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Engineering characteristics of Avlamè lateritic aggregate for it use in road construction in the Republic of Benin

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ABSTRACT: Laterite aggregate is the most widely used material in road construction. In central Benin, laterites aggregates are available in quantity, especially in the Abomey plateau. Thus, the present study is initiated to characterize the laterite aggregate of Avlamè, a locality of the Abomey plateau, for use in road construction. To achieve this, an experimental study based on normative tests was used. The identification tests on the laterite aggregate of Avlamè made it possible to determine the rate of particles with a diameter lower than 80 mm, or 27.77%, the liquidity limit which is 35%, the plasticity index whose value is 17.67%, then the organic matter content equal to 0.03%. Similarly, the mechanical tests carried out resulted in the determination of the CBR index (California Bearing Ratio) evaluated at 58.00% for 95% OPM (modified proctor optimum), then the secant modulus whose value estimated at 360 days is 331.71±0.09 MPa. Determination of the secant modulus of the lateritic gravel makes it possible to evaluate the real deformation. Finally, these studies have shown that its mechanical parameters increase linearly with the maturation time of the specimens analysed. All in all, the analysis of the various results in accordance with the specifications of the CEBTP (Centre of expertise for building and public works) 1984 guide revised in 2019 shows that Avlamè's laterite aggregate can only be used as a sub-base, whatever the type of pavement.

Keywords: *Laterite aggregate, Secant modulus, Avlamè quarry, Physical and mechanical properties, Pavement layers.*

INTRODUCTION

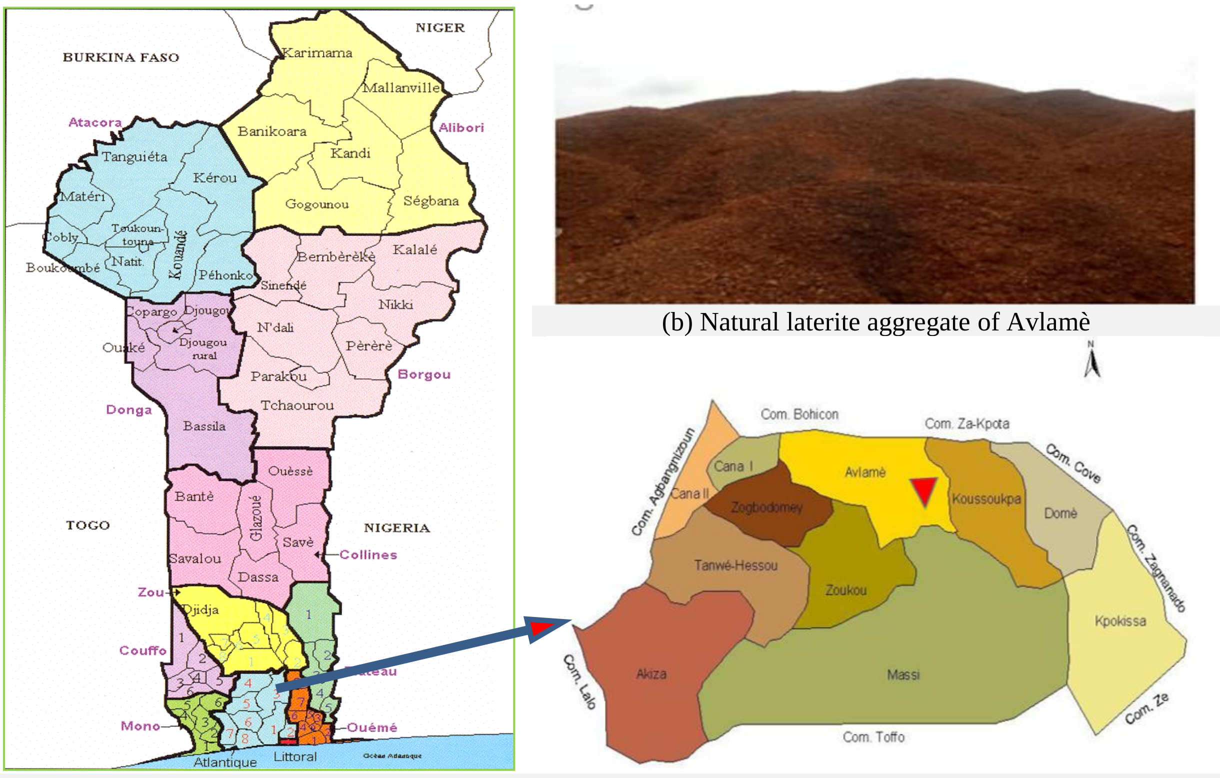
The development of a nation requires the construction of transport infrastructure, such as roads, bridges, ports, airports, and railways to facilitate trade and the movement of goods and people. The structure of these infrastructures requires the use of large quantities of materials (Mengue et al., 2015; Zame et al., 2017; Ndiaye et al., 2018). Laterites aggregates and granites are the most widely used materials in road construction in African countries south of the Sahara (Kanazoe, 2011). Laterites soils are most often located near road alignments (Issiakou et al., 2015; Souley et al., 2017). The abundance of laterites soils and their lower operating costs promote its use despite its variable resistance according to climatic zones (Ykhlef, 2015; ALBTP, 2018). They are materials par excellence, used in the subgrade, subbase, and base courses (Lyon Associates, 1971; CEBTP, 1984; Goual, 2012; CEBTP, 2019; Saing et al., 2020). According to studies conducted by CNERTP in 2017, the commune of Zogbodomey has significant reserves of laterite aggregate that can be used in road construction. Thus, in the context of supplying the new road sites with laterite aggregate, the Avlamè quarry is identified (Kimbonguila et al., 2015; Tchouata et al., 2015; Caro et al., 2019). However, completing geotechnical studies before its use is an asset (Abiola et al., 2018; Ahouet, 2018; Tchouata et al., 2019). In addition, some studies show that some local materials, notably laterites soils, although not meeting the specifications of European or American standards, have proven to be good in use, while some roads built to these same standards have deteriorated prematurely (Weinert, 1980; Nwaiwu et al., 2006; Molenaara, 2013; Cocks et al., 2015; Paige-Green, 2015; Kana, 2016).

