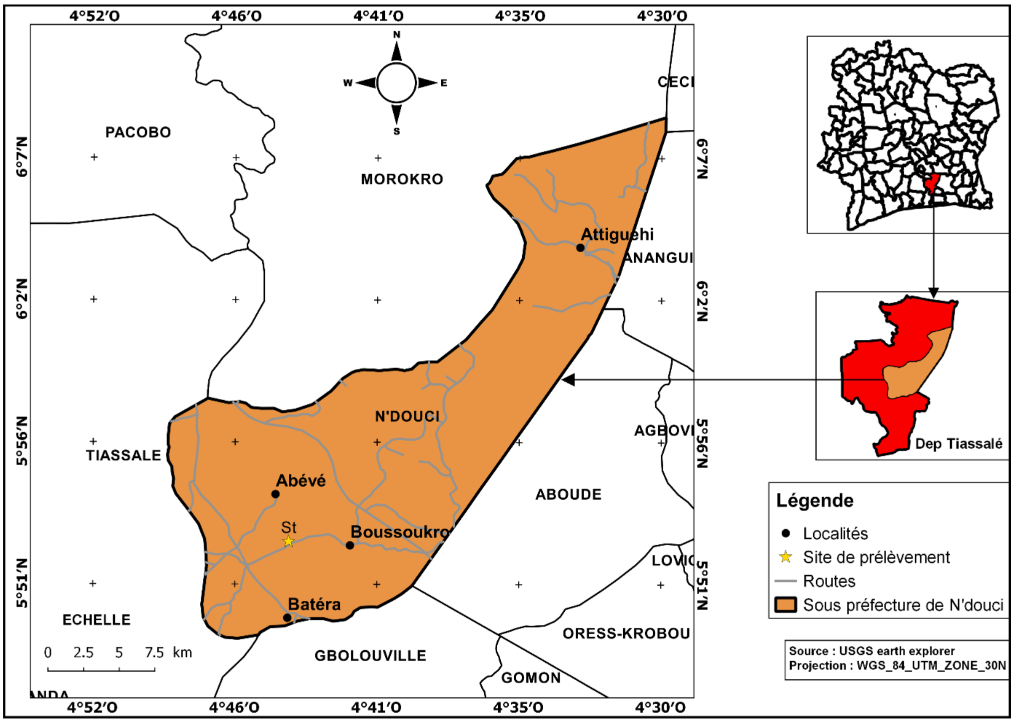

Figure 1: Location of the sampling site

2. 1-2- Granite powder

La poudre de granite est obtenue par broyage et tamisage au tamis de 250 µm de concassé de granite. C'est dans une carrière située sur l'autoroute du Nord, à BAGO, que le concassé de granite a été emprunté.

2. 1-3- Portland cement

The cement powder used is CPJ - CEM II / B - P 42.5 N with a minimum compressive strength RC mini = 42.5 MPa and the brand name "Extra Ciment Bélier". It is produced by the company Lafarge Holcim.

2. 2- Preparation of the specimens

Each soil mixture tested consists of lateritic gravel, cement and/or granite powder. The first mixture consists of lateritic gravel and 8 % by mass of cement. For the other mixtures, cement is progressively substituted by granite powder in the proportions of 2%; 4%; 6% and 8%. These mixtures were first subjected to characterisation tests. They were then used to shape the specimens. This shaping was done in Proctor moulds following the protocol used for the Proctor test. The amount of water added to each mix corresponds to the Proctor optimum. After compaction, the specimens were demoulded and then cured at 26°C, 75% ambient temperature and humidity for 28 days, 60 days and 90 days. Finally, they were also subjected to characterisation tests.

