Open Journal of Civil Engineering, 2023, 13, 411-426
https://www.scirp.org/journal/ojce
ISSN Online: 2164-3172
ISSN Print: 2164-3164

Physical Characterization of Laterite for the Formulation of Structural Concrete

Dekandji Thomas Ekpo[1], Yemalin Daniel Agossou[1,2], Judicial Agbelele[2], Edmond C. Adjovi[1]

[1]INSTI Lokossa, National University of Sciences Technologies Engineering and Mathematics, Abomey, Benin
[2]L2EGC/ENSTP, Materials and Structure Team, National University of Sciences, Technologies, Engineering and Mathematics, Abomey, Benin
Email: yemdag@yahoo.fr

How to cite this paper: Ekpo, D.T., Agossou, Y.D., Agbelele, J. and Adjovi, E.C. (2023) Physical Characterization of Laterite for the Formulation of Structural Concrete. *Open Journal of Civil Engineering*, **13**, 411-426.
https://doi.org/10.4236/ojce.2023.133031

Received: May 23, 2023
Accepted: August 13, 2023
Published: August 16, 2023

Abstract

This study presents another approach to the use of laterite as a common construction material for the development of a new type of concrete. Laterites are found all over the world and are used in various ways in road construction as sub-base, base course or wear courses. Being a material consisting in the raw state of sand and gravel, the study addresses its use for the formulation of structural concrete. The physical characterization made it possible to identify three granular classes distributed as follows: 28.26% passing at 80 µm, 32.12% sand (0.08/4 mm) and 39.62% nodule (4/25) mm. The absolute density of the aggregates varies from 2.73 and 2.82 from the sand to the nodules. The absorption rate varies from 3.01% and 5.71% respectively for sand and nodules. The granular compactness of the different granular classes studied varies from 0.580 to 0.630. The formulation of the concrete was made by the method of absolute volumes by varying the W/C ratio from 0.4 to 0.7, N/S from 2.2 to 2.8 and that of the cement dosage from 350 to 450 kg/m^3. The results obtained show that the density of the concrete formulated based on these aggregates of lateritic origin have a density which varies between 2000 and 2300 kg/m^3. With a cement content of 400 kg/m^3, a W/C ratio of 0.4 and N/S of 2.8, concrete based on lateritic aggregates offers better mechanical performance in compression of approximately 21.23 ± 1.24 MPa at 28 days. This strength class obtained allows laterite concrete to be used as structural concrete in the structure of civil engineering works.

Keywords

Laterite Concrete, Granular Compactness, Mechanical Strength

1. Introduction

Laterites, materials widely distributed throughout the world, but particularly in the tropical regions of Africa, Australia, Southeast Asia and South America and India, are widely used in the construction of various manners. These materials result from the weathering of rocks under the influence of factors such as climate, topography, vegetation, etc. There is a wide variety of morphological characteristics due to the formation conditions of lateritic soils and the nature of the parent rock. They are generally used as a pavement base course in the tropical region of Africa with cement stabilization and compaction energy to provide optimum mechanical performance. Benin abounds like the countries of the aforementioned regions of tropical ferruginous soils [1]. The use of laterites in construction is essentially limited to the manufacture of stabilized cement earth bricks. While in the context of economy and ecology, this material represents a significant resource, which used alone or with a concrete structure for the construction of habitats [2] [3]. Lateritic soils have been the subject of many studies for their use in road construction, but their use in construction has been limited to the manufacture of concrete blocks in certain load-bearing wall structures as shown in **Figure 1**.

Blocks in stabilized earth show that they are likely to be used in construction. The performances developed by this building material would be interesting to be valued in the formulation of concretes for the realization of the frameworks of the works. This study aims to remove this pitfall of the use of laterite in order to replace conventional sand or gravel (crushed or rolled) by sand and lateritic or lateritic nodules for the formulation of structural concretes.

2. Literature Review

2.1. Physical Characteristic of Laterites

According to studies on the lateritic gravels of Senegal by LAQUERBE M. *et al.*, (1995), [5] the laterites contain 10% to 35% of fines (sieve passing from 80 μm) and 20% to 60% of particles coarser (the 2 mm sieve). TAKALA H (2017) [6] shows in his studies on Cameroon laterites, that the granular skeleton (particle size < 2 mm) represents about 26% of the raw material mixture. In addition, the granular curves of the laterites presented the appearance of a sandy-clayey gravel with a level between 0.25 mm and 1 mm according to the studies of R. VAN GANSE, (1957) [7] on the laterite of the Belgian Congo. Notwithstanding a brilliant work carried out by LAQUERBE *et al.*, (1995) [5], on the rational use of lateritic gravel from Senegal and sand from the dunes as concrete aggregate, it appears that the present laterite study has a real density of 2680 kg/m^3, an apparent density of 1500 kg/m^3, an absorption coefficient of 7.15. A. Lawane (2014) [8] in his thesis on the characterization of indurated lateritic materials for better use in habitat in Africa was interested in the physical properties of several laterite quarries in Burkina Faso. The density varies from 2720 kg/m^3 to 2840 kg/m^3 for the three quarries studied. Issiakou MS, (2015) [9] and P. VAN GIMP, (1957) [7] presented in their study a density between 2200 and 2800 kg/m^3. Lawane (2014) [8] in his thesis on the characterization of indurated laterite materials for a

Figure 1. Masonry construction - lateritic blocks - Dano (PN) [4].

better use in habitat Africa was interested in the physical properties of several laterite quarries in Burkina Faso. The density varies from 2720 kg/m³ to 2840 kg/m³ for the three quarries studied. Issiakou MS, (2015) [10] and P. VAN GIMP, (1957) [7] presented in their study a density between 2200 and 2800 kg/m³. A. LAWANE (2014) [8] in his thesis on the characterization of indurated lateritic materials for better use in habitat in Africa was interested in the physical properties of laterites from several quarries in Burkina Faso. His studies show that the laterite density varies from 2720 kg/m³ to 2840 kg/m³ for the three quarries studied. Issiakou MS, (2015) [10] and P. VAN GANSE, (1957) [7] present in their study a density between 2200 and 2800 kg/m³.