Thus, the present study is initiated to characterize the laterite aggregate of Avlamè for use in road construction. To achieve this objective, we will carry out identification and mechanical characterization tests on the Avlamè laterite aggregate according to the specifications of the CEBTP 1984 guide and revised in 2019. Finally, we will measure the influence of the water content on the various mechanical parameters determined to propose some adjustment models.

MATERIAL AND METHODS

2.1. Materials

The laterite aggregate, the subject of this study, was collected in the Arrondissement of Avlamè (Commune of Zogbodomey). The commune of Zogbodomey is located in the southern part of the Abomey plateau, 150 km from Cotonou. It lies between 6°56' and 7°08' north latitude, 1°58' and 2°24' east longitude, and covers an area of 825 km², or 15.74% of the total area of the Zou department. To the north, it is bound by Bohicon and Zakpota communes, to the south by Atlantic and Couffo departments, to the east by Covè, Zgnanado and Ouinhi communes and to the west by Agbangnizoun commune (see Figure 1 below).



(b) Natural laterite aggregate of Avlamè

(a) : Benin map
Source : https://www.google.com/carte Bénin

(c) Zogbodomey map (INSAE, 2017)

Figure 1: Location of the sampling site

2.2. MATERIAL

The equipment used for the work falls into two categories depending on whether it is for geotechnical or mechanical testing.

2.2.1. Geotechnical testing equipment

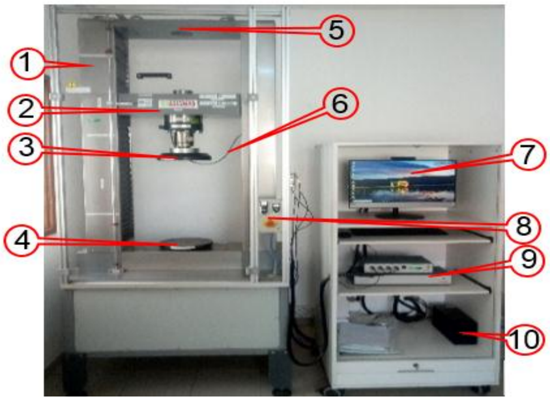
The equipment used in the geotechnical tests complies with the recommendations of the following standards:

- NF P 94-056, 1996. Soils: Investigation and Testing-Granulometric Analysis-Dry Sieving Method after Washing;
- NF P 94-050 , 1995. Soils : Soils: reconnaissance and testing - Determination of weight Content of materials - Steaming method;
- NF P 94-050: 1993, Soils: reconnaissance and Testing-Determination of Atterberg Limits. Limit of liquidity at the cup-Limit of plasticity at the roller;

- NF P 94-051, 1995. Soils: reconnaissance and testing - Determination of Atterberg limits - Cup liquidity limit - Roller plasticity limit;
- XP P 94-047, 1998. Soils: reconnaissance and testing - Determination of the weight content of organic matter in a material - Calcination method.;
- NF P 94-068: 1998. Soils: reconnaissance and testing - Measurement of the methylene blue adsorption capacity of a soil or rock material - Determination of the methylene blue value of a soil or rock material by the spot test.;
- NF P 94-093, 1999. Soils: Recognition and testing. Determination of the compaction references of a material. Normal Proctor test - Modified Proctor test.
- NF P 94-078, 1997. Soils: reconnaissance and testing. CBR index after immersion Immediate CBR index - Immediate index.

2.2.2. Material for the preparation of specimens for mechanical tests

In accordance with standard NF EN 13286-53: 2005, the experimental device for the production of the test specimens is a PROVITEQ automatic electromechanical double screw multi-press machine with a capacity of 300 kN. Its loading speed is adjustable from 10µm/min to 100mm/min. As an illustration, we have the photo below (Figure 2).



Legend:
1-Built; 2-Mobile crossbar; 3-Swivel tray; 4-Bottom tray; 5-Fixed crossbar
6-Strain sensor; 7-Screen; 8-Manual control; 9-Digital encoder; 10-Inverter

Figure 2: Photo of multi-press machine

This press is fitted with a range of equipment to facilitate the production of test specimens. These various pieces of equipment are shown in figure 3.