2. 3- Characterisation of materials

2. 3-1- Characterisation of raw materials and mixtures

- Granulometric analysis

The soil (gravelly laterite) was subjected to particle size analysis. This granulometric analysis was first carried out by wet sieving for particles larger than 80 µm according to standard EN 12620. Then, when the percentage of particles smaller than 80 µm is greater than 10%, it is completed by granulometric analysis by sedimentometry. The sedimentometry was carried out according to standard NF. P 94-056. This granulometric analysis makes it possible to determine the percentage of sand (diameter > 80 µm), silt (80 µm < diameter<2 µm), and clay (diameter <2 µm) and then the texture of the soil.

- Atterberg limits

Depending on its water content, a soil can have three states: solid, plastic and liquid. The Atterberg limits make it possible to determine the remarkable water contents located at the border between these different states: liquidity limit, plasticity limit and plasticity index. The determination of these three parameters was carried out according to the NF P 94 057 standard on the fraction of the soil below 400 µm. The Atterberg limits make it possible to assess the plasticity and activity of the soil.

- Methylene blue value

This test is used to evaluate the clay content of a soil. It is carried out in accordance with standard NF P 94-068. The value of methylene blue (VB) expressed in grams of dye per kilogram of the fraction set (class 0/2) is obtained using the following equation

$$\mathrm{VB} = \frac{\mathrm{V}}{\mathrm{M_s}} \tag{1}$$

Avec V, le volume total de solution injectée (ml) et Ms la masse de la prise d'essai (g)

La fraction prises pour cet essai est la classe 0/2.

- Proctor test

The modified Proctor test makes it possible to determine the maximum dry density and the corresponding Proctor optimum for a given compaction energy. It was carried out on the gravelly lateritic soil and on the various mixes produced in accordance with standard NF P 94-093. The results obtained will be compared with the values given by the specifications used in road construction in order to specify which part of the road structure they can be used for.

- Chemical analysis

Chemical analysis provides information on the chemical composition of a material. Chemical analysis was carried out on the lateritic gravelly soil and on the granite powder by X-ray fluorescence using an EDXRF (energy dispersive X-ray fluorescence) spectrometer. The results are expressed as a percentage of oxide.

- CBR test

The CBR test is used to determine the resistance of a soil to punching. It is carried out on gravelly lateritic soil and on the various mixes compacted to the Proctor optimum according to the NFP94-078 standard. The CBR value retained at 95% of the Proctor optimum is the highest value obtained between the 2.5 mm and 5 mm embedment. The CBR value is used in comparison to the specifications to identify the part of the road structure where the material can be used according to the traffic intensity.

2. 3-2- Characterisation of specimens

- Splitting test

The splitting test is used to determine the ability of a material to resist a compressive effect on two diametrically opposed generatrices. The test is usually performed on cylindrical specimens. A compressive force is applied to these specimens until they break. The tensile stress in the plane through these two generatrices is calculated by the formula:

$T=2F/\pi DL$ (2)

With T: the expressed stress (MPa); F: the maximum load (N); D: the diameter of the test piece (cm); L: the length of the test piece (cm).

- Compression test

The compression test is used to determine the compressive strength of the specimens. It is carried out using a hydraulic press on cylindrical specimens. The compressive strength (σ) is given by the formula.

$\sigma= F/S$ (3)

where F is the maximum load (N), S: the cross-sectional area of the specimen (cm^2).

3. RESULTS AND DISCUSSION

This section will analyse the results of the analyses of the raw material used to carry out this work, and then of the specimens made from the different formulations.

