International Journal of Advanced Materials Research
Vol. 7, No. 1, 2021, pp. 8-17
http://www.aiscience.org/journal/ijamr
ISSN: 2381-6805 (Print); ISSN: 2381-6813 (Online)

Experimental Study of the Mechanical and Hydraulic Behavior of Cement Stabilized Lateritic Soil Blocks CPJ 32.5

Bozabe Renonet Karka[1, *], Bassa Bruno[2]

[1]Department of Civil Engineering, National High School of Publics Works (NHSPW), University of N'Djamena, N'Djamena, Chad
[2]Faculty of Exact and Applied Sciences (FEAS), University of N'Djamena, N'Djamena, Chad

Abstract

The study is an experimental approach to stabilize a soil mass of laterite. Preliminary identification parameters and physical characteristics of the soil collected on site are determined in the laboratory. Next, the "trial and error" method is used to perform different mixtures by varying the proportions of fine particles and CPJ 32.5 cement. With these mixtures and with the help of a manual press, the freestanding and heavy blocks are produced. After cures of 7, 14 and 28 days, the results of the tests show that the resistance to compression (RC) of the blocks in the dry state gradually increases depending on the cement dosage and the duration of cure. At 10% cement and around 30% fine particles, the value of the RC of 7.9 MPa after 28 days is higher than the recommended values of 4.0 MPa for load-bearing walls by the International Centre for Earth Architecture (CRAterre). Moreover, a 24-hour stay of the dry blocks in the water causes the RC to fall from 22% to 28% depending on the cement dosage. However, the absorption coefficient of 2.48 $g/cm^2.s^{1/2}$ of blocks with 10% cement is less than 20 $g/cm^2.s^{1/2}$, limit value below which the NFP554 standard qualifies the low capillarity blocks. However, this loss of RC has no impact because its value at the fall remains higher than the recommended normative values. Finally, this stabilization approach makes it possible to obtain resistant blocks with a rational cement dosage, aesthetic aspect, low capillarity and cost.

Keywords

Absorption Coefficient, Compressive Strength, CPJ 32.5 Cement, Carrier Wall, Fine Particle, Laterite

Received: July 2, 2021 / Accepted: August 11, 2021 / Published online: August 20, 2021

1. Introduction

Chad, the Sahelian country of Central Africa, is full of building materials that are not all of good quality and, moreover, the appropriate technology for their implementation is lacking. This is the case of swollen clay soils called montmorillonite [1, 2]. This type of soil is very sensitive to atmospheric conditions and presents stability problems when used to produce blocks in wall construction [3, 4]. With a view to remedying these handicaps, the idea of highlighting laterite came into being because they abound in the area of this study. In fact, lateritic soils are generally compacted into foundation and base layers in road construction [5, 6]. Also, traditionally, these are used in habitat masonry [7]. After a few months of rains, the walls built with lateritic soils do not collapse completely like the walls made of clay soil blocks but, present enormous degradation to such an extent that it is necessary to regularly rehabilitate them. In order to increase their mechanical and water resistance, it is necessary to modify the quality of lateritic soils with CPJ 32.5 cement and fine particles because, the presence of these two components seems to significantly influence the mechanical and water behavior of the blocks.

* Corresponding author
E-mail address: bozabe_k@live.fr (B. R. Karka)

In selecting cement to stabilize laterite blocks after molding, this study aims to exploit the effects of the chemical reactions between cement and laterite explained in sub-paragraph 2.1.6. Also, an intervention on the soil texture by modifying its granular composition by sieving surplus grain fractions or by adding missing grain fractions is carried out to obtain the best compaction by simple compression. Accordingly, in extension the methods already recommended for compressed earth bricks (CEB) by the International Centre for Earth Architecture, this new approach to earth block stabilization complements the many techniques currently used [8]. For, apart from some physical qualities of the laterite exhibited in the second part of this work, the lateritic soils blocks are very regular in shape and dimension; they are full or perforated; they have many advantages (economic, ecological, availability, comfort, architectural quality, etc.) and allow carrying out very varied masonry works. Also, they are made from moistened earth and simply compacted in a manual press without the use of a fuel for cooking. Finally, this work constitutes the development of local materials in the construction of works accessible by all social ranks.