2.2. Use of Laterite for Concrete Mix

Raju & Ramakrishnan (1972) [11] made experimental studies on fresh concrete and hardened concrete made with laterite aggregates from the southwest coast of India. They made several mixtures whose water/cement ratio varied from 0.40 to 0.60 and the aggregate/cement ratio from 4 to 6. The compressive strength which varied from 5 to 10 MPa proved to be much lower than that of concrete on gravel aggregate or crushed granite for the same proportions of aggregates and water/cement ratio considered in this study. Balogun *et al.*, (1982) [12] studied the variation of the proportions of laterite in the concrete according to the mechanical resistance. They found that the most suitable laterite concrete mix for structural purposes is (1:1.5:3), matching the proportions of (cement, sand, gravel); using a weight dosage with a water/cement ratio of 0.65. The optimum laterite content should not exceed 50% of the total fine aggregate content. Falade, (1994) [13] studied the influence of the W/C ratio and the Laterite/Cement ratio on the workability and the mechanical characteristics of concrete containing laterite instead of conventional sand. He therefore concluded that the workability increases with the increase in the W/C and Laterite/Cement ratio, which however decreases the compressive strength. The mixture giving the best results is 1:1:2 with W/C = 0.50. Osunade, (2002) [14] studied the effect of substitution of lateritic soils by granites for the compressive strength and the tensile strength of lateritic concrete. From their study, it appears that increasing the fine granite content increases the compressive strength and peaks at 50%. Laterite concrete containing 40% fine granite can be used for vibration-free mass foundation concrete, while 20% to 40% fine granite is recommended for hand-compacted slabs. Ukpata *et al.*, (2012) [15] studied the compressive strengths of concrete using laterite and quarry dust as fine aggregates and crushed as coarse aggregates. By varying the quantity of laterite from 0% to 100% and that of quarry dust inversely within an interval of 25% and, by varying the W/C ratio from 0.5 to 0.7; they found a hardened concrete density between 2293 and 2447 Kg/m^3 with a W/C of 0.60 is ideal. The compressive strength is in the range of 17 to 34.2 MPa. This resistance decreased as the amount of laterite increased. They therefore concluded that the combination of quarry dust and laterite can replace conventional sand in the concrete structure provided that the amount of laterite is less than 50%. Kamaruzaman & Muthusamy, (2012) [16] studied the mechanical properties of concrete with a substitution of crushed aggregates by lateritic nodules. In their study, they found that the compressive strength, flexural strength and modulus of elasticity of this concrete decreased as the volume of the lateritic nodules increased. They concluded that a 10% substitution of crushed aggregate with lateritic nodules can produce concrete of comparable strength to normal concrete. In addition, a substitution of up to 30% could produce concrete that could reach a compressive strength of 30 MPa. Ephraim *et al.*, (2016) [17] determined the characteristics of lateritic concrete in which gravel is replaced by lateritic nodules by varying the proportion of concrete components and the W/C ratio. They found a compressive strength of 19.11 MPa for a mixture of 1-2-4 (respective proportions of cement, sand and gravel) with a W/C ratio of 0.60 and 24.67 MPa for a mixture of 1-1.5-3 with a W/C ratio of 0.55. From these studies, they concluded that lateritic nodule concrete can be used for lightly loaded structures.

Note that apart from Raju & Ramakrishnan (1972) [11] who dared to study a total substitution of laterite aggregates, other researchers are partly concerned with the process of partial substitution of laterite sands and/or laterite gravels. The results of (Raju & Ramakrishnan 1972) certainly threw cold water on the idea. This work is part of the long term in a complete substitution of aggregates to achieve structural concrete.

3. Study Zone

The study is made in the Guinean region of Benin (between 6˚25', 7˚30'N by 2˚ and 2˚30'E). The Allada plateau descends to the valleys of the Ouémé, the Couffo and the Lama depression. This plateau is largely covered by tropical ferruginous soils and weakly ferralitic earth bar soils.

4. Materials and Methods Used

4.1. Cement

The cement used is Portland limestone compound cement CEM II/B-LL class 42.5R 42.5 MPa from NOCIBE cement. Due to its high short-term strength, it offers very good productivity in the manufacture of concrete products while distinguishing itself by a reduced CO_2 footprint. The chemical analysis shows that according to the NFP 15-301 standard showed that it contained 63% C3S, 10% C2S, 8% C3A and 7% C 4 AF. It has a rejection of 63% on a 7 mm sieve and 25% on a 16 mm sieve. The apparent density 1270 g/L and an absolute density = 3050 g/L. The BLAINE specific surface = 4700 cm^2.

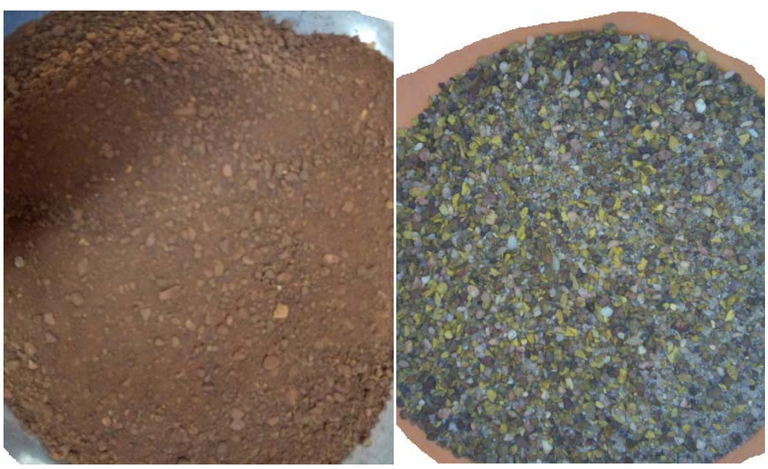
4.2. Water

The water used is drinking water that meets the requirements of the NFP 18-303 standard [13].

