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Chemical-mechanical characterizations of lateritic nodules for the implementation of hydraulic concrete

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ABSTRACT: The control of the mechanical performance of concretes of lateritic nodules requires a perfect knowledge of the physicochemical and mechanical properties of the nodules. Several researchers have approached the characterization of concretes of lateritic nodules and, by ricochet, of lateritic nodules used as coarse aggregates. The specification of this study is not only the varieties of chemical-mechanical results obtained, but also the water saturation time of the various lateritic nodules. Among the objectives of this study are: i) the determination of the dominant oxides, ii) the study of physical properties and the time zone of water saturation curves, iii) the control of the mixing water of the lateritic nodules; v) the determination of the hardness range of ten samples. Chemical analysis shows that the dominant oxides in the laterites are SiO_2, Al_2O_3, Fe_2O_3, CaO is very low in the lateritic nodules. The content of these oxides varies from sample to sample. The granularity of the materials studied is of the spread type. The apparent and absolute densities of the nodules vary from 1.43 to 1.51 and from 2.61 to 2.81 respectively. The degree of absorption and porosity vary from 0.81 to 5.81 and from 2.11 to 16.03. The water saturation time of lateritic nodules is between 18 hours and 24 hours. The hardness of the nodules, following the fragmentation test, varies from 43 to 55 and some exceeds the required value.

KEYWORDS: Aggregate, chemical analysis, oxides, water absorption, porosity, mechanical properties.

1 INTRODUCTION

Concrete material is used in the construction works. Common aggregates used in the formulation of hydraulic concrete (rolled gravel, sand) are non-renewable. The extraction of aggregates in quarries is a real industry [1]. In Benin, common aggregate quarries do not cover the entire national territory, this has a strong impact on the cost of construction materials or even access to decent housing for the underprivileged. Reflections on the use of locally available building materials are developing more and more. Laterites and their gravel are widespread throughout the world and particularly in the tropical region of Australia, India, Southeast Asia, South America and Africa [2]. The partial or total substitution of the rolled gravel by the lateritic nodules in the hydraulic concrete is envisaged. Laterite is available in Benin [3], [4]. Given its ecological opportunity, lateritic soils are sufficiently used as materials for light constructions [5]. The use of laterite nodules affects the mechanical performance of concrete compared to current aggregates [6], [7], [8], [9]. The drop in resistance of lateritic concretes is thought to be due to the ignorance of the chemical and intrinsic properties of lateritic nodules. Referring to the literature, no study (research work) has yet truly addressed the chemical-mechanical characterization of nodules with a view to their use in concrete. A good knowledge of the physicochemical and mechanical properties of the nodules would contribute to improve the mechanical performance of these concretes.

2 MATERIALS AND METHODS

2.1 MATERIALS USED AND BORROWING SITES

Lateritic nodules are concretions resulting from the transformation of fine particles. The materials are ocher, sometimes reddish. The nodules studied were sampled in different localities in Benin (Table 1), after manual or mechanical soundings followed by washing of fine particles.

Table 1. Localization of different nodules

Origin of Nodule	Code	Geographic coordinates of one of the survey locations	
		N	E
Cana	Can	07°05’45,3”	02°05’23,9”
Banikoara	Ban	11°18’45,2”	02°26’02,0”
Allada	All	06°47’04,1”	02°02’38,9”
Savalou	Sav	07°54’28,9”	02°01’55,9”
Dogbo	Dog	06°46’22,9”	01°47’18,6”
Ouaké	Oua	09°32’17,7”	02°22’39,9”
Natitingou	Nat	10°11’30,6”	01°24’52,0”
Houéyogbé	Hou	06°33’05,6”	01°54’14,8”
Pèrèrè	Pèr	09°33’52,6”	02°56’50,7”
Adjohoun	Adj	06°42’53,7”	02°33’34,1”
Sakété	Sak	06°48’38,7”	02°36’25,5”

The rejects and passers-by respectively on the 25 mm and 4 mm sieves are eliminated. The disposal arrangement of loops on the 4 mm sieve is essential to ensure that fine particles and clay balls have been removed. The materials, which are the subject of this study, are taken from various localities in Benin and are presented as indicated in Fig. 1.

A) NODULE OF DOGBO B) NODULE OF ALLADA C) NODULE OF HOUÉYOGBÉ D) NODULE OF CANA

E) NODULE OF SAKÉTÉ F) NODULE OF ADJOHOUN G) NODULE OF SAVALOU H) NODULE OF OUAKÉ

I) NODULE OF NATITINGOU J) NODULE OF BANIKOARA K) NODULE OF PÈRÈRÈ M) GRAVEL OF DÈVÈ

Fig. 1. View of the various lateritic nodules and common aggregates (rolled gravel)

2.2 EXPERIMENTAL METHODS

2.2.1 SAMPLING TECHNIQUE

Borings of various depths were carried out depending on the degree of outcrop of lateritic nodules or the predominance of nodules in the laterite of the region. The samples taken from the samples by region are mixed in order to have a representative material by locality. Part of the representative material is subjected to a sieve over 4 mm in order to ensure a sufficient quantity of lateritic nodules for the various characterizations.

The samples were washed in order to obtain lateritic grains (nodules). The nodules were quartered to ensure the representativeness of the test sample.