2. Materials and Methods

2.1. Materials

Using a manual press (Figure 1) equipped with a mould of dimensions 10 x 15 x 28 cm^3, the compressed blocks are made by mixing with water the laterite soils, the cement CPJ 32.5 and the fine particles of dimensions less than 0.2 mm. The production process of the blocks is explained in sub-paragraph 2.2. 2. Sub-paragraphs 2.1.1 to 2.1.5 provide a brief overview of the different constituents used. These are their intrinsic definitions and properties.

Figure 1. Manual press from 1.1 MPa to 2.3 MPa.

2.1.1. Definition and Families of Laterite

The Larousse dictionary in six volumes (1975 edition) defines laterite in the following way: « *feminine name, later - eris Latin, brick, bright red or brown red soil, soil very rich in iron oxide and alumina formed in a warm climate. Laterite are highly leached soils, rich in iron in the form of hematite* *(Fe_2O_3)(OH), free alumina (AL_2O_3) and silica (SiO_2)* ».

For more than two centuries the term laterite has appeared in the scientific literature. According to multiple research on Laterite, and in particular those of Autret (1983), which have made it possible to identify a large number of books devoted to the formulation of Laterite, four (04) essential families of lateritic soils are distinguished: *Fine ferralitic soils; lateritic gravel, most often used in road construction; the lateritic carapace, very hard but can be used thanks to earth moving machines and the laterite armour which is a layer of highly agglomerated slag-like materials.*

2.1.2. Origin and Process of Laterization

The phenomenon of laterization is a process of soil formation specific to hot and humid tropical regions. This is an alteration of the parent rock, the essential characteristic of which is the solution and then the departure of silica. This leaching phenomenon is accompanied by an enrichment of iron and alumina in the form of Fe_2O_3 and Al_2O_3 oxides. Indeed, Seaton et al. (1938) demonstrate that the word laterite does not describe a material with constant properties but rather a family of different materials. This family diversity is linked to climatic conditions (alternating between a rainy and dry season, rainfall, temperature, vegetation) and geology (mother rock and topography) according to the summary of researchers by De Graft-Johnson and Bathia (1969) to the 7th International Congress of Soil Mechanics and Foundation Work.

2.1.3. Distribution and Field of Use of Laterite in Chad

In general, Laterite is located in areas where it is very hot and rains are abundant either throughout the year or during a wet season. In fact, laterite can be found in several southern regions of Chad, more precisely in the Mayo-Kébbi West, the two Logones, the Mandoul, the Moyen Chari, the Guéra, the Tandjilé West, the Wadi-Fira, the Batha Est and in the Salamat [9]. The laterite used for this study is that of the West Tandjilé quarry (Figure 2-a) which is located on the Kélo - Moundou axis. These are gravelly lateritic with an image shown in Figure 2-b. The Latitude, Longitude and Altitude are respectively 9.299615; 15.801094 and 374 meters. According to the Google Maps application consulted on April 25, 2015 at 10:00 p.m., the coordinates of the site are: 9°17'58.612''N, 15°48'3.937''E.

For centuries, they have been used multiple times in the field of Civil Engineering, especially in pavement bodies as base layer and foundation layer and given their best characteristics; they may be used for other purposes, in particular in the production of blocks for the construction of walls.

Figure 2. (a) Lateritic quarry operated – (b) Laterite used.

2.1.4. Fine particles in Laterite

The fine particles constitute the set of solid grains with an average diameter of less than 0.2 mm contained in the laterite under study. This is silt (between 0.002 mm and 0.063 mm) and fine sand (between 0.063 mm and 0.2 mm) [10]. Generally, the clay fraction (less than 0.080 mm) contained in the laterite is very small.

