Original Research Article

Technical parameters of the Cana-Atchia lateritic aggregate for its use in road engineering in Southern Benin

ABSTRACT

Aims: To determine the technical parameters sought in road engineering of the lateritic aggregate of Atchia village in the Arrondissement of Cana, Commune of Zogbodomey.
Study design: To valorize the lateritic aggregate of Cana-Atchia in the construction of roads in Benin.
Place and Duration of Study: Colas Benin Entreprise Laboratory and Laboratory of Energetic and Applied Mechanic, Polytechnic School of Abomey-Calavi, University of Abomey-Calavi, Abomey-Calavi, between January 2021 and March 2022.
Methodology: Thus, with the help of classical road material characterization tests, the values of technical road engineering parameters are determined on prepared specimens
Results: The different results obtained are the percentage of passings at the 80 µm sieve (13%), the liquidity limit (32.67%), the plasticity index (13.67%), the dry density obtained at the Proctor optimum (2.28t/m^3), the CBR index (106%) and the swelling index (0.04%). In the Proctor test, the water content at the OPM is evaluated at 8.20%. Similarly, studies have shown that the lateritic gravel of Cana-Atchia has a natural water content of 3.5% and an organic matter content of 0.75%.
Conclusion: From this study, it appears that the lateritic aggregate of Cana-Atchia has very good technical parameters sought in road engineering, with regard to the technical specifications of the CEBTP guides of 1984 and 2019.

Keywords: Lateritic aggregate-technical parameters-road engineering-pavement base layers.

1. INTRODUCTION

According to Buchanan [1] reported by Gansonré et al. [2], lateritic materials are, by definition, materials resulting from the physicochemical alteration of the source rock in tropical climates. These materials are ideally used in form layer, foundation layer or base layer of pavements. However, some pavements built with lateritic aggregate show disorders very early on. These disorders tend to worsen over time, sometimes making the road impassable before the project horizon. Among these, we can cite the deformations (ruts, subsidence), the cracks of which the cracks and tears (peeling, potholes) [3]. The main causes of these disorders can be traffic, climatic conditions, quality of materials or implementation [4-5-6].

Indeed, some studies show that certain local materials, notably lateritic soils, although not meeting the specifications of European or American standards, have proven to be good in use, whereas some roads built in compliance with these same standards have deteriorated prematurely [7-8-9]. In this case, it seems difficult to imagine a universal standard for the use of these materials, but each country should establish its own standard [10]. The definition of a standard for a rational use of lateritic aggregate in road construction necessarily requires the control of its characteristics.

In order to define how to use lateritic gravel in road construction in Benin, the lateritic gravel quarry of Atchia, Cana district in the commune of Zogbodomey is targeted. Thus, the present study is initiated to determine the technical parameters of the lateritic gravel of Cana-Atchia for its use in road engineering in Southern Benin. Specifically, from an experimental program, it will be necessary to determine the values of these technical parameters sought in road engineering, i.e. the percentage of passings in the 80 µm sieve, the liquidity limit, the plasticity index, the dry density obtained at the Proctor optimum, the CBR index and the swelling index in accordance with the recommendations of the CEBTP guide [11-12].

2. MATERIAL AND METHODS

2.1. Materials

The lateritic gravel, the subject of this study, was collected in the village of Atchia in the Arrondissement of Cana (Commune of Zogbodomey). This site is located at 07°05'28.56'' latitude and 02°04'27.33'' longitude. Figure 1 below presents information on the location of the Cana-Atchia quarry.