2.2.2 CHEMICAL CHARACTERIZATION

Laterite nodules contain chemical elements such as Calcium Oxide, Silica Oxide, Aluminate Oxide, Ferric Oxide [6]. The chemical analysis of lateritic nodules from Benin and Togo, likely to substitute for conventional aggregate, also contain these same oxides at different levels. The substance of this research is to focus on the impact of these oxides in concrete. The chemical characterization carried out consists in determining the essential chemical constituents of lateritic nodules, in particular the content of dominant oxides and calcium oxide (CaO). For the dominant oxides, the molecules SiO_2, Al_2O_3, Fe_2O_3 were chosen because of their high content in most nodules. As for calcium oxide, it was chosen because of its significant predominance in cement and its presence in all the nodules studied. Images and chemical measurements were collected under the following operating conditions: i) Voltage d 20 kV acceleration, ii) 20 mA excitation current, iii) 15.8 mm working distance. The samples were covered with a C coating using a Cressington 208HR sprayer.

2.2.3 PHYSICAL CHARACTERIZATION

GRANULARITY OF LATERITIC NODULES

The particle size analysis test is used to determine the weight distribution of the grains (expressed as a percentage) of the materials following their dimensions. The particle size analysis of each sample was carried out by wet sieving for all the laterite nodules in accordance with standard NF EN 933-1 (2012).

VOLUME MASSES OF NODULES

The apparent and specific densities are carried out in accordance with standards NF EN 1097-3 (2014) and NF EN 1097-6 (2014).

WATER ABSORPTION AND POROSITY

The water absorption test was carried out on each material in accordance with the approach proposed by BISHWEKA BIRYONDEKE Cherif and al., (2016). The porosity of each nodule was determined by calculation, from the degree of water absorption of each material knowing its specific density.

Fig. 2. Water absorption of lateritic nodules

2.2.4 MECHANICAL CHARACTERIZATION

The mechanical characterization consisted in carrying out the nodule fragmentation test under the effect of shocks. The resistance to abrasion of lateritic nodules (aggregates) is a very important parameter in assessing the quality of the material. The test consists of subjecting the aggregates to standardized ball impacts and reciprocal friction in the Los Angeles machine in order to evaluate the quantity of elements smaller than 1.60 mm obtained.