Legend:
1- Bucket; 2- Balance; 3- Moulding plunger; 4-Wedge peace 101x50mm; 5-Wedge peace 101x33mm; 6-Wedge peace 101x20mm; 7- Moulding100x340mm; 8-Demoulding base; 9- Demoulding plunger; 10-Funnel; 11-Glove

Figure 3: Accessory equipment for the production of test specimens.

2.2.3. Mechanical testing equipment

The various materials used for mechanical tests comply with the recommendations of the following standards:
- NF EN 13286-53:2005. Unbound and hydraulically bound mixtures - Part 53: Methods for the manufacture of test specimens of hydraulically bound mixtures using axial compression (Figure 3);
- EN 13286-42:2003. Unbound and hydraulically bound mixtures - Part 42: Test method for the determination of the indirect tensile strength of hydraulically bound mixtures (Figure 4(a));

- NF EN 13286-40:2004. Unbound and hydraulically bound mixtures - Part 40: Test method for the determination of the direct tensile strength of hydraulically bound mixtures (Figure 4(a));
- EN 13286-41:2003. Unbound and hydraulically bound mixtures - Part 41: Test method for the determination of the compressive strength of hydraulically bound mixtures (Figure 4(b));
- EN 13286-43: 2004. Unbound and hydraulically bound mixtures - Part 43: Test method for the determination of the modulus of elasticity of hydraulically bound mixtures (Figure 4(c)).

(a) : Splitting device (b) : Axial compression device (c): Displacements and deformations measure device

Figure 4 : Experimental device for the determination of mechanical parameters.

2.3. METHODS

2.3. 1. Method of sampling laterite aggregate
Laterite aggregate samples are taken in accordance with the XP P94-202: 1995 standard. Before the various tests were carried out, the samples were air-dried in the laboratory.

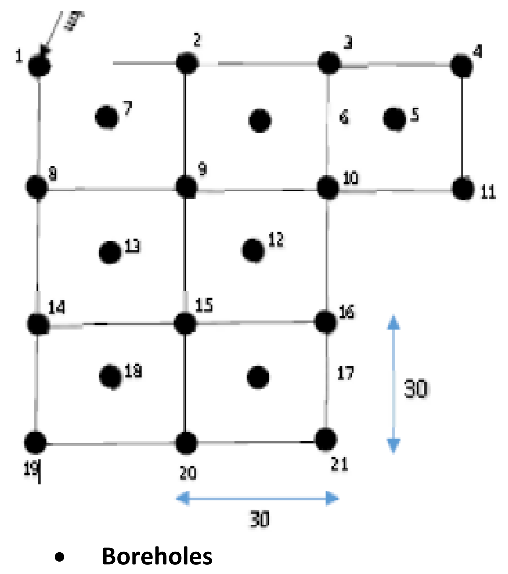
2.3.2. Geotechnical testing method
The various geotechnical testing methods are carried out following the standards cited in § 2.2.1.

2.3.3. Mechanical testing method
The various mechanical tests are carried out following the standards cited in § 2.2.3.

3. RESULTS

3.1. Sample collection
The area is gridded with a 30m x 30m grid. Twenty-one boreholes were drilled for the collection of samples. Table 1 presents the grid of the loan with the different boreholes and their coordinates:

Table 1: The loan grid with the different boreholes and their coordinates.



Boreholes	Coordinates *x*	Coordinates *y*
1	402901.91	786627.75
2	402943.41	786774.52
3	402957.47	786778.98
4	402963.85	786785.56
5	402971.01	786791.89
6	402976.67	786796.87
7	402979.85	786699.88
8	402983.02	786602.53
9	402986.88	786615.76
10	402989.78	786621.05
11	402991.23	786756.19
12	402995.05	786761.89
13	402999.57	786772.45
14	402804.81	786785.05
15	402817.55	786788.71
16	402818.68	786514.02
17	402824.75	786521.21
18	402831.65	786527.09
19	402836.76	786531.26
20	402847.98	786541.25
21	402951.37	786508.42

3.2. Geotechnical testing

 Particle size analysis by sieving

The results of the sieve analysis of the quarry samples yielded the following particle size curves :