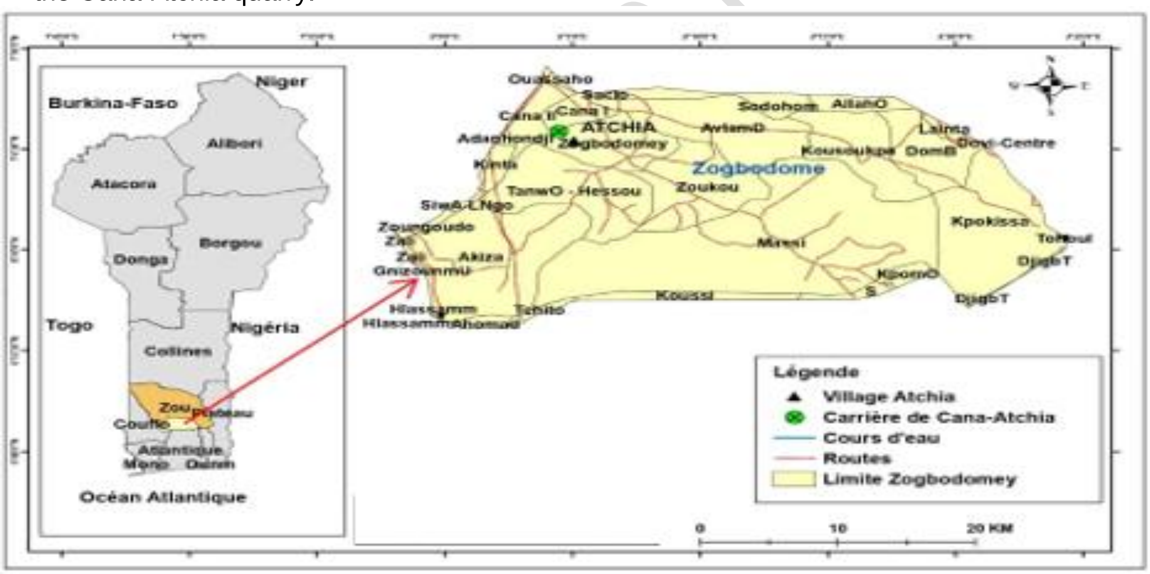


Figure 1: Location of the sampling site
Source : https://images.app.goo.gl/bpZvjxmiBd

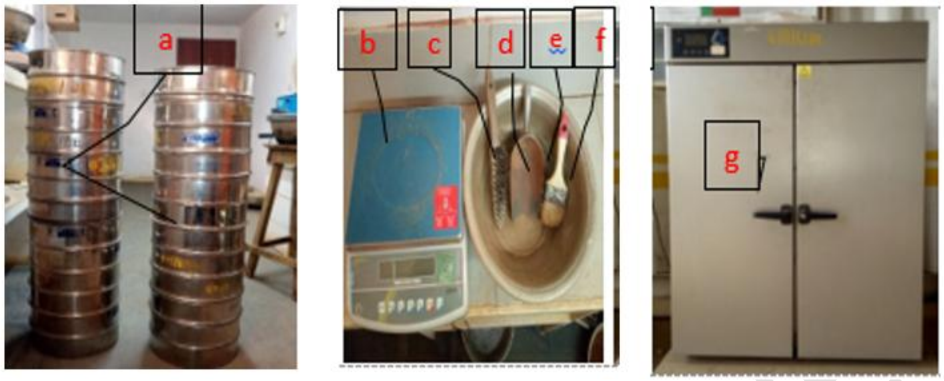
2.2. Equipment

The equipment used in this study consists of identification test equipment, on the one hand, and mechanical test equipment on the other.

2.2.1. Material identification test equipment

The identification test material consists of:

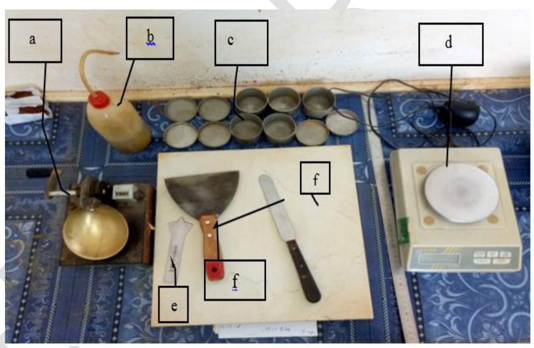
- A set of necessary equipment for particle size distribution test according to NF P 94-056 [13]. Figure 2 shows some of the important equipment in this trial.



Caption:
a : Series of sieves; b : Scale 30kg±0,2g; c : Brush; d : Scoop hand; e : Brush; f : Container
g : Oven with adjustable temperature 50°C to 105°C ± 2°C

Figure 2: Equipment for particle size distribution test

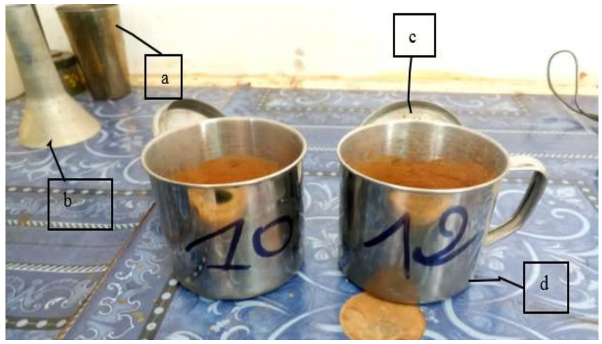
- A batch of necessary equipment for the Atterberg limit according to NF P 94-051 [14]. (see figure 3 below).