2.1.5. CPJ Cement 32.5

Cement is a hydraulic binder that is usually in the form of a grey powder. With a very high mechanical strength, cement is used in the manufacture of concrete and mortar and then plays the role of chemical stabilizer allowing a better use of certain neglected materials faults of their properties like clay and laterite. In contact with water, the cement condenses and takes hold to harden, forming a solid and resistant mass, it is following the change of state in its kind in the presence of water that it is called «the hydraulic binder». It is the local cement whose availability can be permanent, it is type CPA 32.5. The chemical constituents of this cement are presented in table 1.

Table 1. Chemical Constituents of CPJ Cement 32.5.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	N_2O et K_2O
18 – 24%	4 – 8%	1 – 5%	60 – 66%	0.25 – 4%	0.1 – 2%

2.1.6. Reaction Between Cement and Laterite

In the presence of cement, laterite reacts according to three phases: Hydration causes the formation of cement gels on the surface of the laterite agglomerates, then forces it to begin a degradation; Progression of hydration that activates the disintegration of laterite agglomerates, these are penetrated in depth by cement gels and finally the intimate interpenetration of cement gels and lateritic agglomerates, hydration persists but slower. In fact, it is a set of chemical hydration reactions allowing the passage of the cement paste from liquid to solid state. Hydrated cement paste is the result of chemical reactions between water and cement compounds C_3S, C_2S, C_3A and C_4AF. This is a complex process in which these major cement compounds react to form new insoluble compounds of hydrated calcium silicates (C-S-H), portlandite ($Ca(OH)_2$) and ettringite ($(CaO)_6,(Al_2O_3),(SO_3)_3,(32H_2O)$) which causes the material to take and gradually harden [11].

2.2. Methods

In order to better explain compaction and to describe the mechanical and hydraulic behavior of the lateritic soil blocks made up, tests are carried out in the laboratory of the National High School of Public Work of N'Djamena to determine the identification and status parameters (physical characteristics). Each test shall be conducted in accordance with its governing standard.

2.2.1. Laboratory Testing of the Lateritic Soil Used

Density of solid particles Test: Standard NF P 94-054

The absolute density ρ_s of the solid particles of the laterite is determined from the expression (1).

$$\rho_s = \frac{\rho_\omega\,(m3-m1)}{m2+m3-m1-m4} \qquad (1)$$

With γ_ω the density of water equal to 1 g/cm^3; m1: the mass of the empty pycnometer; m2: mass of the pycnometer + distilled water; m3: mass of the pycnometer + soil sample and m4: mass of the pycnometer + soil sample + distilled water.

The apparent density ρ is calculated from the expression (2).

$$\rho = \frac{m}{v} \qquad (2)$$

The results obtained for the lateritic soils studied are ρ_s =2.60 g/cm^3 and ρ =1.874 g/cm^3. According to NF P 94-054, these density values are acceptable for the preparation of blocks of earth.

Particle size analysis by sieving Test: NF P 94-056

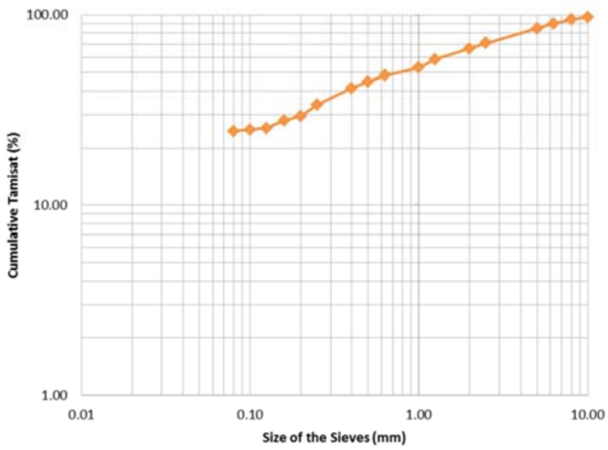

Figure 3. Laterite size curve.