3 RESULTS

3.1 CHEMICAL CHARACTERISTIC

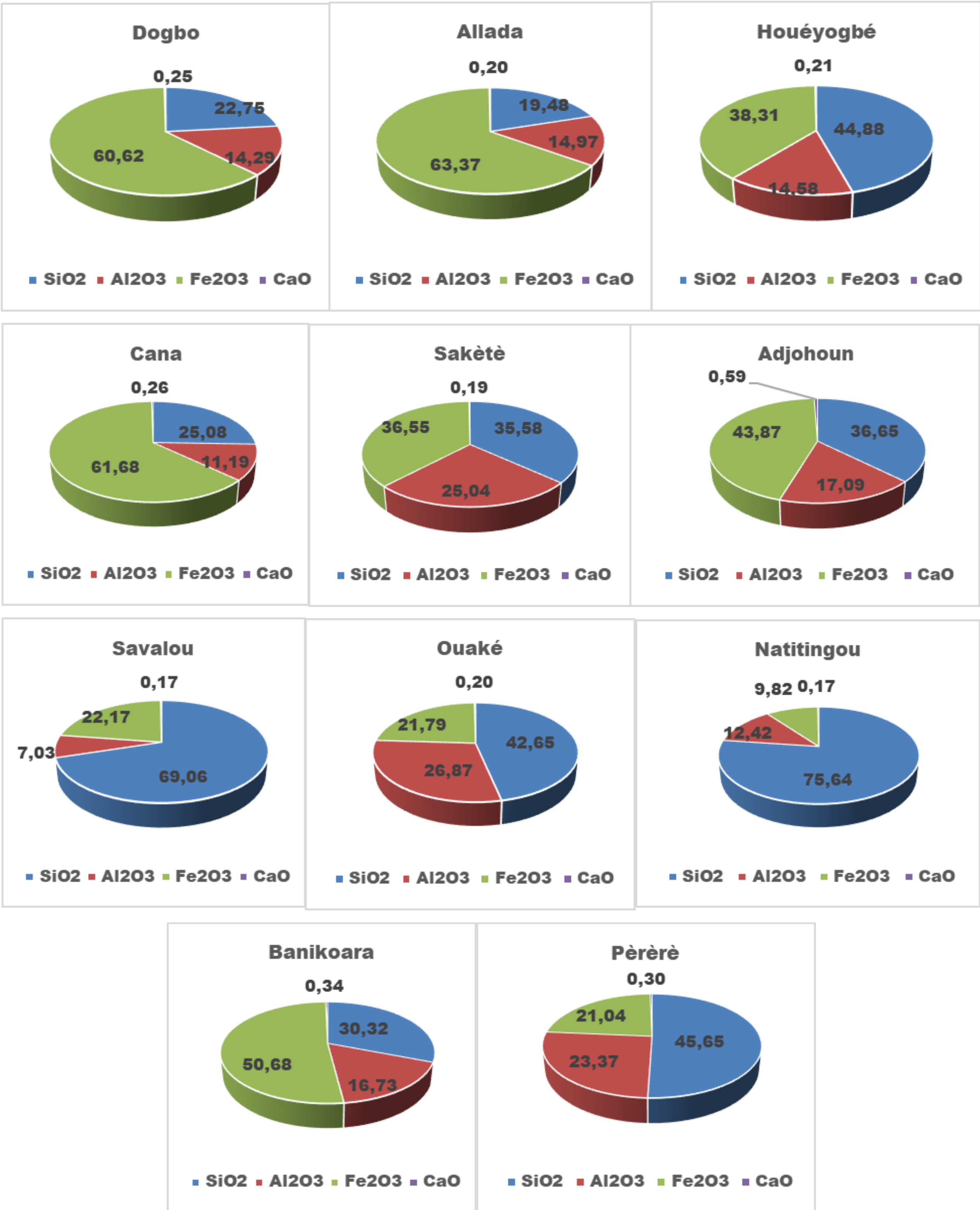

Fig. 3. Rate of major chemical elements in the nodules (%)

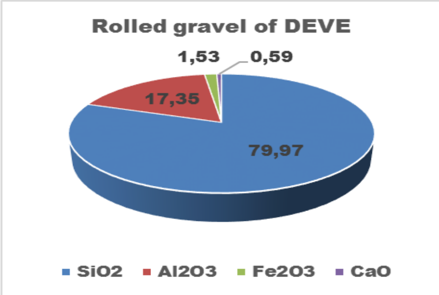

Fig. 4. Rate of major chemical elements in the gravel (%)

Fig. 3. shows the dominance of certain oxides of lateritic nodules according to their locality of origin. The main molecular forms highlighted are the oxides of silica (SiO_2), aluminate (Al_2O_3) and ferric (Fe_2O_3). Calcium oxide being very dominant in cement and in aggregate, it is necessary that its impact in concrete is also taken into account despite its low content in nodules.

Fig. 4. shows the dominance of silica (SiO_2) in the gravel than all lateritic nodules.

The silica oxide content varies for most nodules from 20% to 45% with rates of over 69% for the nodules in the Natitingou and Savalou regions. In comparison with the SiO_2 content of the rolled gravel of Dèvè (Dogbo), which is of the order of 53%, it appears that the lateritic nodules of most localities are poor in silica apart from the nodules coming from Natitingou and Savalou.

Aluminate oxide essentially evolves from 11% to 28%, while for the nodules in the Natitingou and Savalou regions, this rate is 7% to 12%. The Al_2O_3 content of the rolled gravel is of the order of 37%, it follows that most lateritic nodules are poor in Aluminate.

The predominance of ferric oxide varies, for most nodules from 37% to 63% with rates of over 10% to 22% for nodules in the Natitingou and Savalou regions. The Fe_2O_3 content of the common aggregate is around 2%. It appears from this analysis that ferric oxide is quite abundant in the nodules.

The calcium oxide content in the nodules ranges from 0.2% to 0.6% as long as it is around 3% in the gravel. It should be remembered that lateritic nodules are very poor in CaO.

In view of the results, two subgroups were distinguished:

- LNG 1: It groups together the nodules whose SiO_2, Al_2O_3 and Fe_2O_3 levels vary respectively from 20% to 45%, 11% to 28% and from 37% to 63%. These are laterites from Allada, Dogbo, Houéyogbé, Cana, Adjohoun, Sakété, Ouaké, Banikoara and Pèrèrè.
- LNG 2: These are nodules whose SiO_2, Al_2O_3, Fe_2O_3 levels vary in this order from 69% to 76%, 7% to 12% and from 10% to 22%. This categorization concerns the nodules of Savalou and Natitingou.

The results thus obtained are in agreement with those of other authors. Indeed [6], a comparative chemical characterization of ten various laterites and granite have been made. He pointed out that the dominant oxides are SiO_2, Al_2O_3, Fe_2O_3 and their contents vary from one laterite aggregate to another. Oxide SiO_2 is less dominant in lateritic nodules compared to granite. The chemical composition of laterite in Burkina Faso, Congo and Niger respectively. It emerges from their research that the dominant chemical elements in these laterites are respectively SiO_2, Al_2O_3, Fe_2O_3 [10], [11], [12]. In order, these elements varied from 44.40% to 66.34%, 20.65% to 29.24% and from 8.78% to 16.09%. According to [13], the nodules are mainly composed of quartz, gibbsite and hematite, which correspond respectively to the oxides of silica (SiO_2), aluminate (Al_2O_3) and ferric, (Fe_2O_3).

The chemical composition contents of lateritic aggregates varied according to the various origins of the nodules and could be due to their geological formations.