Caption
a : Casagrande's apparatus; b : Water cooler; c : Capsules and petri dishes; d : Scale of 600g±0,1g; e : Grooving tool; f : Spatulas
g : Marble base

Figure 3: Material for Atterberg limit test

- A set of necessary equipment for the test of organic matter content according to XP P 94-047 [15]. Figure 4 shows some of the important equipment in this trial.



Caption:
a : Mortar; b : Pestle; c : Lid; d : Crucibles
Figure 4: Equipment for organic matter content test

- Equipment required to perform the methylene blue value test according to the XP P 94-068 [16]. Some of equipment is shown in Figure 5 below.

Caption:
a : Winged stirrer; b : Stand; c : Yellow glass bottle; d :Dried Kaolinite; e : Volumetric flask; f : Beaker; g : Burette; h : Methylene blue; i : White filter paper; j : Balance of 1000g±0,1 g
Figure 5: Material for methylene blue value test

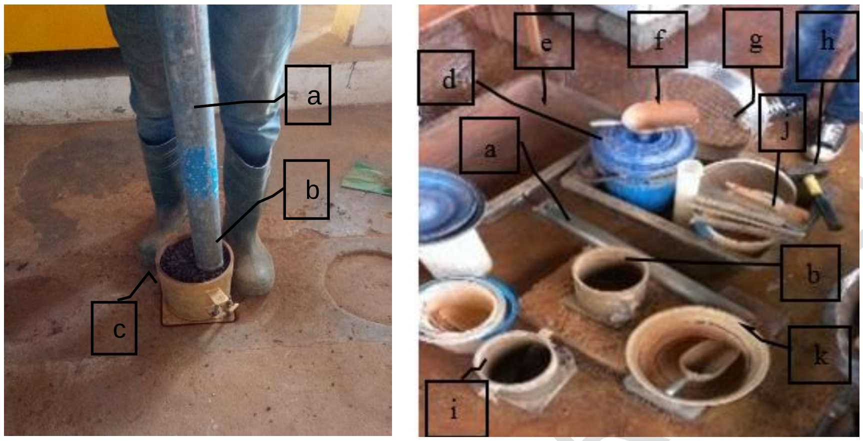
- Several necessary equipment for weight water content test according to NF P94-050 [17]. Some of the materials from this trial are shown in the following Figure 6:

Caption:
a : Material bin; b : Gas burner; c : Ladle; d : Scale of 24kg±0,2g
Figure 6: Equipment for water content measuring test

2.2.2. Mechanical test equipment

The mechanical testing equipment consists of:

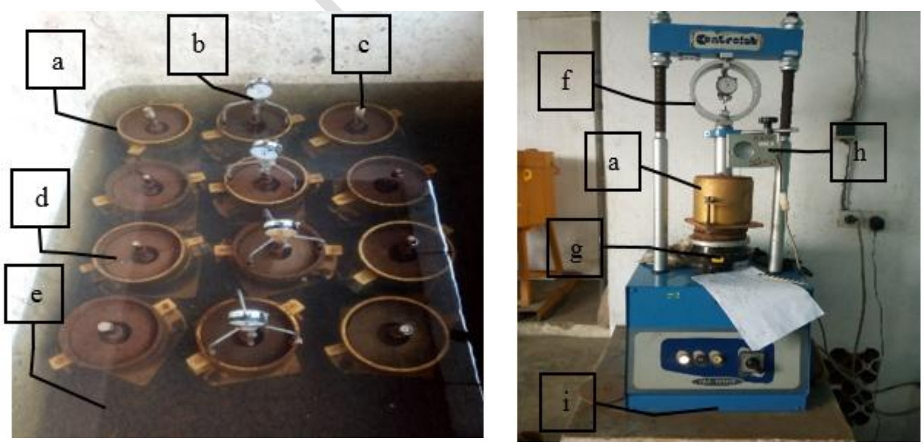
- A set of necessary devices for the Modified Proctor test according to NF P94-093 [18]. Some of the materials from this trial are shown in the following figure 7:



Caption:
a: Metal rammer; b: Metal mould; c: Base plate; d: Material tray
e: Tray; : Scoop hand; g: Sieve; h: Hammer; i: Metal mould; j: Accessories ; k: Container

Figure 7: Material for the determination of compaction references

- A set of necessary devices for the CBR test according to NF P94-078 [19]. Some of the materials of this test are shown in Figure 8:



Caption:
a : CBR mould; b : Comparator; c : Overload series; d : Perforated metal disc; e : Immersion tank; f : Cadencenter; h : Comparator; g : Raises ; i : CBR press

Figure 8: Material for CBR test setup

2.3. Methods

2.3.1. Method of sampling lateritic aggregate

The samples are taken in accordance with XP P94-202 [20].