3. 1- Properties of the raw material

3. 1-1- Particle size analysis of the lateritic gravelly soil

The results of the particle size analyses carried out on the lateritic gravel samples are presented in Figure 2

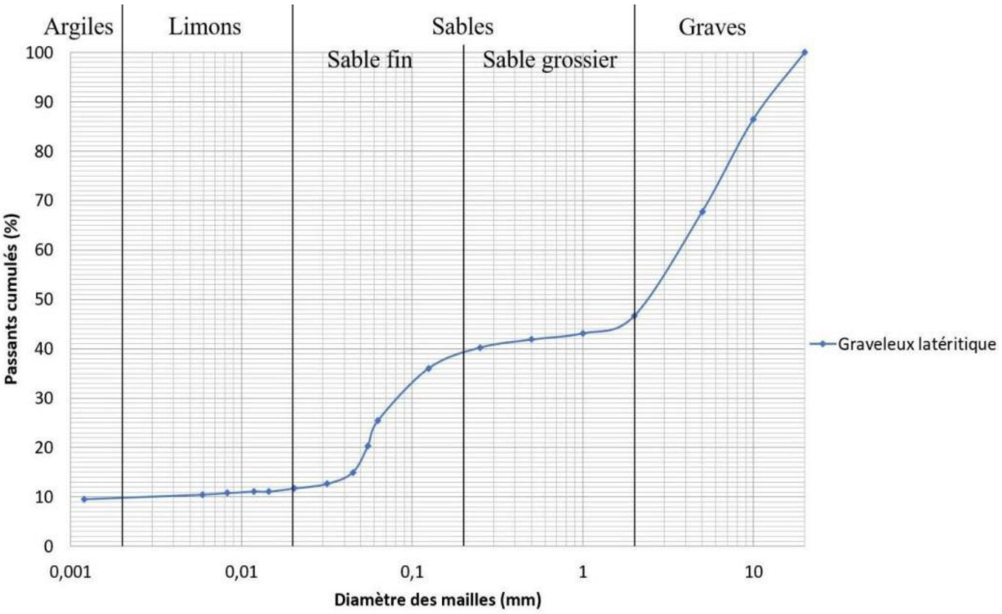

Figure 2: Grain size distribution of lateritic gravel

According to this curve, the lateritic gravelly soil contains clay, silt, sand and gravel fractions according to the sizes defined by Berthaud et al, 2013. This soil has a proportion of particles smaller than 80 µm between 12% and 35%. According to the GTR classification, this is a water-sensitive soil and will therefore have a more or less high retention capacity. In addition, this soil is mainly composed of coarse elements (> 20 µm) at 88%. It will therefore give very dense products because these particles will contribute to the setting of the skeleton of the products, thus to their resistance. Moreover, the grading curve of the lateritic gravel is perfectly in line with the typical spindle of the sub-base layers recommended by CEBTP (1984) (figure 3-a) in the guide for pavement design in tropical Africa.

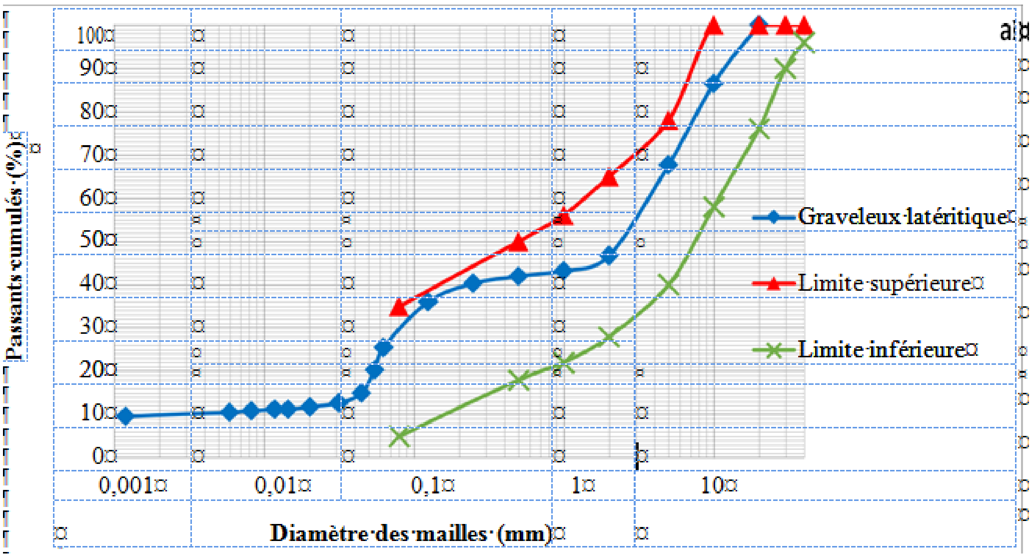

Figure 3: Typical grading range for lateritic soil for use in road construction (CEBTP, 1984)