4.3. Aggregates

This is the draft taken from a laterite quarry located in Attotinga in the municipality of Allada and separated into two granular classes 0/4 and 4/25. Class 0/4 was reconstituted in granular fraction 0/0.08, 0.08/0.16, 0.16/1.25, 1.25/4. The physical characteristics sought are absolute densities, real and apparent particle density, absorption, Atterberg limits, blue value, equivalent to resistance to sand and abrasion.

The particle size analysis was carried out by wet sieving according to standard NF P 94-056 on the raw material. This allowed the constitution of the different granular classes and their percentage by weight. Figure 2 shows the material before washing (a) and the material after washing (b).



(a) (b)

Figure 2. (a) Unwashed material; (b) washed material.

The particle size analysis by sieving was supplemented by that by sedimentation according to the standard (NF P 94-057). The Atterberg limits according to the standards (NF P 94-051) were determined to complete the characterization of passers-by using a 0.08 mm sieve. The sand equivalent was measured according to standard NF P 18-598. The real and absolute density, the absorption was measured according to standard norms (EN 1097-6/EN 1097-6/A1) However, the apparent density by NF EN 1097-3. The compactness of the different granular classes, the protocol established by François LARRARD [18] was determined.

4.4. Formulation Methods

Two formulation methods were explored: the Dreux-Gorisse method [19] and the absolute volume method [20]. Using the Dreux-Gorisse method, nine (9) specimens were manufactured and stored in three different ways to provide clarification on the best concrete curing method:

- 3 specimens in the open air.
- 3 test tubes in a water tray, and
- 3 remaining are packed in plastic bags.

Figure 3 shows the samples kept in the plastic packaging for curing the concrete.

As for the method of absolute volumes, it is assumed that the sum of the volumes of each of the constituents of concrete (sand, gravel, cement, water and air) gives the unit (one cubic meter) of concrete. Equation (1) relating to the method of absolute volumes, makes it possible to have the mass quantities of each constituent of the concrete.

$$\frac{C}{\rho_c}+\frac{S}{\rho_S}+\frac{E}{\rho_E}+\frac{N}{\rho_N}+V_V=1 \quad (1)$$

From this formula, the mass of sand can be found by the formula below. Let K_e be the W/C ratio and K_b the N/S.

Figure 3. Conservation of specimens.

$$S = \frac{\frac{\rho_E C + k_e \rho_e C + \rho_e \rho_E V_V}{\rho_e \rho_E C}}{1 - \left(\frac{1}{\rho_S C} + \frac{k_b}{\rho_N C} \right)} \quad (2)$$

Or:

ρ_c is the density of the cement t/m³;

ρ_S is the density of the sand in t/m³;

ρ_N is the nodule density in t/m³;

ρ_E is the density of water in t/m³;

C is the mass of a ton of cement;

S is the mass of a tonne of lateritic sand;

N is the mass of nodules ton;

E is the mass of water ton.

The unknowns of this equation are the proportions of aggregates, the cement content, the quantity of water and the volume of empty V_V. By calling K_e the E/C ratio and k_b the N/S ratio and not being able to study all the parameters at the same time, we propose to use, according to certain authors, the void volume ratios V_v = 15% and the N/S ratio = 2.5 [21] initially then by varying the N/S ratio from 2.2 to 2.8.

The optimization therefore consisted of varying the values of E/C. Thus, the concrete mix has led to the use of W/C value ranges ranging from 0.4 to 0.7 and that of the cement content in the range from 350 to 450 kg per cubic meter.

The most sought-after characteristics are the resistance to compression and shear by splitting, the workability, and the density in the fresh state and in the solid state, without forgetting to be interested in the behavior of this concrete.

5. Analysis and Discussion of Results

5.1. Physical Properties of Aggregates

Studies carried out on lateral aggregates have shown that the distribution of grains varies according to the granular class. **Figure 4** shows the grain size curve of the raw laterite and that of the different granular classes.

Studies carried out on lateral aggregates have shown that the distribution of grains varies according to the granular class. **Table 1** presents the results of the physical characterization of the aggregates by granular class constituted following the granulometric analysis.

The absolute density of passers-by through a 0.08 mm sieve, measured with a helium pycnometer, gives a value of 2.661 g/cm³. The VBS value which makes it possible to characterize the clay content of a soil is 0.66. This shows that the study material is a clayey-sandy soil sensitive to water. However, the sand equivalent is 21.96 ± 0.91 which is well below the indicative value of normal sand (70 ≤ ES < 80) used in the production of good concrete. The measured Atterberg limits give WL = 40%, WP = IP = 21% and 19%.