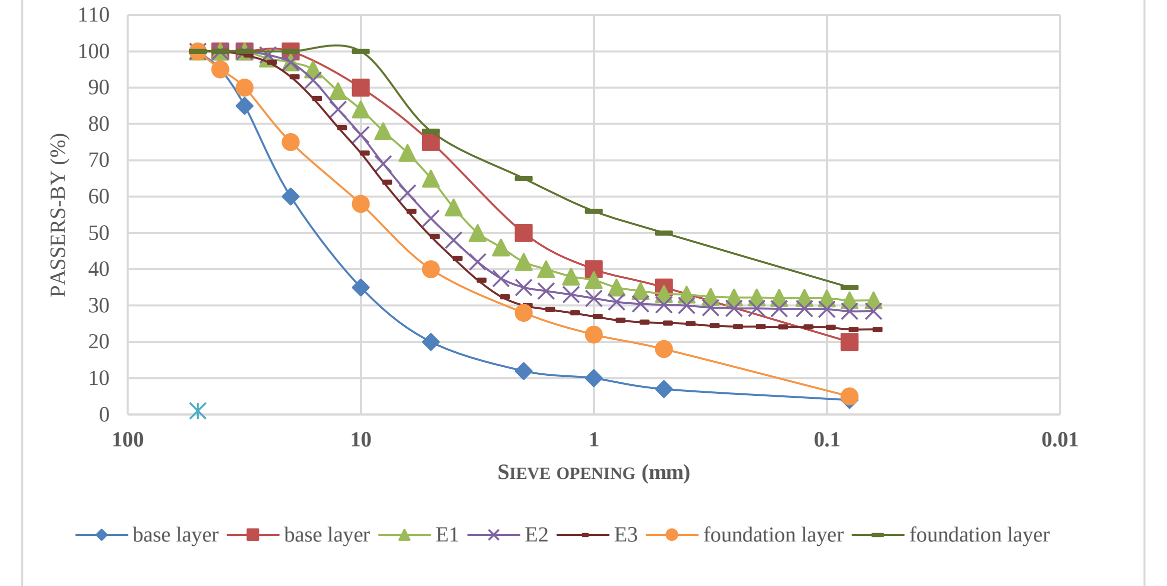


Figure 5 : Particle size curves for laterite aggregate and reference spindles from CEBTP 1984.

We note that the curves of the three samples fit perfectly into the CEBTP spindles for the subbase course. However, they do not fit into the CEBTP grading range for laterite aggregate to be used as a base layer.

 Geotechnical testing

The results of the geotechnical tests are presented in table 2 below:

Table 2: Geotechnical test results

Caractéristiques	Obtained values	Seuils CEBTP1984[a]	
		Foundation layer	Base layer
% passing the 80 mm sieve	27.77	< 35	< 20
Liquidity limit	35	<50	<35
Plasticity Index	17.67	<25	<15
Dry density at 95% OPM	2.16	≥ 1.8-2	≥ 2
Linear swelling index	0.63	<1	<1
CBR Index at 95% OPM	58	≥ 30	≥ 80
Organic matter content	0.03	-	-

[a] *relating to flexible pavements*

From the analysis of the results in table 2, it appears that the laterite aggregate of Avlamè according to the requirements of CEBTP 1984 can be used as a sub-base.

However, it cannot be used as a base course because the rate of passing the 0.080 mm sieve, or 27.77%, is higher than 20%, the plasticity index of 17.67% is higher than 15% and the CBR index at 95% OPM is equal to 58.00%, which is contrary to the requirements of CEBTP 1984.

3.3. Mechanical testing

- Tensile strength (direct and indirect) and compressive strength

Figure 6 shows the histogram of the different results of mechanical tests according to the maturation of the specimens.