However, it is not aligned with the same CEBTP-type spindle for the base layers (Figure 3-b), nor with the UNESCO Hand Book spindle (Figure 4).

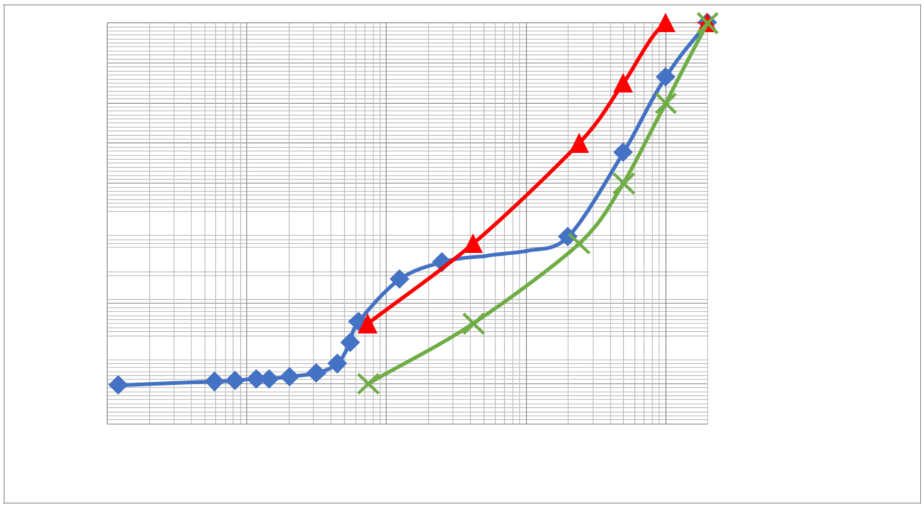

Figure 4: UNESCO Hand Book particle size range

This gravel could therefore be used in pavement layers. However, it is important to note that these lateritic gravels have a smaller diameter Dmax than the lateritic gravels used in road techniques.

3. 1-2 Atterberg limits of lateritic gravels

The results obtained are summarised in Table 1

Table 1: Atterberg limits of lateritic gravel

Atterberg limits	Liquid limits (WL)	Plasticity limits (WP)	Plasticity index (PI)
Values (%)	34.8	19.46	15.34

The projection of the Atterberg limit values in the Casagrande plasticity diagram is given in Figure 5 (Philipponnat, 1997).