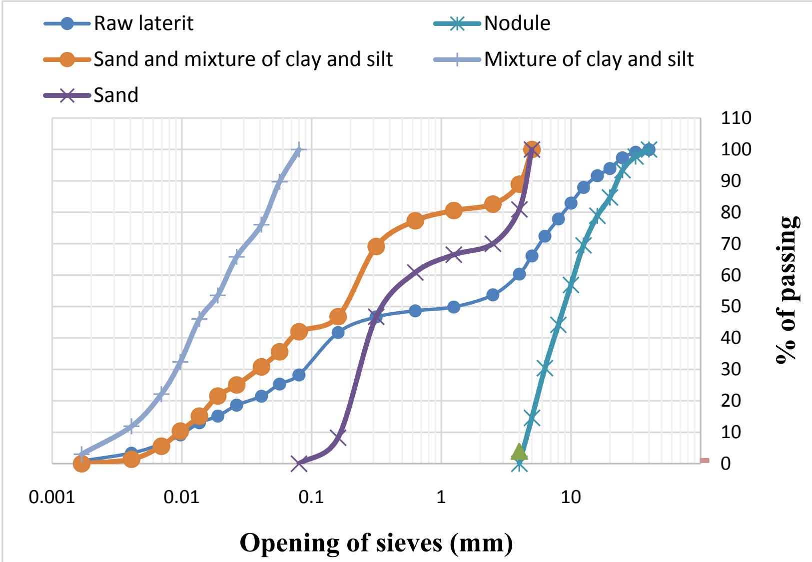


Figure 4. Particle size of aggregates.

Table 1. Physical characteristics of granular aggregates by class.

Settings	Granular classes				Average weight
	25/4	1.25/4	0.16/1.25	0.08/0.16	
Average diameter (mm)	14.500	2.625	0.705	0.120	-
MVV (g/cm³)	1.613	1.577	1.534	1.518	**1.560**
MVAb (g/cm³)	2822	2.992	2.813	2.715	**2862**
MVR (g/cm³)	2.575	2.682	2.636	2.620	**2.628**
Absorption (%)	4.609	3.853	2.375	1.338	**3.044**
Compactness	0.626	0.588	0.582	0.580	**0.594**

The measurement of the abrasion rate on the nodules reveals that the 6/10 laterite class gives a Los Angeles coefficient equal to 75.1 greater than 40, which classifies the 6/10 laterite as a poor and friable aggregate. The Los Angeles coefficient of laterite class 10/14 is 67.5, also greater than 40. From these results, it can be concluded that the laterite nodules, object of this study, have an unacceptable quality for the works of implementation of conventional concretes.

It emerges from the particle size analysis that the raw laterite under study contains approximately 28.26% of particles with a size of less than 80 µm, 32.12% of particles with a diameter between 80 µm and 4 mm (sand) and 39.62% of nodules (particles with a diameter between 4 mm and 25 mm. According to studies of lateritic gravels in Senegal by Ndiaye, (2013) [22], the laterites contain 10% to 35% of fines (sieve going from 80 µm) and 20% to 60% of coarser particles (2 mm reject sieve). TAKALA H, (2017) [6] shows in his studies on Cameroon laterites that the granular skeleton (particle size < 2 mm) represents approximately 26% of the raw material mixture. This value is lower than that found but does not influence the nature of the lateritic material In addition, the curve has the appearance of a clayey-sandy gravel with an appearance between

0.25 mm and 1 mm This is not different from the results of P. VAN GANSE, (1957) [7], on the laterite of the Belgian Congo According to M. NDIAYE *et al.*, (2013) [22], the plasticity index of Senegalese gravels is studied between 22.1 and 23.2. On the other hand, for laterite from another quarry (Samba), the plasticity index is 16.4. This shows the variability of its parameters. Nevertheless, these determined values make it possible to make a classification of the studied material. Studies by (M. LAQUERBE *et al.*, 1995) [5], on the rational use of lateritic gravel from Senegal and sand from the dunes as concrete aggregate, show that the laterite studied has a real density of 2.68 g/cm^3, an apparent density of 1.5 g/cm^3, an absorption coefficient of 7.15. Issiakou MS (2015) [9] and P. VAN GIMP, (1957) [7] present in their study a density of between 2.2 and 2.8 g/cm^3. These data clearly confirm the values found, which fall well within the same range. However, with respect to the actual density of the nodules, there is a loss of mass during the test. Which has not been reported by any author. This mass loss shows subjectivity of the actual nodule density even though it is within the indicated range. To better understand this phenomenon, it is important to push curiosity to better justify the results. Thus, the analysis of this phenomenon depending on the residence time in water of the material was made. On a 1000 g sample soaked in water, a loss of about 46 g is observed after 10 hours. **Figure 5** shows mass loss by nodules over time. However, **Figure 6** shows the density variations according to the granular classes.

5.2. Strength of Laterite Concrete

The results of the mechanical performance of the concrete vary according to the exposure of the latter (mode of preservation). These results are presented in **Table 2** for the samples after 28 days of age.

Table 2. Densities and average strength of the specimens at 28 days.

Reference specimens	Gravity Moy	σ MPA
Samples stored in the open air	2041.98	0.27
Test tubes wrapped in bag	2194.74	6.30
Specimens stored in water	2201.08	1.94

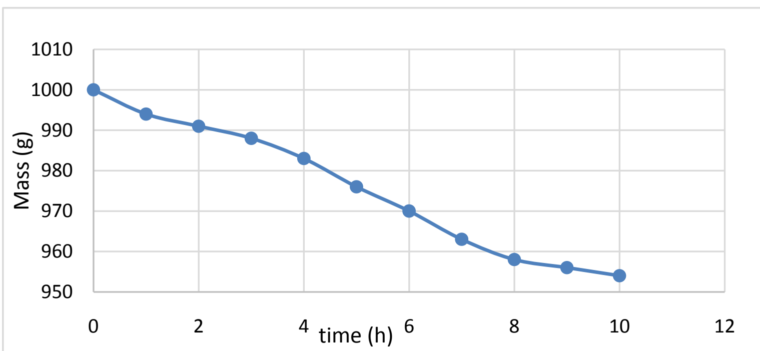


Figure 5. Variation in nodule mass as a function of time in the presence of water.