2.3.2. Geotechnical test method

The various geotechnical tests are performed in accordance with the standards cited in Section 2.2.

3. RESULTS AND DISCUSSION

3.1. Particle size analysis by sieving

The sieve size analysis performed on the borrow samples yielded the following particle size distribution curves (see Figure 9) :

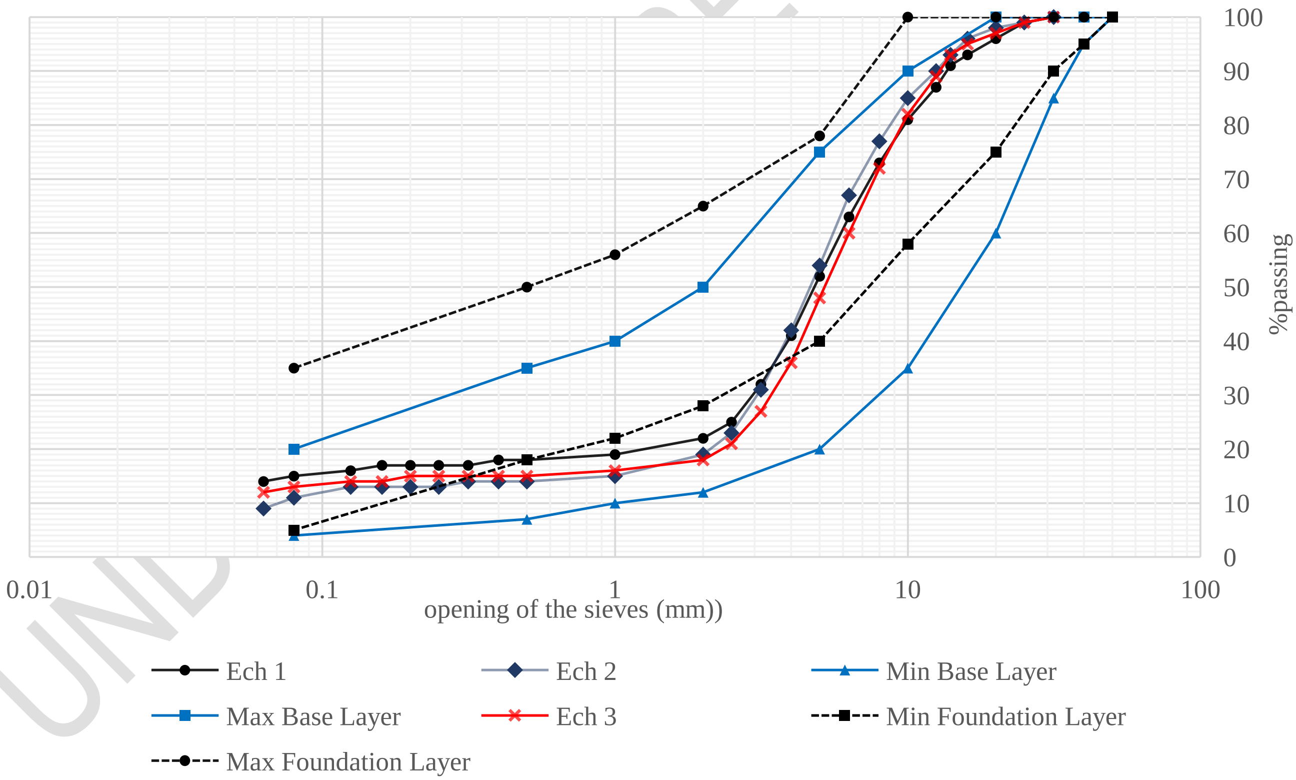


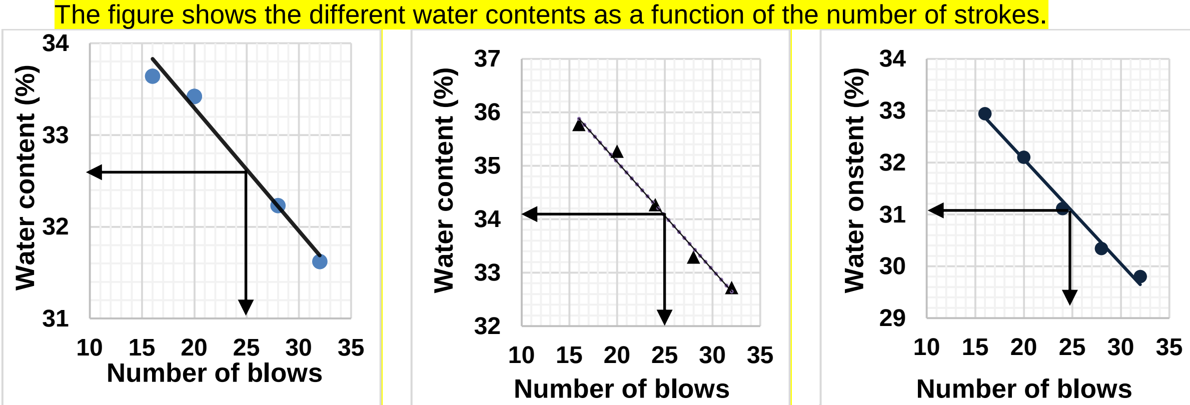
Figure 9 : Particle size distribution curves of lateritic aggregate and reference spindles of the CEBTP guide [11-12].

The results of the particle size analysis show that the particle size distribution curves of the three samples submitted fall within the reference particle size range of CEBTP guide [11-12] for materials intended for the base course. On the other hand, they are not entirely contained in the reference particle size range of the subgrade materials because the curves of the grains with diameters from 0.5 to 2 mm are outside the range.

3.2. Atterberg Limits

The tests carried out on the samples allowed us to have on the one hand the Liquid limits (Figure 10) and the limits of plasticity on the other hand (Table 1):

The figure shows the different water contents as a function of the number of strokes.



Sample 1 Sample 2 Sample 3

Figure 10: Determination of the Liquid limit

Table 1: Results of Atterberg Limits tests on lateritic aggregate

Lateritic aggregate	**Atterberg's limits**			
	Liquid limit W_L (%)	**Plastic limit W_P (%)**	**Plasticity Index IP (%)**	**Consistency Index**