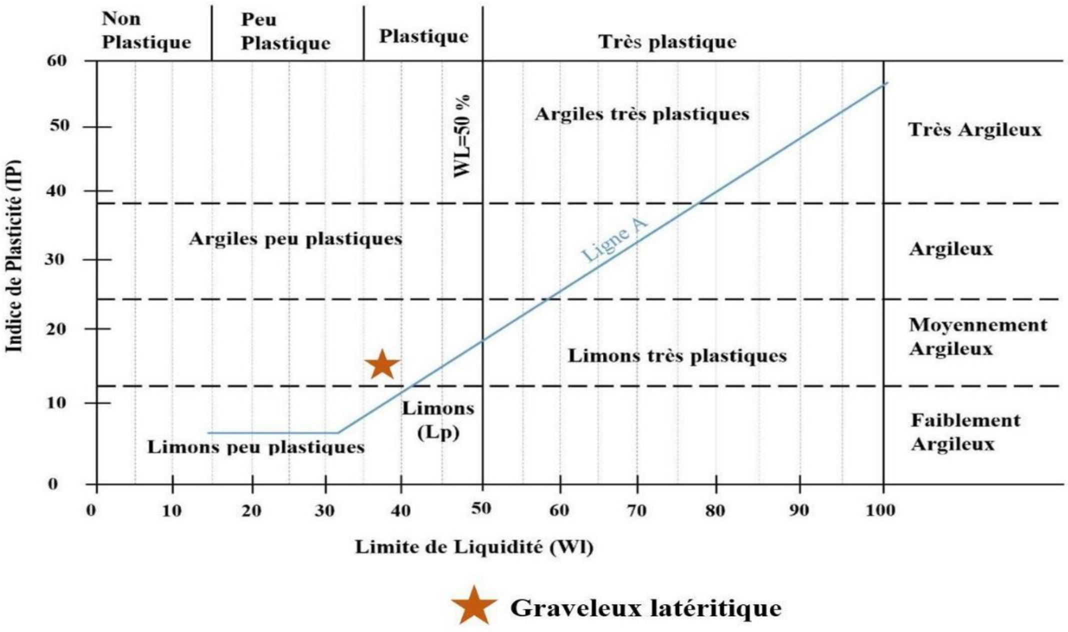

Figure 6: Casagrande plasticity diagram (Philipponnat, 1997)

The analysis of this diagram shows that the lateritic gravelly material studied is located above line A, which means that it is of a clayey nature. Moreover, its plasticity index is between 12% and 25%. The projection of this sample on the different axes of the diagram reveals that it is a moderately clayey and plastic soil. This analysis is consistent with Messou's (1980) analysis that the majority of figurative African grain soils lie above line A of the Casagrande diagram with a liquidity limit <60% as well as Millogo's (2017) work on pavement rehabilitation. However, this soil is more plastic than the soils studied by Millogo (2008). Indeed, the average value of the plasticity indices of the soils studied is 10.5%. This difference in value could be explained by the low clay content of these samples and the high sand content.

3. 1-3 Methylene Blue Value

The methylene blue value VBS is equal to 0.6. In order to determine the clayey nature of the lateritic gravel, the VBS has been introduced in the intervals of the soil classification table according to the Guide des Terrassements Routiers (GTR, 1992).

Table 2: Soil type according to VBS (GTR, 1992)

Methylene blue soil value	Less than 0.2	0.2-1,5	1.5-2.5	2.5-6	6-8	More than 8
Nature of the soil	Water-insensitive soil	Sandy-silt soil	More plastic sandy-clay soil	Medium plasticity silty soil	Clay soil	Sol très argileux

The methylene blue value of this soil is between 0.2 and 1.5. This value corresponds to a sandy loam soil, sensitive to water. This methylene blue value corroborates the results of the plasticity index. The low VBS is therefore due to the absence of swelling clays in the sample (Millogo, 2008).