The coefficient of uniformity C_u and the coefficient of curvature C_c are calculated from the following expressions (3) and (4):

$$C_u = \frac{d_{10}}{d_{60}} \qquad (3)$$

$$C_c = \frac{(d_{30})^2}{(d_{10}\ x\ d_{60})} \quad (4)$$

With d_n, the sieve diameter (x-axis) corresponding to n% of the cumulative sieve size (y-axis). According to the particle size curve in figure 3 and the expressions (3) and (4), the lateritic soil is composed of about 25% silt or silt (between 0.002 mm and 0.063 mm), 5% fine sand (between 0.063 mm and 0.2 mm), 37% coarse sand (between 0.63 mm and 2 mm) and 33% gravel (between 2 mm and 20 mm). Since the elements corresponding to 10% of sieve are less than 0,080 mm, the coefficients C_u and C_c of the laterite used cannot be determined.

Atterberg Limits Test: NF P 94-051

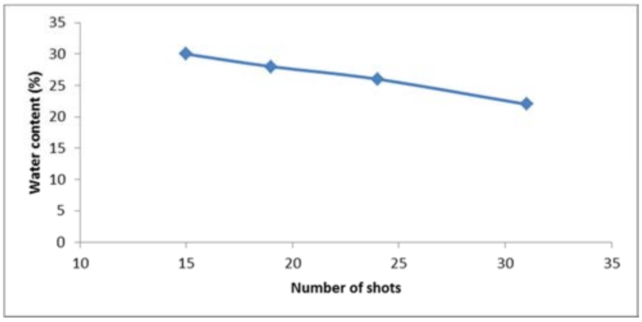

Figure 4. Laterite liquidity limit curve.

Atterberg limits consist of determining the moisture content of two consistencies of a coherent soil. Its purpose is to measure water contents and the identification of limits (liquid or plastic) to allow the classification of soils.

Liquidity limit: The liquidity limit ω_l is the water content that corresponds to a closure of 25 blows. The Casagrande device is used to determine the liquidity limit. The mean line is drawn between the points whose abscissa are the number of strokes and the ordinates, the corresponding water contents. According to Figure 4, the liquidity limit of laterite is ω_l = 25.00%.

Plasticity limit: The plasticity limit ω_p is the water content expressed as a percentage of the spindle that breaks in small sections 1 to 2 centimeters long when its diameter reaches 3 millimeters. The plasticity limit of laterite is ω_p = 22.00%.

Plasticity index: This is the difference between the liquidity limit and the plasticity limit calculated by the expression (5).

$$I_p = \omega_l - \omega_p \quad (5)$$

Consistency index: It is calculated by the expression (6).

$$I_c = \frac{\omega_l - \omega}{I_P} \quad (6)$$

With ω the natural water content this is equal to 8.00%. It follows that the consistency index I_c = 5.6.

From the plasticity index I_p, the consistency index I_c and the consistency zone of CRAterre, the lateritic soil studied can be described as non plastic soil with firm consistency because $I_p = 3 < 12$ and that $I_c = 5.6 > 1$.

Modified Proctor Test: NF P 94-093

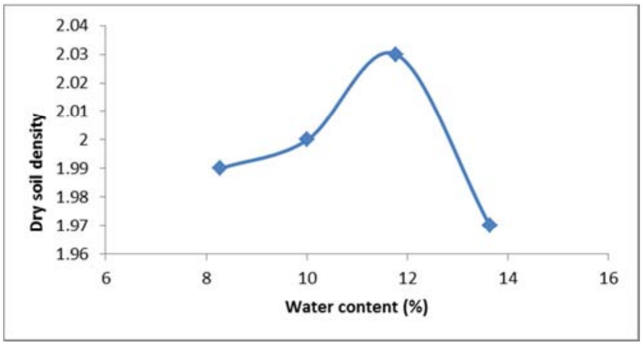

Figure 5. Proctor laterite curve.

Its purpose is to determine the compaction characteristics of a soil. For each compacted mould, the moisture content ω is determined and the dry soil density γ_d is calculated by expression (7).

$$\gamma_d = \frac{\gamma}{1+\omega} \quad (7)$$

With γ wet density of compacted soil which is given by the expression (8).

$$\gamma = \text{(Compacted Soil Weight) / (Mould Volume)} \quad (8)$$

The Proctor curve is plotted in a diagram with water contents ω on the abscissa and dry soil densities γ_d on the ordinate (Figure 5). Finally, the optimum compaction characteristics are the coordinates $(\omega_{Opt,}, \gamma_{dmax})$ of the top of the Proctor curve. Thus, an optimal moisture content of 11.4% and a dry density of 2.03 g/cm^3 are obtained for the laterite studied.