Sample 1	33	19	14	2.11
Sample 2	34	20	14	2.18
Sample 3	31	18	13	2.12
Mean	32.67	19	13.67	2.14
Standard deviation	1.53	1	0.58	0.04

The liquidity limit for all three samples is below 35. It is thus retained that for the lateritic gravel, that its WL is lower than 35 and moreover, its IP is lower than 15 in all the cases: the lateritic gravel respects the requirements of the limits of Atterberg for its use in base course and in sub-base.

3.3. Organic matter content

The results of the determination of the organic matter content of the samples are shown in Table 2 below:

Table 2: Organic matter content of lateritic aggregate

Lateritic aggregate	**Organic matter content**		
	Sample 1	***Sample 2***	***Sample 3***
MO (%)	0.74	0.78	0.76
Mean		0.76	
Standard deviation		0.02	

According to the standard XP P 94-011 [21], the lateritic aggregate of Cana-Atchia can be qualified as non organic because the mean value of its organic matter content is 0,76% lower than 3%.

3.4. Methylene blue value

Table 3 shows the results of the methylene blue test.

Table 3: Methylene blue valueof lateritic aggregate

Lateritic aggregate	Methylene blue value		
	Sample 1	***Sample 2***	***Sample 3***
VBS	0.33	0.36	0.31
Mean		0.33	
Standard deviation		0.03	

The methylene blue values of the three samples are between 0.2 and 1.5. Indeed, according to the NF P94-051[14], the lateritic aggregate of Cana-Atchia is of sandy-silty type.

3.5. Weight water content

The weight water content results are summarized in Table 4 below.