3.2 Physical Characteristic

3.2.1 Granularity

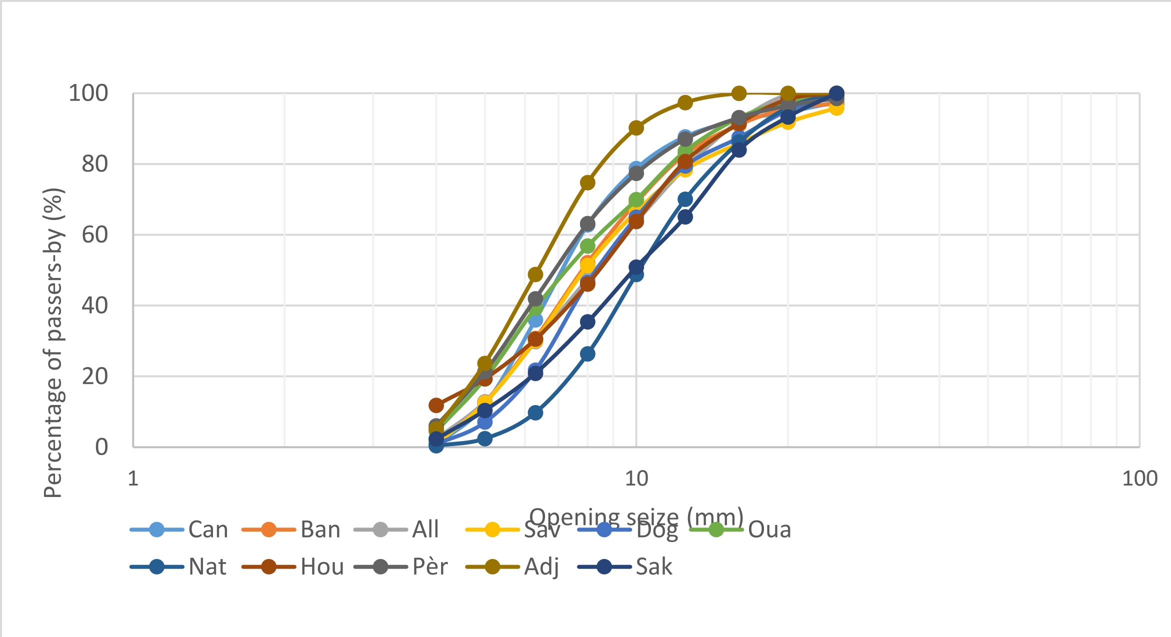

Fig. 5. Particle size curves of 4 / 25 mm laterite nodules

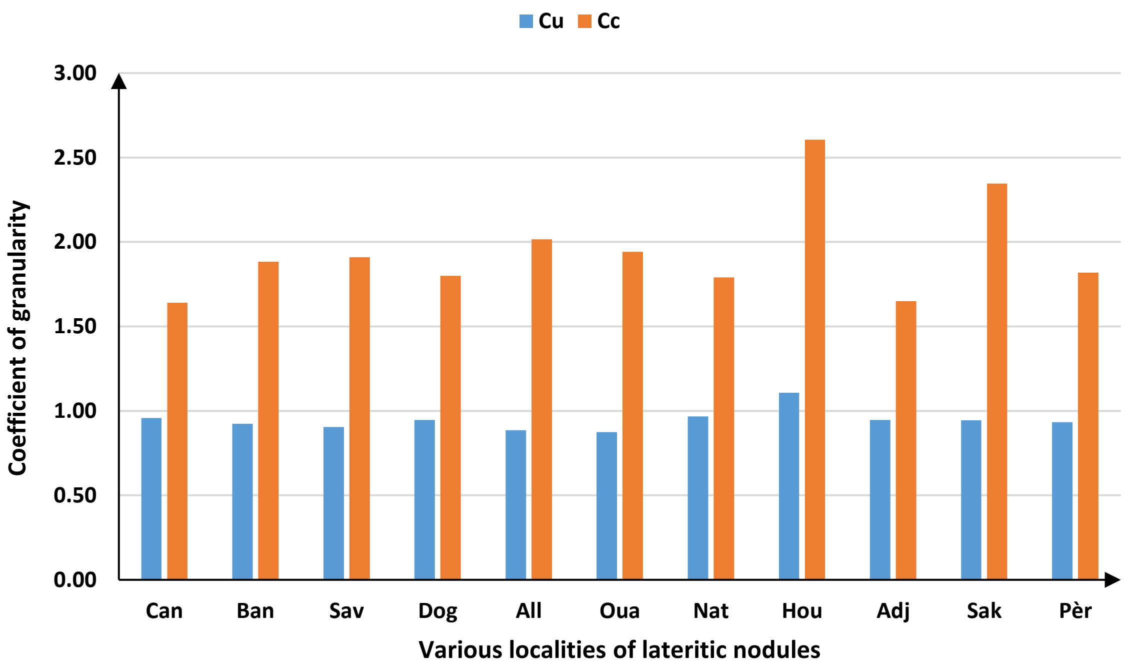

Fig. 6. Histogram indicating the HAZEN Coefficient (Cu) and the Curvature Coefficient for various localities of lateritic nodules

The grain size curves of the various lateritic nodules as indicated in Fig. 5., an almost similar grain size regardless of the locality of origin. The values of the uniformity coefficients are illustrated in Fig. 5. and allow us to conclude that the granularity is of the spread type for all the localities of origin of the lateritic nodules studied. The lateritic nodules have a uniformity coefficient of less than three (Cu <3). According to the LPC classification all the nodules are clean, poorly graded bass [14], [15].

The dimensional distribution of soil grains or lateritic nodules have studied in comparison sometimes with other materials used in the composition of concrete. It emerges from this research that the nodules have a spread particle size [16], [12], [17], [8], [18], [19].