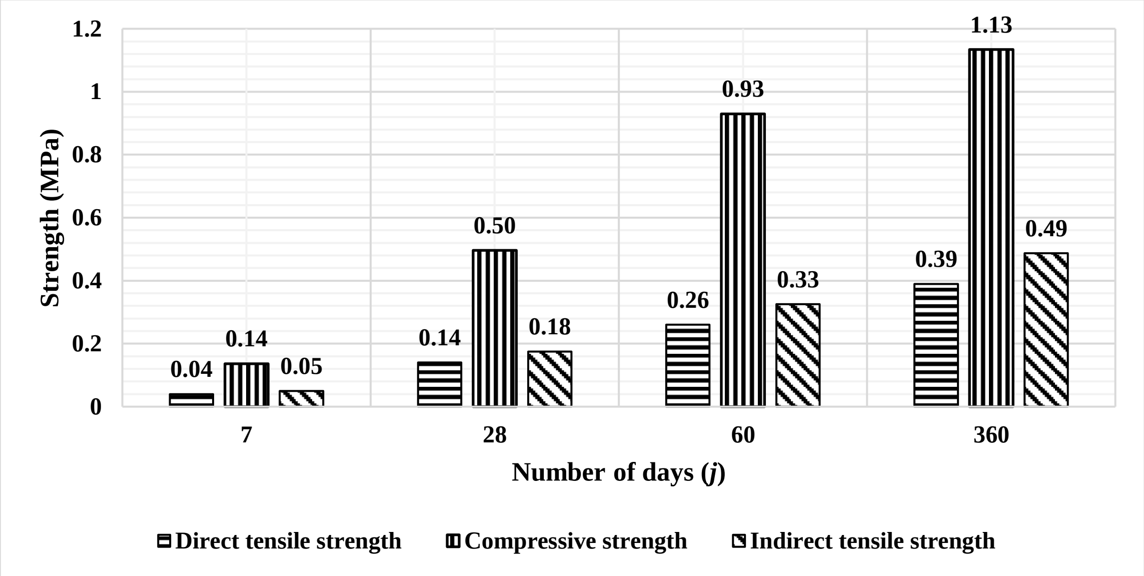
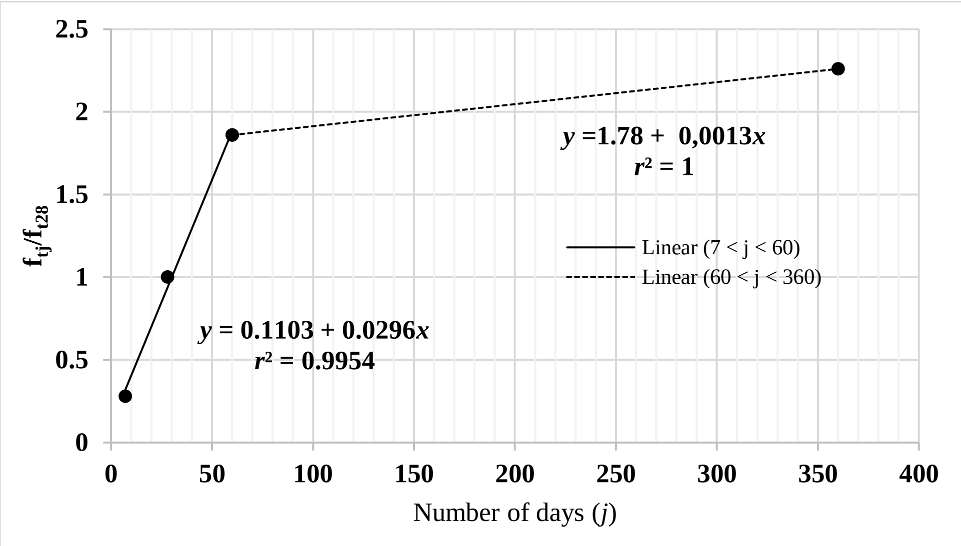
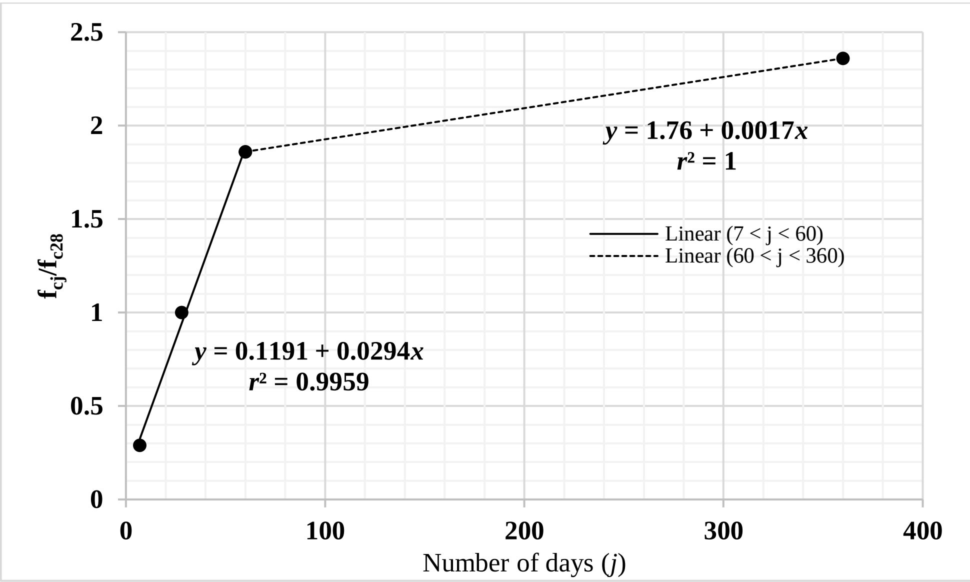


Figure 6: Direct and indirect tensile strength and compressive strength of the laterite aggregate of Avlamè



(a) Direct tensile strength



(b) Compressive strength

Figure 7 : Evolution of the resistance ratio $\frac{f_{tj}}{f_{t28}}$ or $\frac{f_{cj}}{f_{c28}}$ as a function of the number of days

Depending on the maturation, the direct or indirect tensile strength shows a better increase (Figure 6). As an illustration, the indirect tensile strength observed at 28 days, or 0.14 MPa, is 3.5 times that obtained at 7 days. Also, after 60 days and 360 days, it is 6.5 and 9.75 times the 7-day strength, respectively. When analyzing figure 7.a, it is clear that this increase is more marked in the period from 0 to 60 days with a steep slope of 2.96% than that noted from 60 to 360 days with a slope of 0.13%. Similarly, we noted the same evolution for the direct tensile strength.
Considering the 28-day compressive strength of 0.50 MPa, it is found to be 3.57 times the 7-day strength. Similarly, at 60 days and 360 days, the compressive strength is 6.64 and 8.07 times the 7-day strength, respectively. Analysis of Figure 7.b shows a significant increase in the 0-60-day period, with a steep slope of 2.94%, compared with a slope of 0.17% in the next period (60-360 days).

- Evolution of the elastic modulus

Figure 8 shows the histogram of the results of elasticity modulus tests according to the maturation of the specimens.