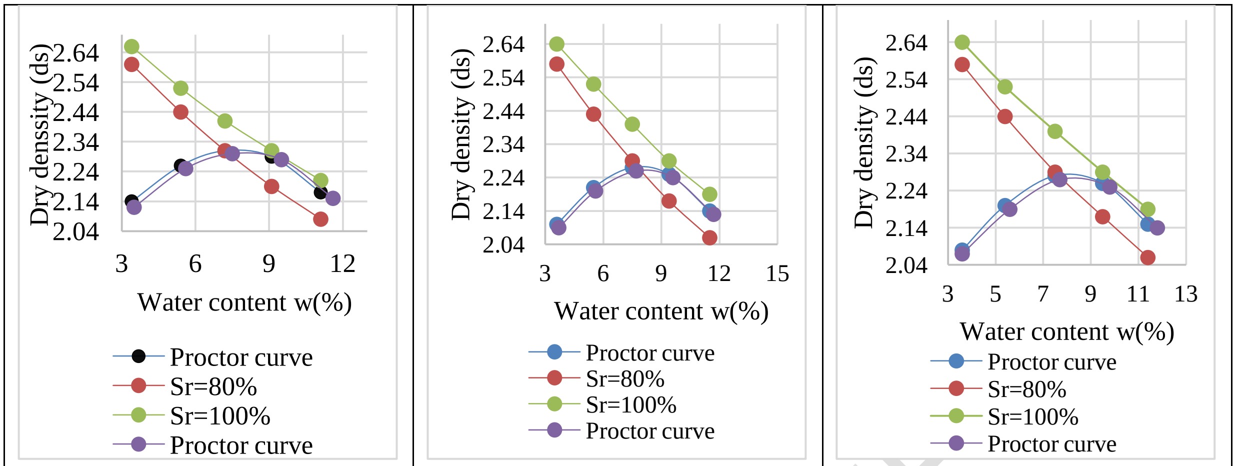
Table 4: Natural water content of the lateritic aggregate

Lateritic aggregate	Natural water content		
	Sample 1	***Sample 2***	***Sample 3***
ω_0 (%)	3.52	3.5	3.48
Mean		3.5	
Standard deviation		0.02	

From the analysis of the data in Table 3, it can be said that the material contains little water because its average water content, 3.5%, is less than 4%. Indeed, according to P94-050 [17], the lateritic aggregate of Cana-Atchia is good for compaction.

3.6. Proctor test

Figure 11 shows the evolution of the dry density as a function of the water content of the different samples studied.



Sample 1	Sample 2	Sample 3

Figure 11: Evolution of dry density as a function of water content

The results obtained are shown in Table 5 below:

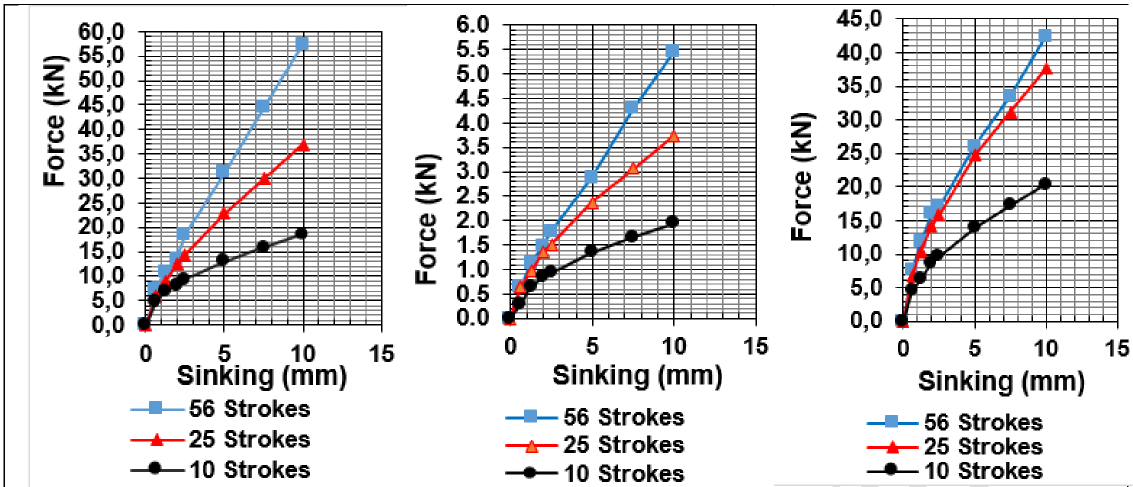
Table 5: Modified Proctor Test Results

	Modified Optimun Proctor (OPM)				
	Sample 1	Sample 2	Sample 3	Mean	Standard deviation
γ_d max (t/m^3)	2,302	2,263	2,275	2,28	0,02
w_{OPM} (%)	8	8,2	8,4	8,2	0,2

The conditions of use of lateritic gravels in pavement base courses require that the minimum dry density required be at least 2 tons/m^3 and for a water content between 7 and 13%. For pavement subbase, they require that lateritic gravels have a minimum required dry density of 1.8 to 2 tons/m^3 and a moisture content of 7 to 13%. These dry density limits are lower than those of the three samples and their water contents are within the required range. The material is ideally suited for base and sub-base courses for paved roads.