Table 2. Summary of the physical characteristics of laterite.

Material	Analysis Particle size					Limits d'Atterberg		
	< 2mm	< 80µm	M_f	C_u	C_c	ω_l	ω_p	I_p
Laterite	66.51	24.63	2.74	-	-	25.00	22.00	3.00

Table 2. Continued.

Material	Consistence	Proctor Modified		Apparent density	Absolute density
	I_c	γ_{dMax}	ω_{Optt}	ρ (g/cm^3)	ρ_s (g/cm^3)
Laterite	5.6	2.03	11.4	1.87	2.60

2.2.2. Laboratory Testing of CPJ Cement 32.5 Used

Testing of CPJ 32.5 cement resulted in the following characteristics:

Fineness of milling Test: ASTM C204

The fineness of the cement milling is determined according to its specific surface by the Blaine apparatus or by the refusal to the 80 micron sieve which must be less than 5%. It expresses the fineness of the particles. Its knowledge provides access to the following information: the rate of hydration which is inversely proportional to the diameter of the cement grains; the amount of gypsum to be added: the finer the cement, the more gypsum is required to control the uptake of tricalcium aluminate and the degree of shrinkage and cracking: the finer the cement, the more prone it is to shrinkage and cracking.

Setting time Test: NF EN 196-3

The Vicat device (Figure 6) is used to determine the start and end time of taking. The starting point, which corresponds to a relative increase in viscosity (loss of plasticity), is the moment when the tip of the 1 mm diameter needle penetrates the 25 mm paste in 30 seconds. The end of taking takes place when the needle no longer penetrates. For the cement used, the start time is 175 minutes and the end time is 275 minutes.

Figure 6. Vicat device.

2.2.3. Lateritic Soil Stabilization

This study combines three (3) ways to stabilize lateritic soils:

Mechanical Stabilization which consists of molding and compacting the soil using a manual press with a capacity of 1.1 to 2.3 MPa of figure 6 in order to modify its compressibility, its density, its mechanical resistance, its permeability and its porosity. This way evacuates the air by reducing the pores and capillary channels.

Physical stabilization is an intervention on the texture of the laterite by modifying its granular composition by varying the percentage of its fine particles from 0% to 50% of the given mass of a laterite sample.

The chemical stabilization which consists in adding by varying the percentages of cement CPJ 32.5 in relation to a given mass of lateritic soils and then homogenizing and pressing them to obtain a good quality product.– Because of this principle, we started with a dosage of 0% then 4%, 6%, 8% and finally 10% cement.

2.2.4. Production of Compressed Soils Blocs

The stabilized block is a mixture of different fractions of lateritic soils with or without fine particles and binder which is cement compound CPJ 32.5. The implementation is done with water. According to the protocols of the reference documents mentioned, the samples of lateritic soil blocks are produced at the Laboratory of the NHSPW of N'Djamena, for a dry cure of 28 days [12-16]. The steps are as follows:

Extraction: The material must be extracted so that the sample is representative of the quarry. Because of this principle, it is recommended to carry out tests to determine the characteristics of a soil, such as sight and touch, which make it possible to identify the particle size of the soil and the test of smell which makes it possible to determine the presence of organic matter. This last test allows to assess the quality of the soil and to confirm its possible use or not.

Preparation: Land preparation operations have a determining role in the final quality of products. They can make possible, by the correction of the granularity that they bring, the use of the land that could not be used crude. This correction consists in removing by sieving, elements of dimension greater than 5 millimeters for example if you wish. The material collected must be kept free from any impurities that could cause pollution, since the material may lose its physical and chemical characteristics through pollution. It is also important to dry the material beforehand before submitting it to use. Thus, this step is essential for obtaining quality products.