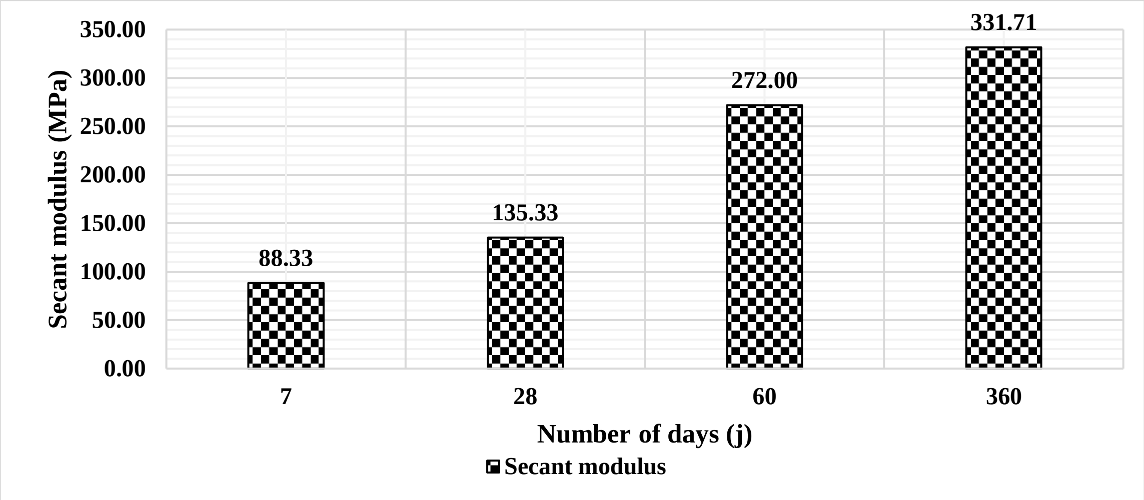


Figure 8: Result of the secant modulus of the laterite aggregate of Avlamè

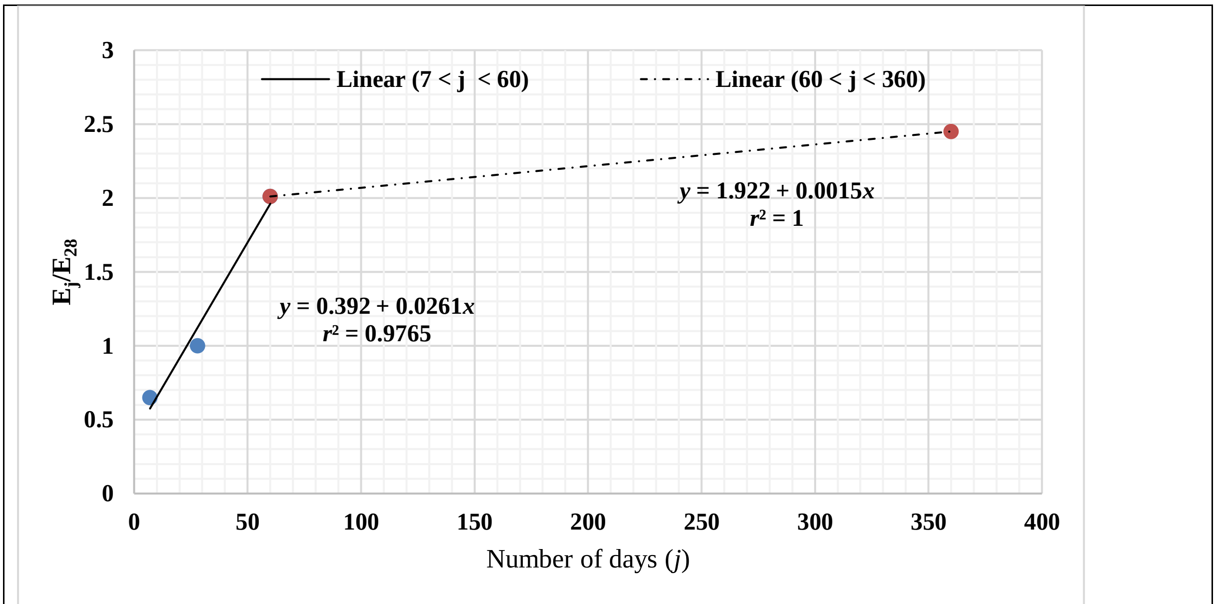


Figure 9: Evolution of the ratio $\frac{E_{Sj}}{E_{s28}}$ according to the number of days

Depending on the maturation, the secant modulus shows a better increase (Figure 8). As an illustration, the secant modulus observed at 28 days, or 135.33 MPa, is 1.53 times that obtained at 7 days. Also, after 60 days and 360 days, it is respectively 3.08 and 3.75 times the secant modulus of 7 days. From the analysis of figure 9, we observe on the one hand that this increase is more marked in the period from 0 to 60 days with a strong slope of 2.61% and, on the other hand, from 60 to 360 days the increase is weak, or a slope of 0.15%.

- Influence of water content on mechanical parameters

Figure 10 shows the variation in the water content of the various mechanical parameters according to the maturation of the specimens.