3. 1-4 Modified Proctor value of lateritic gravels

The results of the Proctor test are shown in Figure 7

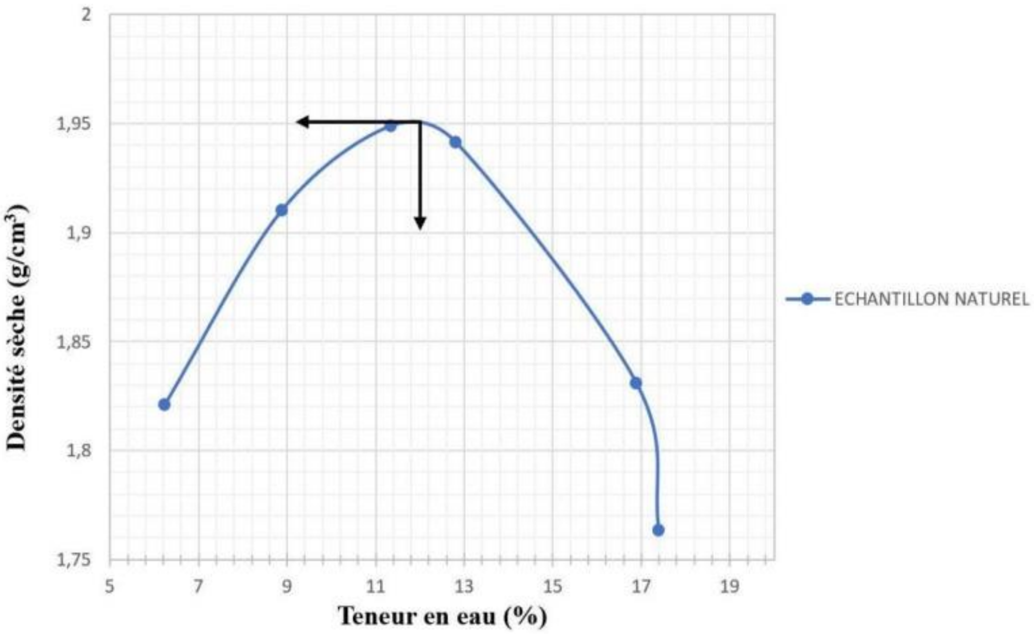

Figure 7: Modified Proctor curve for lateritic gravels

The optimum values for the moisture content and dry density of the lateritic gravel are given in Table 3.

Table 3: Proctor test results

Optimum dry density (%)	Optimal water content (%)
1.95	12

The optimum moisture content is very high. It is 12%. Indeed, in comparison with the classification parameters of lateritic gravels in Ivory Coast, the optimal water content of this soil is the possible limit allowed in road construction (LBTP, 1977). Secondly, the optimum dry density of 1.95% is lower than 2. Previous studies show that such values have been obtained on samples from road construction sites. Thus, Bohi (2008) obtained in his tests, for his samples with the lowest characteristics at the Proctor optimum, values of optimum dry density and optimum moisture content of 1.95% and 13.90% respectively. These values are certainly below the values required for use in road engineering, but for low traffic roads, these samples could be used, provided they have a satisfactory CBR. Hence the analysis of the CBR results.

3. 1-5 CBR value

The results are shown in figure 8

This figure shows an immediate increase in the CBR value with increasing soil density. On the other hand, it decreases when the soil changes from a moist to a wet state. The increase in CBR with density is due to the formation of the soil skeleton which allows the soil to resist punching.

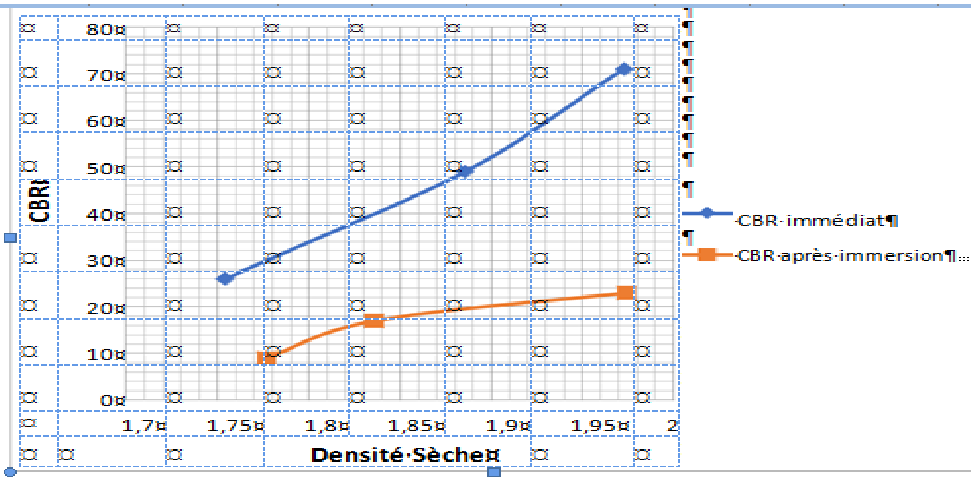

Figure 8: CBR curves for natural gravel versus dry density.