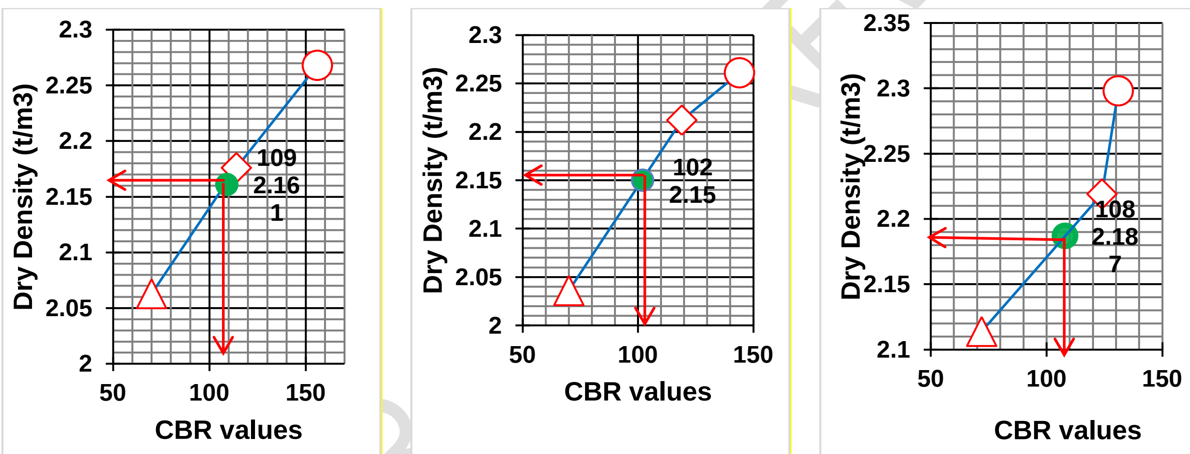
3.7. California Bearing Ratio (CBR) test

For the execution of the test, the material was compacted on the basis of the compaction references obtained by the Modified Proctor test. After four days of soaking, and after the punching test, the CBR of this material was estimated to average 106 at 95% of Modified Proctor Optimum and 144 at 100% of Modified Proctor Optimum.



Sample 1	Sample 2	Sample 3

Figure 12: Punching curves of specimens after 4 days of immersion



Sample 1 Sample 2 Sample 3

Figure 13: Determination of the CBR index as a function of dry density

Table 6 shows the results of the CBR test performed on the three samples.

Table 6: CBR Index Values

Compaction rate	CBR INDEX				
	Sample 1	Sample 2	Sample 3	Mean	Standard deviation
100%	131	144	156	144	12.50
95%	108	102	109	106	3.79
90%	72	70	70	71	1.15

According to Table 6, the 95% CBR of the OPM varies between 102 and 109. It averaged 106.

The relative linear swelling gave an average of 0.04%.

Table 7: Values of relative linear swelling

lateritic aggregate	RELATIVE LINEAR SWELLING				
	Sample 1	Sample 2	Sample 3	Mean	Standard deviation
95 %	0,03	0,05	0,04	0,04	0,01

From Table 7, the linear swelling relative to 95% of OPM averages 0.04%.

- Use in sub-base

The CEBTP [11-12] recommendations stipulate: "Whatever the structure in which they are included, materials for sub-base courses must have a CBR at least equal to 30 obtained for a dry density corresponding to 95% of the OPM. However, a value of 25 is allowed for T1 traffic and 35 for T4 and T5 traffic" [11-12]. These recommendations are verified since the CBR index after 96h soaking gives an average of 106 for 95% of the OPM. The material can therefore be used as a pavement base course.

- Use in base course

Concerning the base course: "The CBR index will be at least equal to 80 for a density corresponding to 95% of the OPM. If the material does not reach this bearing capacity, it must be improved or treated. A CBR of 60 can be accepted for T1" traffic [11-12].
The CBR of our material being 106, then the material is usable in base course since the CBR remains higher than 80 which is the value admitted by the CEBTP [11-12]. However, we hesitate when it comes to the behaviour of the material because the base course must have a material that performs well enough.
In addition, "the relative linear swelling measured during the CBR test must remain below 1%": value respected since the relative swelling is only 0.04% on average.