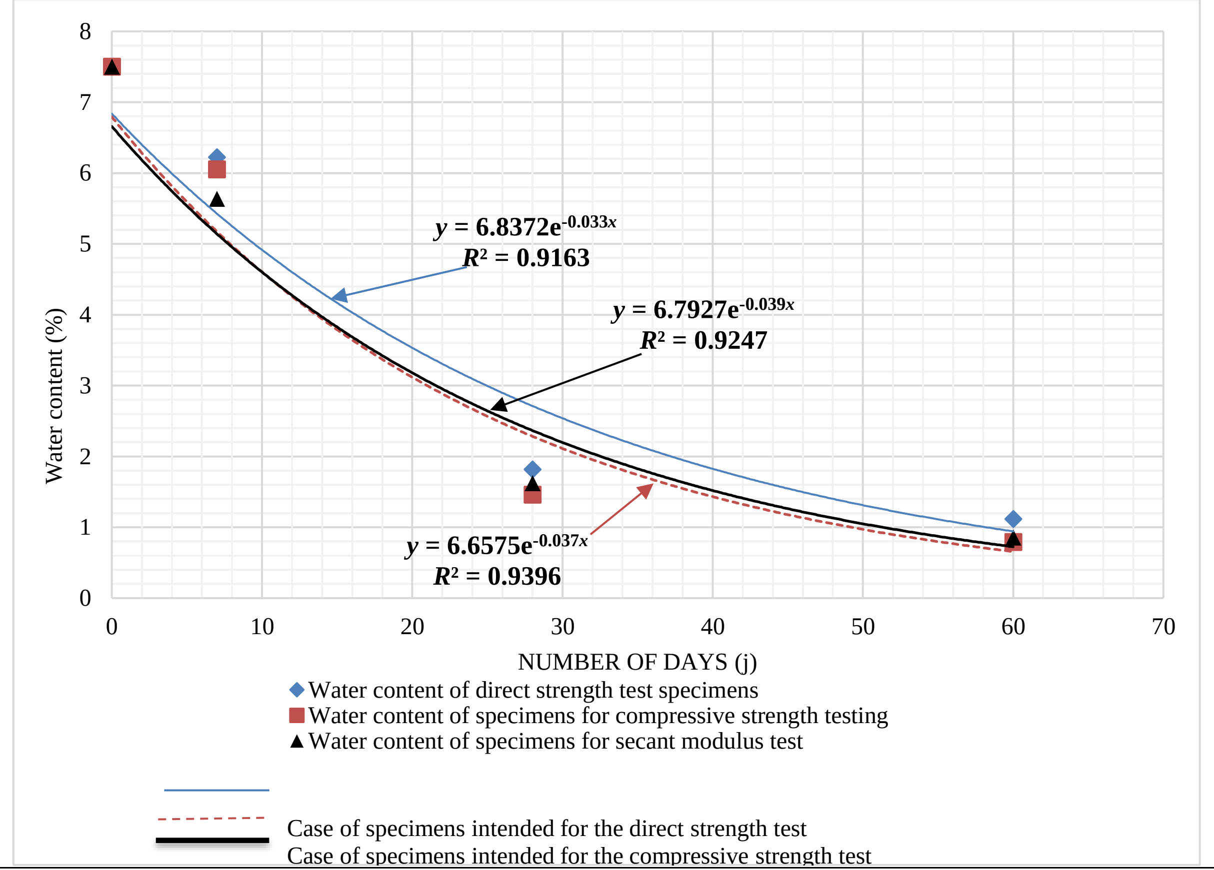


Figure 10: Variation of the water content of test specimens as a function of the number of days

Figure 10 shows a decrease in the water content of the different test specimens as a function of the residence time of the specimens in the self-regulating chamber at 20°C. Unlike the various mechanical parameters, which increase linearly (Figures 7 and 9), the evolution of the water content of the various specimens follows a decreasing exponential law (Figure 10).
The analytical expressions translating the evolution of the water content of the analyzed specimens according to the type of test is presented as follows:

- w(%)=6.6575exp(-0.037j) with a coefficient of determination R^2=93.96% for the secant modulus test specimens;
- w(%)=6.8372exp(-0.033j) with a coefficient of determination R^2=91.63% for the test specimens for determining the direct tensile strength;
- w(%)=6.7927exp(-0.039j) with a coefficient of determination R^2=92.47% for the test specimens for determining the compressive strength.

4. DISCUSSION

The results of the granulometric analysis show that the granulometric curves are within the standard range for both coarse and fine elements. These results are similar to those found by Bohi (2008), Ndiaye et al., (2013), Madjadoumbaye et al. (2013), Issiakou (2016); Ahouet et al., (2018) and Babaliyè O. (2020).

Similar results obtained by Hyoumbi et al. (2018) and Ogbuagu et al. (2019) on laterite aggregate, allowed them to recommend them as fill material and not in the construction of the pavement body. Similarly, laterites soils from Côte d'Ivoire studied by Bohi (2010) and Niangoran et al. (2020), Madagascar studied by Ratsifarehandahy et al. (2020), Cameroon studied by Kamtchueng et al. (2015), Mvindi et al. (2017), Biaou et al. (2018), Keyangue et al. (2019) and Deodonne et al. (2021), from the Democratic Republic of Congo studied by Ahouet et al. (2018), from Niger studied by Issiakou (2016), from Senegal by Ndiaye (2013) which presented similar mechanical characteristics to the laterite aggregate of Avlamè will be improved before their probable use in road construction.