Mixture: The distribution of the stabilizer must be uniform for its effect to be uniform throughout the mixture. This homogeneity is conditioned by mixing. The more homogeneous it is, the lower the stabilization rate. The mixture is first made dry, that is to say soil with cement. The water needed for the mixture will only be added by spraying at the end of the dry mixture. It will be added gradually until a homogeneous mixture is obtained at the optimal water content. The time between mixing and casting should be reduced to avoid the anticipated setting of cement.

Pressing: This action consists in tightening the grains by a mechanical energy on the material filled in the mould. It allows obtaining a densification of the material. The tightness of the solid grains gives the product a very good compressive strength.

Measurement of the mortar setting time: This is the time that elapses between the moment when the binder has been put in contact with the mixing water and the beginning of setting. The importance of this test is to determine the length of time necessary to evacuate each mixed quantity, after which the mortar is no longer usable. It is important to understand that the hardening of the cement paste depends essentially on the quantity of the cement, its hydration kinetics which is itself conditioned by its chemical components and the temperature of the medium. Indeed, with two mortars composed from different proportions of cement submitted under the same temperature conditions will not have the same setting times. As a result, we determined the capture times of our different mortars using the VICAT device (Figure 6).

Table 3. Mortar Setting Time.

Cement	Start (in minutes)	End (in minutes)
4%	230	365
6%	225	345
7%	210	323
8%	193	300
10%	185	280

Calculation of Dosages

The dosing calculation consists of determining the exact values of the elements used in the formulation of a product. For this project, it is cement and water to measure laterite.

Cement dosage: The calculation is based on arithmetic operations (addition, multiplication and division). According to POTEMAT-EPAC of the University of Abomey – Calavi in Cotonou, Benin, measurements are made using a container (bucket) of known volume and the different proportions obtained are converted into suitable units. Knowing that the volume of the bucket is 10 litters, the mass of a dry laterite bucket is 18.7 kg, the apparent density of the laterite is 1.87 kg/litters (Table 2) and the volume of the wheelbarrow is 60 litters, an example of 4% cement dosage is presented below.

The 4% dosage corresponds to 4 kg of cement for 100 kg of lateritic soils with 0%, 20%, 30%, 40% and 50% of fine particles respectively.

1/4 bag of 50 kg cement or 12.5 kg of cement corresponds to: (12.5 x 100)/4 = 312.5 kg of soil. By volume, 312.5 kg of soil is equivalent to: 312.5/1.87 = 167 litters; 167 litters of soil is equivalent to 2 wheelbarrows and 5 buckets of 10 litters. Finally, with a bag of cement, you need: 11 wheelbarrows and 2 buckets of lateritic soils. The same calculations are repeated for a dosage of 6%, 8% and 10% CPJ 32.5 cement.

Water dosage: The goal is to determine with accuracy the amount of water needed to obtain a good mixture and a good compactness. It's the amount of water that gets the heaviest compacted soil. In other words, the heaviest blocks. To do this, a series of production tests must be performed and compared on a curve. The test consists of mixing the material with water content close to the optimal water content and making a few blocks (about 4) then weighing and averaging. Repeat the same operation 4 or 5 times, increasing the percentage of water each time. This gives us 4 or 5 points through which a curve passes. The abscissa of the top of this curve is the optimal water content to consider (Figure 7). Below is an example of a 6% water dosage of CPJ 32.5 cement (Tables 4, 5).

Table 4. Summary of 6% water determination of CPJ cement 32.5.

Cement in kg	¼ de sac (12.5)	½ sac (25)	1 sac (50)
Laterite in kg	208,33	416,66	833,32
Dry mixture mass in kg	220,83	441,66	883,32
Volume of water (12.6%) in liters	27,8	56,65	111,29

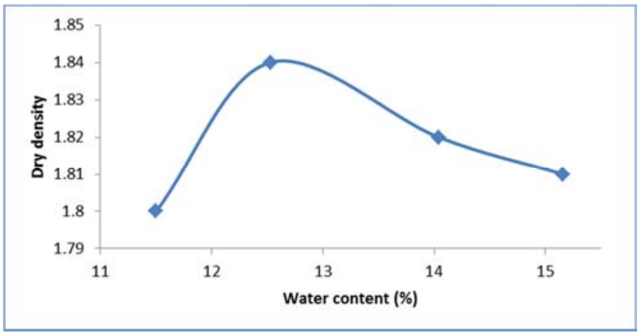

Figure 7. Optimum water content at 6% cement - ω_{Opt} = 12.6%.