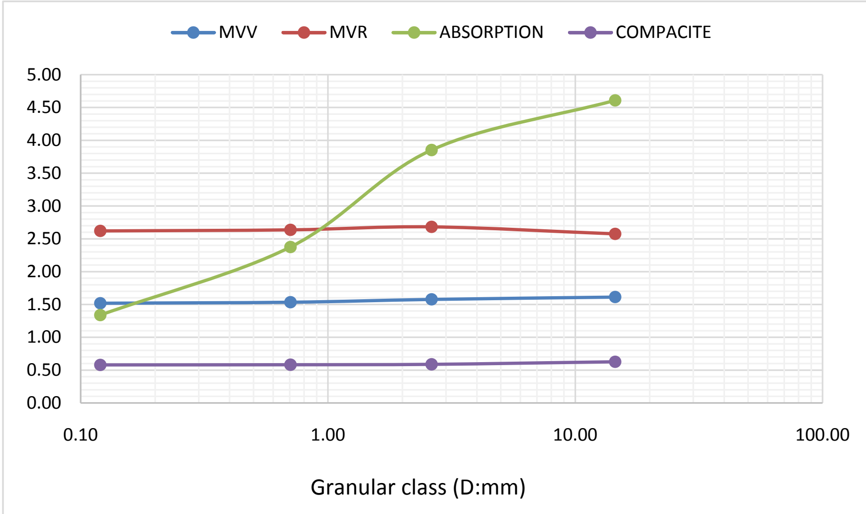


Figure 6. Variation of the apparent, effective, compact, and absorbent density of granules according to different granular classes.

As can be seen, specimens held in a plastic bag wrap give the highest compressive strengths. However, those kept in the open air offer almost no resistance. This can be explained by the fact that the hydration of the cement was quickly interrupted due to the evaporation of water in the specimens. Thus, the results of this study make it possible to choose as method of conservation of the specimens, the method of the plastic bags which allows the specimen to preserve an important humidity for a better adhesion and a better curing of the concrete.

The target resistance is far from being reached. The best resistance at 28 days is around 31.5% of 20 MPa. This can be explained by the fact that the aggregates used do not meet the criteria of the aggregates commonly used and considered by DREUX GORISSE [19]. In particular, the fineness modulus = 2.0 which must be between 2.2 and 2.8; ES sand equivalent = 21.96%, which must be at least greater than 60%.

The absolute volume method is the one chosen because of its simplicity in determining the different components and above all it allows several parameters to be studied at the same time. However, the Dreux-GORISSE method has made it possible to identify a few concrete parameters to be achieved, in particular how to preserve the specimens. The concretes were subjected to compression tests on cylindrical specimens of (11 × 22) cm^2, each series is made up of three specimens.

5.2.1. Physical Characteristics of Concrete

Figure 7 and **Figure 8** show respectively the variation of the deflection and the variation of the density of hardened concrete.

There is an increase in slump as the W/C ratio increases and so does the cement dosage. Indeed, the running is linked to the quantity of water in the mixture. This explains why the concrete becomes more and more fluid with the increase in water in the mixture.

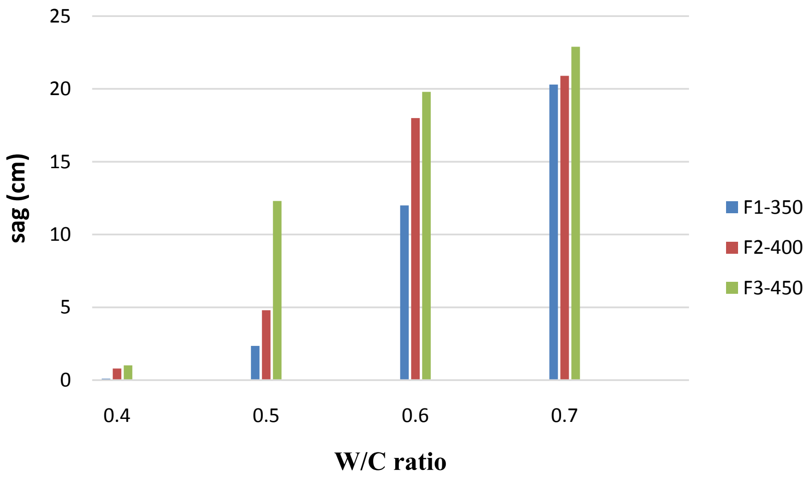


Figure 7. Evolution of the casting of the type of formulation according to the W/C ratio.

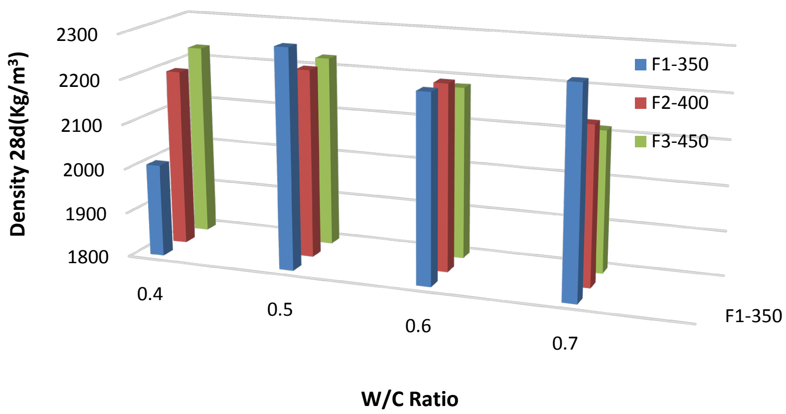


Figure 8. Density variation as a function of dosage and W/C ratio.