3.2.2 Density Of Lateritic Nodules

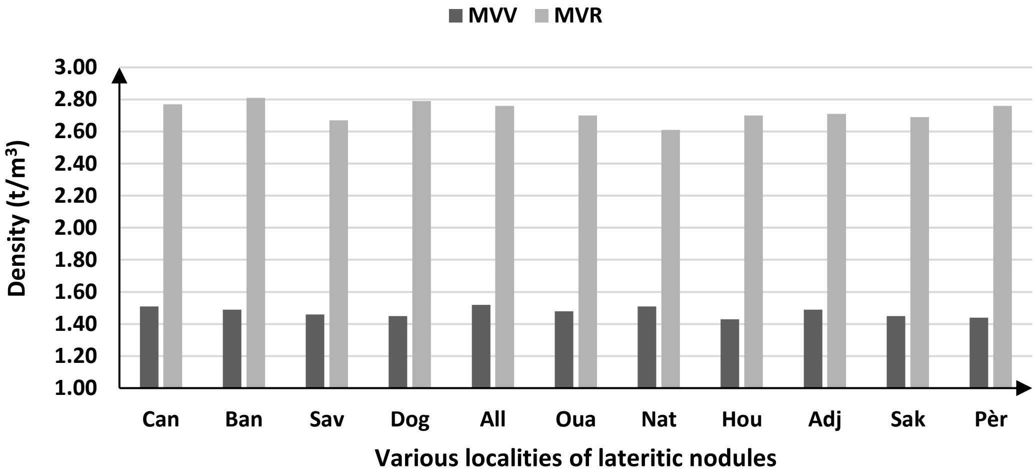

Fig. 7. Histogram of the variation in apparent and absolute densities of lateritic nodules

The apparent and absolute densities respectively translate the mass of the material to the volume occupied by the aggregates including voids and without voids.

The density of laterite or its aggregates have been evaluated and obtained results ranging from 2.56 to 2.99 t/m^3 [20], [7], [21], [9], [18], [19]. The densities obtained from various lateritic nodules varied from 2.61 t/m^3 and 2.81 t/m^3. The results of his work are in harmony with those revealed by the predecessors.

[20], [7], [18] determined the apparent density of laterite or its aggregates and the results obtained varied from 1.32 and 1.83 t/m^3. The work resulted in a variation in the apparent density of 1.44 t/m^3 and 1.52 t/m^3 for the different nodules studied. A comparative study with the previous results, it appears that the densities reflect reality perfectly.

3.2.3 Water Absorption And Porosity On The Nodules 4/25

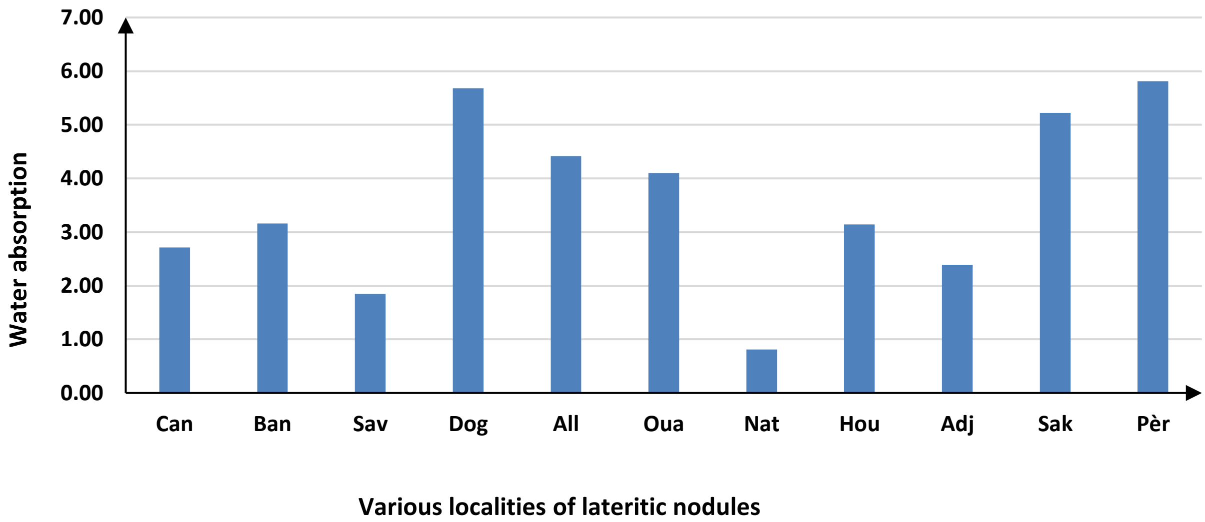

Fig. 8. Histogram of the variation in water absorption of the various lateritic nodules