Table 5. Summary of water dosages for 1 bag of 50 kg of cement.

Cement dosage (%)	4	6	8	10
Laterite (kg)	1250	833.32	624	500
Water (%)	12	12.6	13,6	14

2.2.5. Testing of Compressed Lateritic Soil Blocks

In general, by varying the fine particles in the mixture and compressing it into a mould, cracking is eliminated and the lateritic soils blocks give a good appearance. Compression resistance tests and capillary absorption tests of the blocks are carried out according to the reference documents mentioned after cures of 7, 14 and 28 days (Figure 8) [17-20].

Figure 8. Treatment conditions.

Dry compression test and after immersion of the blocks

Figure 9. Testing of Compressed Lateritic Soil Blocks by Hydraulic concrete press.

Also known as the crushing test, the compression test is performed using the hydraulic press (Figure 9). Its purpose is to determine the maximum compressive strength of the compressed and stabilized earth blocks according to the dosages to get the best out of it. We were able to determine the resistance to compression by the following principle: Split the blocks into two parts; Calculate the surface of the two parts (S in m²); Read the loads until the break of these two blocks (F in kN); RC compression resistance in MPa is determined using formula (9):

$$RC = \frac{F}{S} \quad (9)$$

Capillary absorption test: NF P 554

Figure 10. Capillary immersion and suction of the blocks.

This test makes it possible to determine the behavior of the blocks vis-à-vis humidity conditions. The procedure is as follows: Dry the different blocks in the oven for 24 hours; After cooling, they are weighed either M1; Immersed the inner face of these blocks at a depth of 5 mm (Figure 10); 10 minutes later, they are taken out of the water to weigh them or M2; The surface immersed in the water is determined. The absorption coefficient is calculated by the formula (10).

$$C_b = \frac{M2-M1}{S\sqrt{T}} \text{ x } 100 \quad (10)$$

C_b: absorption coefficient in g/cm².s$^{1/2}$; S: submerged surface in cm²; M1 et M2 in grams and T: time in seconds.

3. Results and Discussions

3.1. Characteristics of Lateritic Soils Used

The results of preliminary investigations on untreated lateritic soils are presented in Table 2. Based on the CRAterre consistency spindle and the LCPC classification of the Central Laboratory of Bridges and Pavements of Paris, which is only a derivative of the American classification USCS (Unified Soil Classification System) and adopted by French standards, the lateritic soil being the subject of this study is red-brown. It is qualified as *a firm, non-plastic soil with a plasticity index I_p of 3 and a consistency index I_c of 5.6 respectively*. Figure 3 shows the distribution of solid grains for which the coefficient of uniformity C_u and the coefficient of curvature C_c cannot be determined because the elements corresponding to 10% of sieve are less than 0.080 mm. From this observation, it is necessary to correct the texture of this soil by adding fine particles for example to reduce the percentages of coarse sand (37%) and gravel (33%) contained in the lateritic soils studied (Figure 3). For heavy blocks, the density result gives an acceptable value because it is between the normative limit values of 2.6 and 2.8 g/cm^3 recommended by NF P 94-054.

3.2. Results of Compression Resistance and Capillary Absorption Tests of Blocks

3.2.1. Dry Compression Resistance Test Results

Table 6. Summary of Dry compressive strength in MPa.