3.8 Analysis of the results with regard to the recommendations of the CEBTP guide [11-12].

Table 8 below presents the geotechnical characteristic values of Cana-Atchia lateritic aggregate compare to the threshold of the CEBTP guide [11-12].

Table 8: Geotechnical characteristics of Cana-Atchia lateritic aggregate and threshold of CEBTP guide [11-12].

Characteristics	Obtained values	Thresholds of CEBTP guide [11-12]	
		Foundation layer	Base layer
% passing the 80 µm sieve	13.00	< 35	< 20
Liquidity limit (%)	32.67	<50	<35
Plasticity Index (%)	13.67	<25	<15
Dry density at 95% OPM (t/m^3)	2.28	≥ 1.8-2	≥ 2
Linear swelling index (%)	0.04	<1	<1
CBR Index at 95% OPM	106.00	≥ 30	≥ 80

The analysis of the results in Table 8 allows us to conclude that the characteristic values of all the geotechnical tests carried out on the material comply with the specifications of the CEBTP guide [11-12] for a material intended for sub-base or base course. Thus, the lateritic aggregate of Cana-Atchia can be directly used in road construction in the mentioned layers.

Work conducted by Ogbuagu and Okeke [22] on two lateritic gravel samples resulted in an evaluation of their fine particle content at 11% and 35% respectively. These values are within the range of the Cana-Atchia lateritic gravel which is 13%. It should be noted that this average value of the fine particle rate is higher than that found by Caro et al [23] and Ratsifarehandahy et al [24], on the one hand, and lower than the result obtained by Hermann et al [25], Mvindi et al [26], Ndiaye et al [27] and Nzabakurikiza et al [28].

As for the liquidity limit, the average value obtained in this study is 32.67. It is close to the values found by Ndiaye et al [27]. However, it is lower than the values obtained by Ogbuagu and Okeke [22], Ratsifarehandahy et al [24], Nzabakurikiza et al [28] and Onana et al [29].

As for the plasticity index whose average is 13.67, it should be noted that this value is close to that found by Ratsifarehandahy et al. [24]. However, it is lower than the values found by Ogbuagu and Okeke [22], Mvindi et al [26], Nzabakurikiza et al [28], Onana et al [29] and Hassaballah et al [30].

Finally, the index bearing CBR at 95% OPM, averaging 106, is similar to the value obtained by Ogbuagu and Okeke [22]. However, this value is higher than those obtained by Ratsifarehandahy et al [24], Hermann et al [25], Ndiaye et al [27] and Onana et al [29].

4. CONCLUSION

In order to characterize locally available materials for road construction in Benin, characterization studies of the lateritic gravel of Cana-Atchia have been initiated. They led to the realization of physical and mechanical tests such as granulometric analysis, limits of Atterberg, Modified Proctor and CBR. The various test results are compared with the technical specifications contained in the practical guide to pavement design for tropical countries published by CEBTP in 1984.

These geotechnical tests carried out on the lateritic gravel allowed us to know that it is of very good quality and is usable in sub-base layer according to the requirements of the CEBTP (1984).

The values of the technical parameters of the Cana-Atchia lateritic aggregate from the tests are as follows: $W_{nat} = (3{,}50 \pm 0{,}02)\%$; $C_{2mm} = (20{,}00 \pm 2{,}08)\ \%$; $C_{0{,}5mm} = (16{,}00 \pm 2{,}08)\ \%$; $C_{0{,}08mm} = (13{,}00 \pm 2)\ \%$; $W_L = (33{,}00 \pm 1{,}53)\ \%$; $IP = (14{,}00 \pm 0{,}58)\ \%$; $MO = (0{,}75 \pm 0{,}02)\ \%$; $W_{OPM} = (8{,}20 \pm 0{,}02)\ \%$; $\gamma_s = (2{,}28 \pm 0{,}02)\ t/m^3$; $ICBR_{95\%} = (106{,}00 \pm 3{,}79)\ \%$. All these values are well within the range of CEBTP requirements for the use of the material as a base course and as a sub-base for paved roads.

COMPETING INTERESTS:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

CBR: Californian Bearing Research
CEBTP: Centre Expérimental de Recherche et d’Etudes du Bâtiment et des Travaux Publics (Experimental Center for Research and Studies in Building and Public Works)
OPM: Optimum Proctor Modifié (Modified Proctor Optimum)