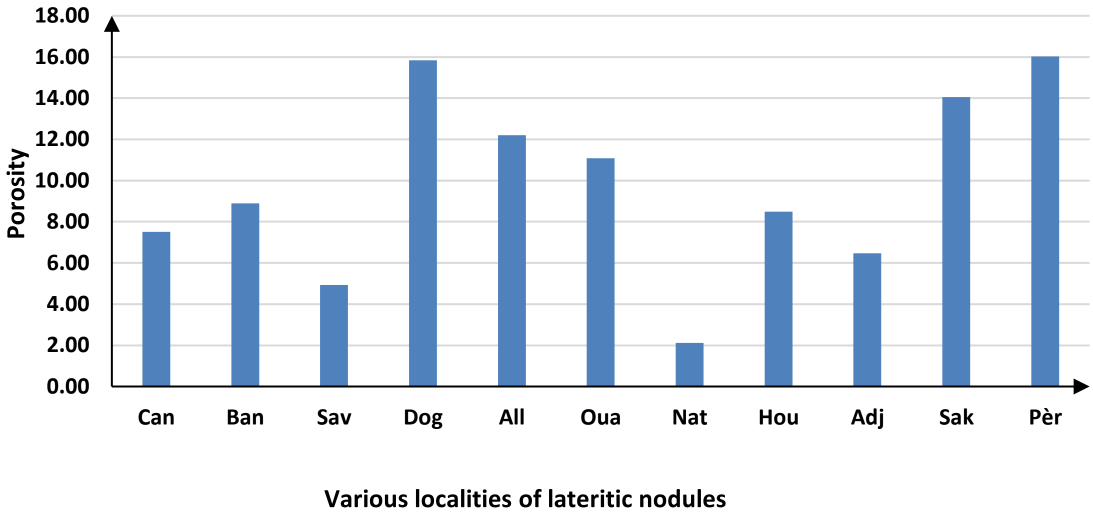

Fig. 9. Histogram of the variation in porosity of the various lateritic nodules

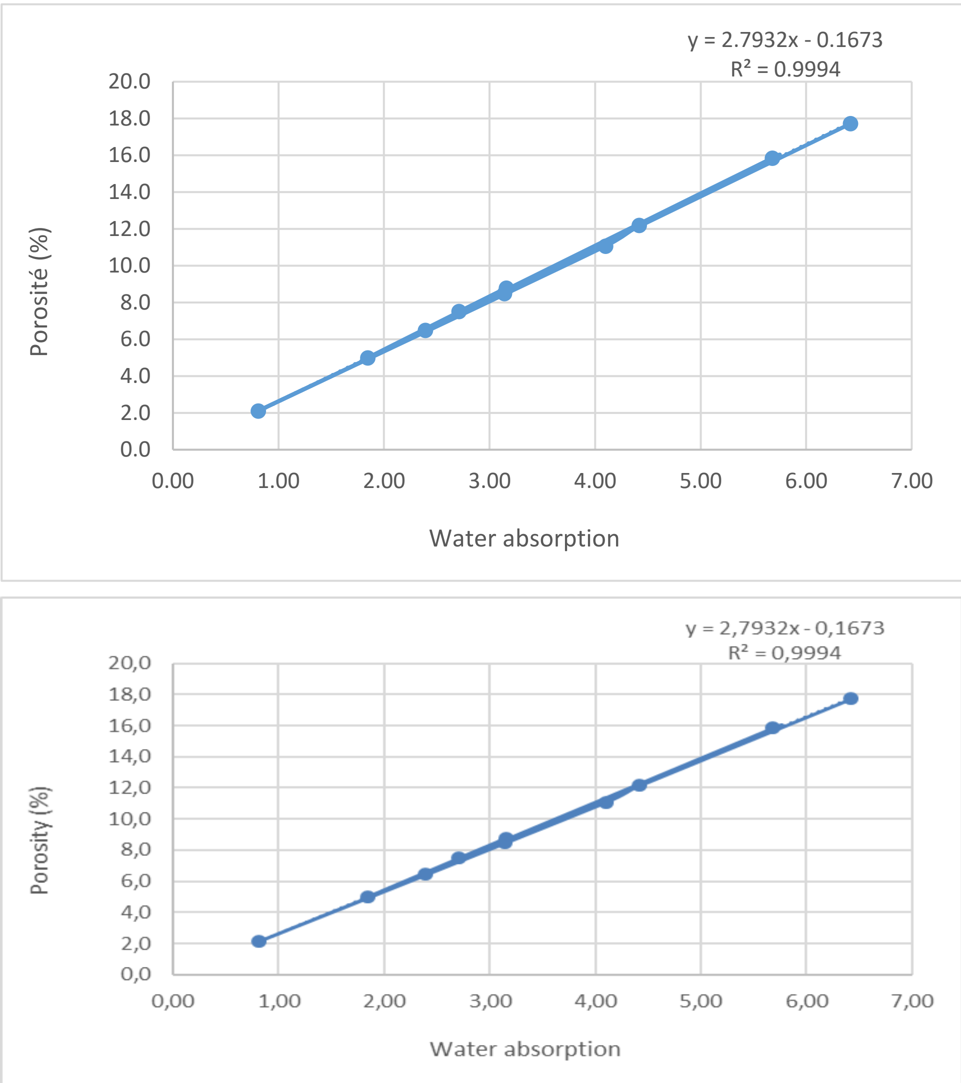

Fig. 10. Evolution water absorption-porosity of lateritic nodules

Figure 10 shows the variation in the ability of the eleven lateritic nodules to absorb water as a function of the voids they contain.