On the other hand, the laterite aggregate studied by Nzabakurikiza et al. (2016), Onana et al. (2017) and Babaiye (2020), whose characteristics are clearly better than those of Avlamè in accordance with the CEBTP 2019 guide, are recommended for use in sub-base and base courses.

Previous geotechnical studies by Jacques L. (2006) show that a laterite aggregate is inorganic if organic matter is less than 3%. Thus, from the analysis of the results of the organic matter content of the laterite aggregate of Avlamè, or 0.03%, it appears that it is inorganic. The results of previous studies conducted by Babaliyè et al., (2020), it appears that the gravels of Djakotomey and Djidja, which can be used in road construction, have respectively a CBR index measured at 95% OPM equal to 34.33% and 82%. Therefore, the laterites aggregates of Avlamè with a CBR index at 95% OPM equal to 58% can be used in road construction. Similarly, several works carried out in the sub-region show that laterites aggregates with CBR indices at 95% OPM varying from 11 to 36% (Bohi, 2008), from 14 to 21% (Issiakou, 2016), are employable with or without improvement in road construction. It should also be noted that the various results of the work of Ndiaye (2013) reported by Ndiaye et al. (2018) show that laterites aggregates from Senegal with a CBR index at 95% OPM varying from 18% to 84% can be used in road construction.

In our study, the direct and indirect tensile strength values obtained at 28 days (Figure 6) are similar to those found by Onana et al. (2017) and Hyoumbi et al. (2018). For this study, the compressive strength values obtained at 28 days (Figure 3) are lower than those obtained on laterites soils by Nzabakurikiza et al. (2016), Onana et al. (2017), Hyoumbi et al. (2018) and Ratsifarehandahy et al. (2020). In this study, the secant modulus obtained (see Figure 5) is similar to that found by Mengue et al. (2015) and Ratsifarehandahy et al. (2020). The analysis of the influence of water content on the mechanical parameters gives results that confirm those obtained by Laou et al. (2017) in their work on the evaluation of the mechanical properties of mud bricks at different moisture contents. According to the work of Ykhlef (2012), the evolution of the water content becomes increasingly low after 28 days. He adds that the variation in the strength of the natural soil also remains low after 28 days. This explains the slow evolution of the mechanical strength between 28 and 180 days. Similarly, studies conducted by Guerif (1988) show that tensile strength decreases with an increasing water content. According to Dawson et al. (1996), a decrease in water content tends to increase the stiffness due to the suction phenomenon. As for the work of Xuan Nam HO (2013), it follows that the presence of water in the granular material has a significant influence on its strength and behaviour. it follows that the presence of water in the material has a significant influence on the strength and behaviour of granular materials. Bilodeau and Doré (2012) showed that the resilient modulus in the dry state is greater than that in the saturated state. Similarly, Hicks and Monismith (1971) showed that the resilient modulus decreases with an increasing water content above the optimum.

5. CONCLUSION

In order to valorise locally available materials in road construction, characterisation studies of the laterite aggregate of Avlamè have been initiated. They led to the carrying out of geotechnical tests such as granulometric analysis, Atterberg limits, Modified Proctor and CBR on the one hand, and on the other hand, mechanical tests, i.e. tests to determine direct and indirect tensile strength and compressive strength and tests to determine the secant modulus. The various test results compare with the technical specifications contained in the practical guide to pavement design for tropical countries published by CEBTP in 1984, revised 2019.

This work has shown that the laterite aggregate of Avlamè can only be used as a sub-base in accordance with the requirements of CEBTP (1984). These studies also show that the mechanical parameters of this material increase linearly with the maturation time of the specimens. During the same period, it has been noted that the water content of the aforementioned is falling exponentially. Similarly, the present work made it possible to determine the pavement design parameters according to the curing period, or 7 days, 28 days, 60 days and 360 days. The different values obtained on these dates are as follows:

- secant modulus: 88.33±3.00 MPa, 135.33±2.00 MPa, 272.00±4.51 MPa and 331.71±0.09 MPa ;
- indirect tensile strength: 0.05±0.01 MPa, 0.18±0.00 MPa, 0.33±0.01 MPa and 0.49±0.01 MPa;
- indirect tensile strength: 0.04±0.01 MPa, 0.14±0.00 MPa, 0.26±0.01 MPa and 0.39±0.01 MPa;
- compressive strength: 0.14±0.03 MPa, 0.50±0.05 MPa, 0.93±0.07 MPa and 1.13±0.09 MPa.

Studies have shown that different strengths, i.e. compressive strength, direct or indirect tensile strength and secant modulus, increase linearly with the maturation time as a consequence of the water content of the different specimens falling exponentially with the same dates.

In order to use Avlamè's laterite aggregate in all layers of the pavement structure, it is important to improve its characteristics by litho stabilization or cement improvement techniques.

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7. ETHICAL CLEARANCE NUMBER

No available.

8. COMPETING INTERESTS

No potential conflict of interest was reported by the authors.

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10. AUTHORS CONTRIBUTIONS

All the authors contributed equally to this work.

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