5.2.2. Mechanical Properties of Concrete

The results presented in **Figure 9** show that the compressive strength at 28 days is a decreasing function of the Eeff/C ratio if the dosage is between 350 and 400 and simultaneously of the Eeff/C ratio between 0.4 and 0.6. The compressive strength at 28 days decreases by 17% by increasing the W/C ratio from 0.5 to 0.55. The decrease in resistance with increasing W/C ratio is mainly due to a lack of formation of hydrated calcium silicate (CSH) which participates in the development of resistance [23].

With the results obtained, we can be convinced that the best mechanical performance is obtained with a formulation in which the N/S ratio is 2.5, the W/C ratio is 0.5 and a cement content of 450 kg/m^3. The resistance obtained is better for a concrete structure, but its thermal conductivity is closely linked to several parameters, including the cement content, which opens up discussions on the cost and further reflection on laterite aggregate based on concrete.

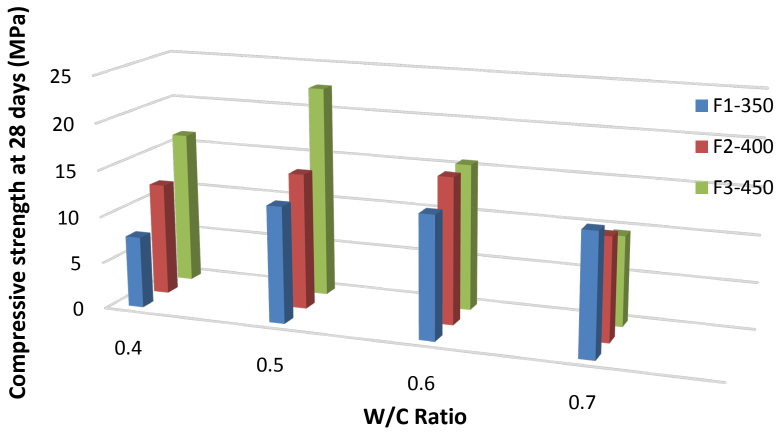


Figure 9. Variation in compressive strength as a function of dosage and W/C ratio.

5.3. Cement and Compressive Strength

Optimization for better performance then consisted of varying the N/S parameter from 2.2 to 2.8 by setting the cement content at 400 kg/m^3 and still maintaining the previous variation of E/C. **Table 3** presents the concrete strength results at 14 days of age.

However, **Table 4** and **Table 5** respectively present the results of concrete compressive strength at 14 days of age and the density of the latter.

After changing the N/S ratio, it should be noted that the best resistances are obtained with an N/S of 2.8 and an E/C ratio of 0.4. This resistance decreases as the E/C increases. However, the density of the concrete thus obtained also decreases as the W/C ratio increases. The concrete thus obtained has a very low workability compared to the value recommended for normal concrete. **Figure 10** shows the results of the concrete workability for the ratio G/S = 2.8. These results show that the workability increases as the C/E ratio itself increases.

From the previous results, it is important to remember that the ratio G/S = 2.8 is the optimal formulation. Based on these results, the study presented below presents the results at 7, 14, 21 and 28 days. The results make it possible to calculate the rate of increase in resistance from the 7th day to the 28th day when the resistances are almost maximum. **Table 6** and **Figure 11** show you the results obtained for the different granular mixtures.

As the W/C ratio increases, the density of the concrete obtained decreases. However, the maneuverability increases. Similarly, the strength of concrete decreases with the W/C ratio. According to the work of Falade, (1994) [13] presented, the same behavior is observed on the formulated lateritic concrete. After the formulation, it is important to note that the increase in W/C does not favor the improvement of the mechanical characteristics of the concrete in compression as in traction. The best resistances are obtained with the mixture (1:1:2.8) which corresponds to the weight proportions of (cement, sand, gravel) with a W/C = 0.40 taking the absorption of the aggregates. Going back to the results of

Balogun & Adepegba, (1982) and Falade, (1994) [13] who proposed mixtures respectively (1:1.5:3) and (1:1:2), at the best resistance, the mixture obtained is part of a perspective of rationalization of aggregates for the same objectives of obtaining concrete structures.

Table 3. Mechanical compressive strength of laterite concrete at 14 days according to the different formulations.

mechanical resistance to 14 days of age (MPa)		N/S		
		2.2	2.5	2.8
W/C	0.4	8.1	11.9	15.58
	0.5	13.75	10.04	14.24
	0.6	12.48	7.95	11.72
	0.7	7.71	9.78	9.86

Table 4. Mechanical resistance in compression and in tension by splitting of laterite concrete at 28 days according to the different formulations.

compressive strength and tensile splitting formulated concretes							
		G/S					
		2.2		2.5		2.8	
		C	T	C	T	C	T
W/C	0.4	14.64 ± 1.42	1.13 ± 0.39	13.46 ± 1.37	1.37 ± 0.19	21.23 ± 1.24	1.87 ± 0.10
	0.5	16.81 ± 1.8	1.25 ± 0.1	13.81 ± 1.18	1.26 ± 0.07	17.26 ± 1.65	1.18 ± 0.31
	0.6	15.79 ± 0.57	1.20 ± 0.2	11.45 ± 0.88	1.31 ± 0.33	16.68 ± 1.38	1.53 ± 0.12
	0.7	10.89 ± 0.36	1.15 ± 0.27	11.06 ± 0.99	1.22 ± 0.27	13.35 ± 1.25	1.26 ± 0.30

Table 5. Density of laterite concrete according to formulation parameters.