In their document "Science of construction materials, practical work", studied absorption and porosity. The method involves filling the pores of the nodules, heating the soaking water for two hours and allowing it to cool for 24 hours. The absorbed water is deduced by weighing. Porosity is calculated from the specific density of the material knowing the degree of absorption [22]. A particular approach was used by [23]. From this method, it emerges that the water absorption coefficient of the volcanic aggregates of Goma which is 13.55% and 13.60% respectively for class 5-15 gravel and class 15-25 gravel. [23] research has led to the deduction that the Goma aggregates and laterite nodules in general absorb a significant amount of water. [21] obtained a value of 8.84% during his work. A study on laterite treated and replacing granite with river sand have conducted [24]. The grain diameter variation range is 0.15 mm to 2.36 mm. The treated laterite has a very high water absorption potential compared to sand.

As a result of the work of [23], [24] it has been noticed that the water absorption ranges from 4.60% to 13.60%. It was retained, following research work that the water absorption of the nodules led to the categorization of the aggregates in two into two subclasses:

LNG 1: It combines the nodules of Allada, Dogbo, Houéyogbé, Cana, Adjohoun, Sakété, Ouaké, Banikoara and Pèrèrè: water absorption varies from 2.11% to 5.81%.

LNG 2: It combines the Savalou and Natitingou nodules: water absorption varies from 0.81% to 1.85%.

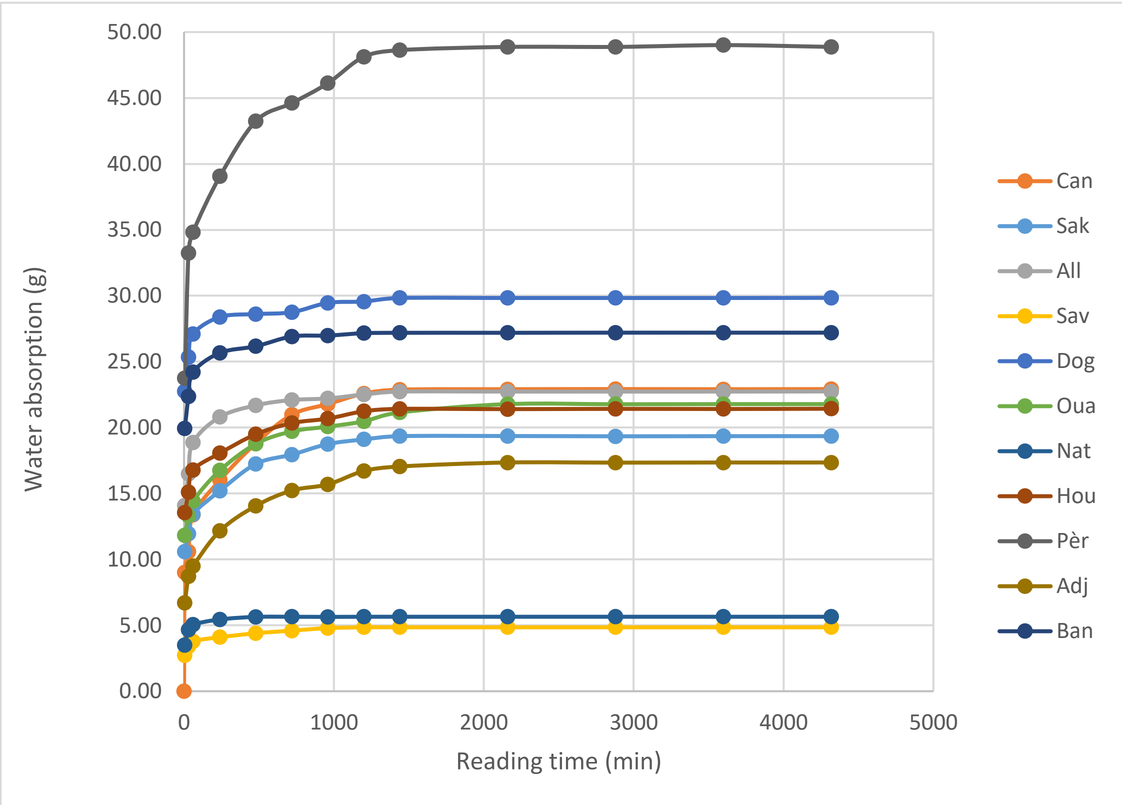

Fig. 11. Various absorption kinetics of lateritic nodules

Fig. 11. shows the degree of water saturation of each aggregate as a function of time.

[25] have carried out work on the absorption kinetics of natural and recycled aggregates. These studies have made it possible to retain that the absorption kinetics are linked to the type of aggregate. Also, 80% of the absorption rate of natural aggregates is obtained after four (4) hours of imbibition.

This study shows that the water absorption of the nodules is maximal between 18 and 24 hours.