3-1-6 Analyse chimique des graveleux latéritiques

Les résultats de l'analyse chimique sont consignés dans les tableaux 4

3-1-6 Chemical analysis of lateritic gravels

The results of the chemical analysis are given in Tables 4

Table 4: Oxide contents of lateritic gravel

Oxydes	Cr2O3	ZrO2	Fe2O3	VO2	TiO2	CaO	K2O	SO2	BaO	**Ind**	Al2O3	SiO2
Teneur (%)	0.02	5.17	0.02	0.02	0.74	0.15	0.62	0.04	0.01	**35.25**	8.84	48.62

Analysis of the results in Table 4 shows that the lateritic gravel sample is essentially composed of silica (48.62%), alumina (8.84%) and iron (5.17%), corresponding to 75.67%, 13.76% and 8.05% of the oxides identified respectively. This can be explained by the fact that the parent rock that gave rise to the formation of these lateritic gravels is an acid rock.

3.2 Influence of the effect of granite powder in substitution of cement on the material.

3.2-1 Split tensile strength of specimens

The maximum splitting tensile strength values obtained on the specimens are presented in Figure 9.

The tensile strength values increase with the curing time for a given granite powder content and decrease with the proportion of granite powder added for the same curing time. These variations are explained by the hardening of the cement and the possible pozzolanic reaction between the free lime and the granite powder. These values are as low as the results of Messou (1980). The low value of these resistances could be explained by the operating mode and the way the samples were preserved.

Indeed, Messou's (1980) samples were made at a water content equal to the Proctor optimum of his samples plus 2% water. This extra water addition could be the cause of more hydration reaction within the material during the curing time.

The improvement of the sample without cement is explained by the induration reactions that take place in laterites. These reactions are favoured by the iron, aluminium and silica that are present in very large quantities in the lateritic gravel-granite powder-cement mixture. For these resistance values, the lateritic gravels of N'Douci, according to the literature data (Messou, 1980) are suitable, at the limit, for a sub-base layer

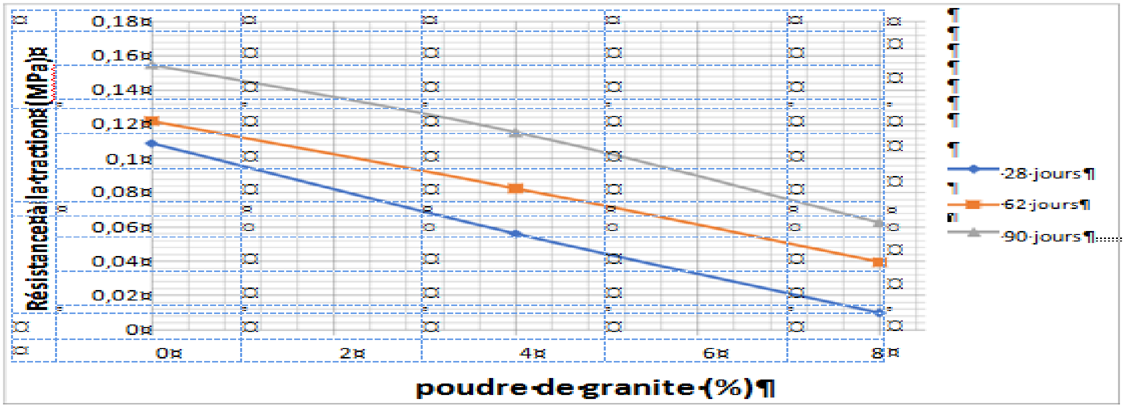

Figure 9: Evolution of the tensile strength as a function of the percentage of granite powder