Change in density concretes a function of E/C and G/S				
		G/S		
		2.2	2.5	2.8
W/C	0.4	2167.8 ± 47.01	2218.07 ± 19.48	2230.02 ± 61.65
	0.5	2126.68 ± 12.73	2169.0 ± 11.13	2156.67 ± 32.11
	0.6	2106.95 ± 19.09	2069, 11 ± 31.77	2140.81 ± 38.49
	0.7	2052.93 ± 64.13	2063.9 ± 53.19	2066.12 ± 14.17

Table 6. Evolution of resistance over time (at J days of age).

kn	ke	Date				Rate of increase
		7 days	14 days	21 Days	28 Days	
2.8	0.4	18.02 ± 1.38	19.4 ± 0.43	21.95 ± 0.85	22.89 ± 1.39	21.28%
	0.5	12.73 ± 0.36	15.12 ± 0.33	16.69 ± 0.82	18.37 ± 1.45	30.70%
	0.6	8.47 ± 0.74	9.17 ± 0.51	9.97 ± 3.24	13.07 ± 0.96	35.20%
	0.7	6.64 ± 1.21	7.26 ± 0.74	7.71 ± 0.66	8.04 ± 0.51	17.41%

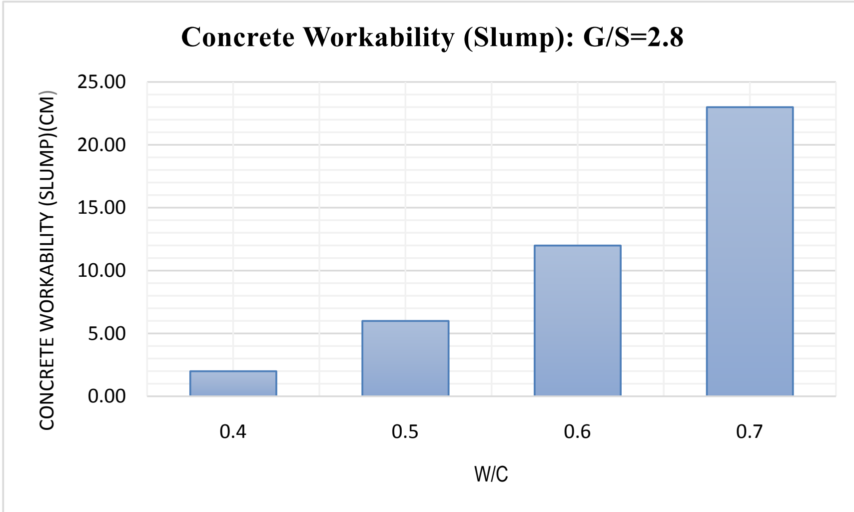


Figure 10. Workability variability as a function of the Eeff/C ratio.

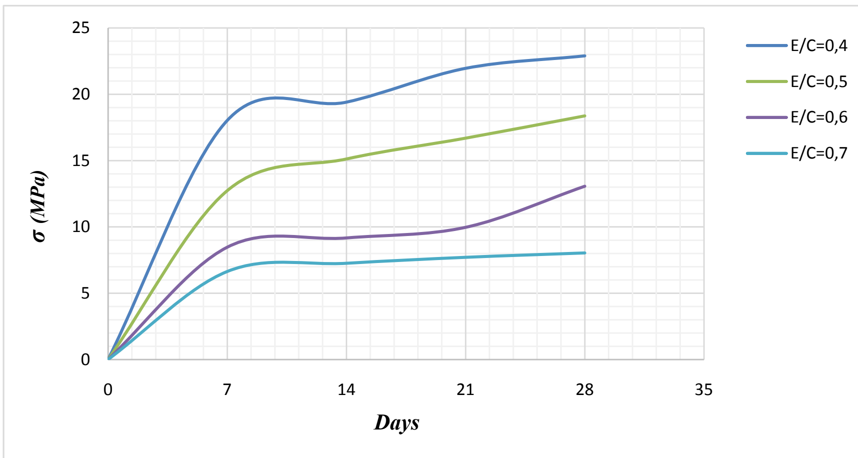


Figure 11. Evolution of resistance over time (at J days of age).

Analysis of **Table 6** and **Figure 11** shows that the chemical reaction that allows cement concrete to set is quite rapid. After 7 days, the mechanical strength is already around 80% of the final strength of the concrete at 28 days. The hardening speed of the concrete can however be affected by the nature of the cement used (CEM II-B-LL-42.5R), the temperature of the material during its hardening, the quantity of water used, the fineness of the grinding of the cement, and the mode of conservation. It is noted that after 28 days, an ascent of the resistance curves is noted for the formulations for which E/C takes the values 0.4 and 0.5. However, stabilization for the formulations for which E/C takes the values 0.6 and 0.7, which clearly indicates that beyond 28 days, even better mechanical performance can be obtained for the laterite concrete thus formulated.

6. Conclusions

The results of this study offer many perspectives on the use of raw laterite as concrete formulation materials. Initially, the study is essentially based on the determination of the physical characteristics of lateritic aggregates. The aggregates used have an absolute density equal to 2.73 and 2.82 for sand with nodules. The absorption rate is 3.01% and 5.71% respectively for sand and nodules. The study of the distribution of grains on the sand and its behavior in water revealed the presence of some water-sensitive plastic clay sand. The density variation detected results from the non-homogeneity of the grains forming the nodules. This fact generates a nodule of dimensional change of the grains in the presence of water,

In a second time, the formulation of the lateritic concrete made shows that the design of the mixture passes by the control of the parameters. This revealed that the density of lateritic concrete varies between 2000 and 2250 kg/m^3. It reveals that a dosage of 400 kg of cement with a W/C ratio equal to 0.4 and an L/S ratio = 2.8 gives greater compressive strength up to 23 MPa at 28 days. This strength class allows concrete to be used as concrete in the structure of civil engineering works. To better control this concrete, it is necessary to take an interest in its durability and its thermal conductivity.