Table 2. Equation and coefficient of determination R^2

Origin Nodule of:	Code	Equation and coefficient of determination R^2 of the graph	
		y	R^2
Cana	Can	2.4289ln (x) +3.9618	0.9625
Banikoara	Ban	1.5012ln (x) +7.6728	0.9588
Allada	All	1.3157ln (x) +12.7800	0.9351
Savalou	Sav	0.3276ln (x) +2.3428	0.9584
Dogbo	Dog	1.0117ln (x) +22.077	0.9314
Ouaké	Oua	1.6951ln (x) +8.2059	0.9750
Natitingou	Nat	0.2789ln (x) +3.6141	0.8199
Houéyogbé	Hou	1.2978ln (x) +11.3460	0.9668
Pèrèrè	Pèr	3.8281ln (x) +19.0840	0.9739
Adjohoun	Adj	1.8085ln (x) +3.0118	0.9703
Sakété	Sak	1.0761ln (x) +19.1130	0.9256

3.3 MECHANICAL CHARACTERIZATION

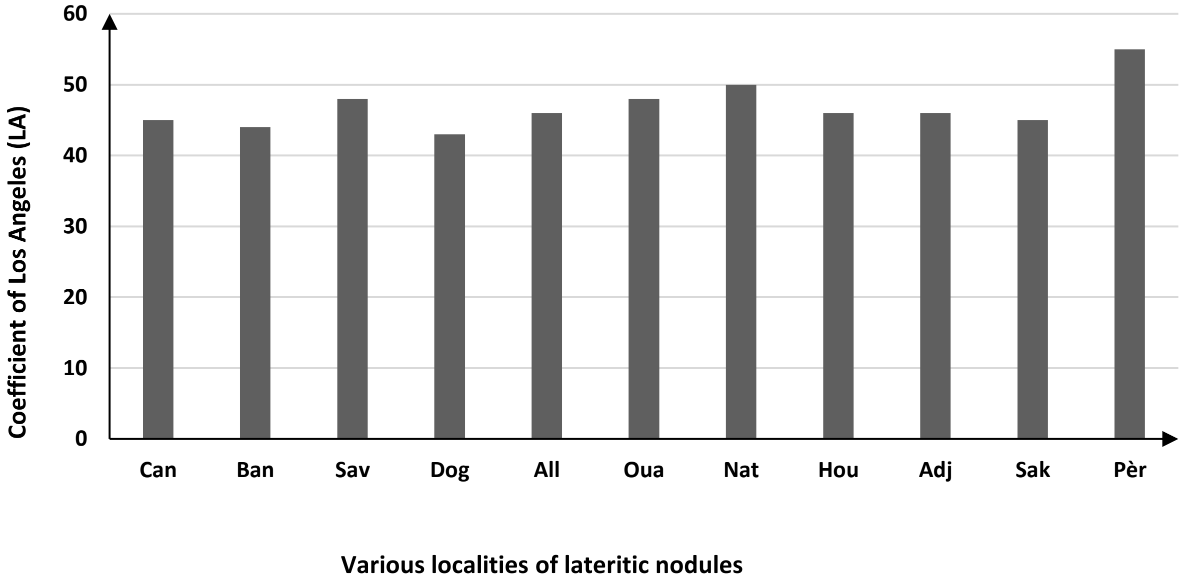

Fig. 12. Resistance to fragmentation under the impact of lateritic nodules

Fig. 12. explains the hardness of the nodules studied. Knowledge of the resistance to fragmentation under the impact of the coarse aggregate used in the composition of concrete is a very decisive parameter. The harder the coarse aggregate, the more easily the expected mechanical performance of concrete would be achieved. Lateritic nodules are recognized as altered aggregates but available in tropical regions, [26], [27]. Thus, some authors have been interested in the hardness of the nodules.

[28], carried out, from the Los Angeles test, a comparative study of the hardness on the laterite nodule and the granite and the results revealed 62.00% and 14.00% respectively. [8] performed a similar study. The results obtained were respectively 24.90% and 15.40% for lateritic nodules and granite. The work of [19] made it possible to have Los Angeles LA coefficients on lateritic nodules, varying from 37% to 48%.

The hardness of the nodules studied ranged from 43% to 55% and is similar with the results found by the researchers.

4 CONCLUSION

Our results showed that:

- The dominant oxides in lateritic nodules are SiO_2, $Al2O_3$, Fe_2O_3. The contents of these oxides vary according to the origin of the samples and may be justified by the diversity of the geological formations.
- Quartz is very prevalent in common aggregates (granite, rolled gravel) while it has a relatively low content in nodules.
- Water absorption changes with the degree of porosity of the lateritic nodules. This water absorption is higher at the level of the Pèrèrè nodule where the degree of fragmentation is also higher. The lateritic nodules have an absorption kinetics which reaches its saturation between 18 and 24 hours.
- The porous nature of the nodules requires a perfect mastery of certain properties such as the quantity of water absorbed (Eabs) by the lateritic gravel. The major advantage is the deduction of the total quantity of water (Etot) by the equation [a]:

Etot = Eeff + Eabs

Etot: quantity of water for mixing the concrete; Eeff (effective mixing water): quantity of water for the chemical reactions of hydration and Eabs: quantity of water taking into account the porous aspect of large aggregates.

We recommend that the nodules intended for making concrete be imbibed for twenty-four (24) hours, and put them in the "Saturated Surface Dry" state before use. The purpose of this practice is to better control the actual mixing water. The equation [b] corresponding to this option is summarized as follows:

Etot = Eeff

- The friable state makes some lateritic aggregates more absorbent and would adversely affect the mechanical strength of the concrete.
- Calcium oxide is at a low level in all the nodules and would impact the performance of lateritic concretes.

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