3. 2-2 Compressive strength of specimens

The maximum compressive strength values achieved on the specimens are presented in Figure 10. This figure shows that the maximum compressive strength values decrease with increasing granite powder content regardless of the curing time. Furthermore, for the same powder content > 2, the compressive strength increases with the curing time. The drop in compressive strength with increasing granite powder content is due to the decrease in cement content. This is because the cement crystallises in the compound to form Calcium Silicate Hydrate (CSH) and provides the strength. As the percentage of cement decreases, the CSH content decreases, resulting in a drop in compressive strength. All specimens almost reached twice their maximum 28-day strengths at 62 days. The observed increase in strength is mainly attributed to the pozzolanic reaction. Baron et al (1995) showed that the pozzolanic reaction is almost constant between 2 and 28 days, but after 28 days the pozzolanic activity increases, leading to an increase in strength and durability. However, at 90 days, a drop in strength is observed for mixes not containing cement with compressive strength values lower than those obtained at 62 days. These results confirm those of Messou (1980).

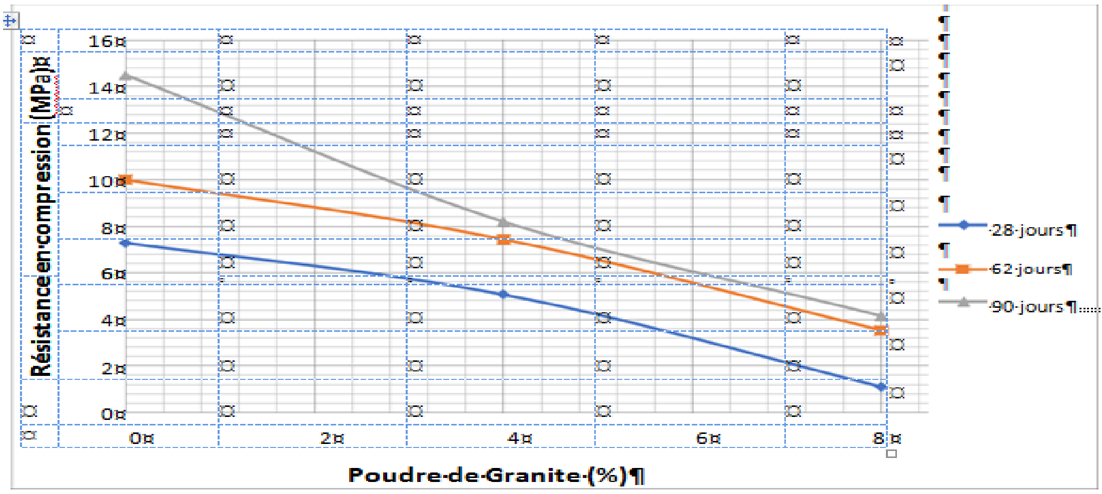

Figure 10: Evolution of the compressive strength as a function of the percentage of granite powder

Conclusion

The N'Douci lateritic gravel, like most lateritic gravels, has physical properties that do not meet the specifications for use as a road base. On its own, it could only be used as a sub-base for pavements that carry low traffic (T1 or T2). The addition of granite powder and cement to the lateritic gravel has improved its properties, namely the optimum dry density and the CBR bearing capacity after immersion for 4 days. These new geotechnical and mechanical properties of the material could facilitate its use in road techniques, in the construction of road base layers. These positive impacts are essentially due to the hydration reaction of the cement. On the other hand, this is related to the reformulation of the mix size with the addition of a reasonable proportion of sand. Most of the composites obtained are suitable for use as a base course in road construction, regardless of the traffic intensity, except for the mixture without the addition of cement, which can only be used as a sub-base course. For economic reasons, a small amount of cement such as 2% combined with 6% granite powder is sufficient to obtain a good base course material in road construction, but would only be suitable for medium T2 and T3 traffic. For heavier traffic the best solution would be to use the formulation incorporating the proportions 4% G - 4% C.

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