Conflicts of Interest

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

References

[1] Youssouf, I. and Lawani, M. (2002) Les sols beninois: Classification dans la Base de référence mondiale, 29-50. (In French) https://docplayer.fr/58370601-Les-sols-beninois-classification-dans-la-base-de-reference-mondiale.html

[2] Kasthurba, A.K. (2006) Characterization and Study of Weathering Mechanisms of Malabar Laterite for Building Purposes. Unpublished PhD Thesis, Indian Institute of Technology, Madras.

[3] Kasthurba, A.K., Santhanam, M. and Mathews, M.S. (2007) Investigation of Laterite Stones for Building Purpose from Malabar Region, Kerala State, SW India—Part 1: Field Studies and Profile Characterisation. *Construction and Building Materials*, **21**, 73-82. https://doi.org/10.1016/j.conbuildmat.2005.07.006

[4] Lawane, A., Pantet, A., Vinai, R. and Thomassin, J.H. (2011) Geological and Geomechanical Study of the Laterites of Dano (Burkina Faso) for Use in Housing. 29*th University Meetings of Civil Engineering*, Tlemcen, 29-31 May 2011, 206-215.

[5] Laquerbe, M., Cisse, I. and Ahouansou, G. (1995) For Rational Use of Lateritic Gravel and Dune Sand as Concrete Aggregate Application to the Case of Senegal. *Materials and Structures*, **28**, 604-610. https://doi.org/10.1007/BF02473193

[6] Takala, H.B. (2017) Geotechnical Characterization and Evaluation in Road Construction of the Laterites of Batoufam, West Cameroon. 16.

[7] Van Ganse, R. (1957) Properties and Applications of Laterites in the Belgian Congo. Royal Academy of Colonial Sciences, Editions J.Duculot, S.A. Gembloux, Belgique.

[8] Lawane Gana, A. (2014) Characterization of Indurated Lateritic Materials for Better

Use in Habitat in Africa. PhD Thesis, Le Havre University, Le Havre.

[9] Issiakou, M.S., Saiyouri, N., Anguy, Y., Gaborieau, C. and Fabre, R. (2015) Study of Lateritic Materials Used in Road Construction in Niger: Improvement Method.

[10] Issiakou, M.S. (2016) Characterization and Valuation of Lateritic Materials Used in Road Construction in Niger. 350.

[11] Raju, N.K. and Ramakrishnan, R. (1972) Properties of Laterite Aggregate Concrete. *Materiaux et Construction*, **5**, 307-314. https://doi.org/10.1007/BF02474873

[12] Balogun, L.A. and Adepegba, D. (1982) Effect of Varying Sand Content in Laterized Concrete. *International Journal of Cement Composites and Lightweight Concrete*, **4**, 235-240. https://doi.org/10.1016/0262-5075(82)90027-6

[13] Falade, F. (1994) Influence of Water/Cement Ratios and Mix Proportions on Workability and Characteristic Strength of Concrete Containing Laterite Fine Aggregate. *Building and Environment*, **29**, 237-240. https://doi.org/10.1016/0360-1323(94)90073-6

[14] Osunade, J.A. (2002) The Influence of Coarse Aggregate and Reinforcement on the Anchorage Bond Strength of Laterized Concrete. *Building and Environment*, **37**, 727-732. https://doi.org/10.1016/S0360-1323(01)00050-6

[15] Ukpata, J.O., Ephraim, M.E. and Akeke, G.A. (2012) Compressive Strength of Concrete Using Lateritic Sand and Quarry Dust as Fine Aggregate. *ARPN Journal of Engineering and Applied Sciences*, **7**, 81-92. https://doi.org/10.1201/b13165-68

[16] Kamaruzaman, N.W. and Muthusamy, K. (2012) Engineering Properties of Concrete with Laterite Aggregate as Partial Coarse Aggregate Replacement. *International Journal of Civil Engineering and Geo-Environmental*, **3**, 47-50.

[17] Salako, V.K., Kénou, C., Dainou, K., Assogbadjo, A.E. and Kakaï, R.G. (2019) Impacts of Land Use Types on Spatial Patterns and Neighborhood Distance of the Agroforestry Palm *Borassus aethiopum* Mart. in Two Climatic Regions in Benin, West Africa. *Agroforestry Systems*, **93**, 1057-1071. https://doi.org/10.1007/s10457-018-0205-y

[18] Dreux, G. (1981) New Guide to Concrete-3rd Edition. Collect. UTI-ITBTP.

[19] Dreux, G. (1982) Composition of Concretes. Tech. The Engineer C, Vol. 2, p. 220.

[20] Drissi, M., Mezghiche, B. and Khouadia, M.L.K. (2015) Influence of Concrete Composition Parameters on Its Compressive Strength. Courier Knowledge, No. 20, 73-78.

[21] Ndiaye, M. (2013) Contribution to the Study of Lateritic Soils in Senegal and Brazil. PhD Thesis, Paris Est.

[22] Salau, M.A. and Busari, A.O. (2015) Effect of Different Coarse Aggregate Sizes on the Strength Characteristics of Laterized Concrete. *IOP Conference Series*: *Materials Science and Engineering*, **96**, Article ID: 012079. https://doi.org/10.1088/1757-899X/96/1/012079

[23] Agossou, Y.D., Lecomte, A., Boissiere, R., Adjovi, E.C., et al. (2022) Use of Benin Laterites for the Mix Design of Structural Concrete. *World Academy of Science, Engineering and Technology*, *International Journal of Structural and Construction Engineering*, **16**, 278-288.