Cure	Fines	0%	4%	6%	8%	10%
7 Days	0%	0.97	1.01	1.38	1.47	1.63
	20%	1.61	1.93	1.99	2.10	2.88
	30%	1.84	2.80	2.90	3.80	4.40
	40%	1.78	1.78	1.60	2.55	3.10
	50%	0.88	0.76	0.97	1.10	1.38
14 Days	0%	0.35	1.54	1.72	2.35	2.01
	20%	1.46	2.79	3.01	3.70	3.86
	30%	1.80	4.03	4.20	5.1	5.7
	40%	1.72	3.00	3.34	3.97	4.10
	50%	0.61	1.12	1.28	1.88	2.22
28 Days	0	0.76	1.87	2.11	3.77	4.22
	20%	2.08	3.73	3.98	5.97	7.12
	30%	2.56	4.45	4.55	6.60	7.90
	40%	2.58	2.88	3.11	4.78	5.42
	50%	1.88	1.27	1.43	3.10	3.60

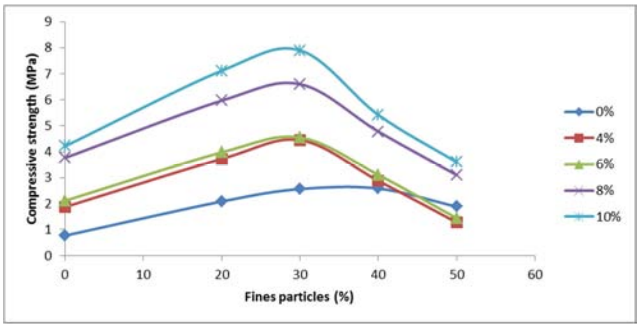

Figure 11. CR curve in MPa - % Fine - % Cement.

Figure 11 shows details of the change in dry compressive strength (CR) of the 28-day blocks based on the percentage of fine particles and cement content. The storage period is spread over 28 days to learn about the short- and long-term behavior of the material. The shape of the 0% cement curve gives a low resistance and gradually evolves according to the percentage of fine particles.

By varying the different percentages of fine particles, we notice an improvement in the aesthetic aspect of the blocks and a good compactness and there is strong growth in block strength when the CPJ 32.5 cement dosage is high. According to Table 6, in the absence of cement, the strength increases depending on the percentage of fines and the number of days. In the presence of cement, the resistance increases from 0 to 30% of fine particles but it falls to 40% of fine. This allows us to say that the high percentage of fine reduces the compressive strength in the presence of the stabilizer. The highest resistance at 28 days of cure is that of 10% of the cement content with a percentage of 30% of fines and the lowest resistance is that of 4% of the cement content at 28 days of cure with a percentage of 50% of fines. Since the highest resistance is obtained for an optimal percentage of fine particles of 30%, this value is used for the continuation of the work.

The dry compressive resistance of the blocks to 30% fine particles is high compared to other percentages. This proves that fines play a very important role in the construction of lateritic soils blocks. For these types of blocks, the sufficient amount of fine (≥ 40%) or insufficient amount of fine ≤ 20%) significantly reduces their resistance. The study reveals that over 45% of fine a block of laterite unsuitable cement soils may be more resistant than a block dosed with 4 or 6% cement (Figure 11). This confirms the idea of some construction technicians who still think, without irrefutable evidence, that the abuse of fine particles in concrete reduces its resistance to compression but, they say nothing when the amount of fine is low.

3.2.2. Results of Immersion Compressive Strength Tests

Table 7. Comparison of resistance after immersion with dry resistance.

Cement dosage	Area (mm^2)	Load (N)	RC after immersion (MPa)	RC dry (MPa)	Loss (%)
0%	20665	-	-	2.56	100.00
4%	38920	125	3.21	4.45	28.00
6%	39200	135	3.44	4.55	24.00
8%	39200	200	5.10	6.60	23.00
10%	39200	240	6.12	7.90	22.10

In unfavorable conditions, that is to say in the presence of moisture, it is also important to determine resistance to compression of the blocks in the wet state because any structure must have a minimum of resistance to the weather. Thus, a sample of each dosage at 28 days of cure is soaked for 24 hours and subjected to compression. Table 7 shows that 0% cement blocks are not moisture resistant. Also, the loss of resistance decreases gradually when the percentage of cement is increased. Under moisture conditions, the blocks have less resistance (22-28% loss) but these values are not of concern, unlike clay soil blocks where resistance loss can reach 72% even in the presence of a stabilizer (Bozabe Renonet Karka et al., 2021).

3.2.3. Capillary Absorption Test Results

Based on the results in Table 8, the capillary absorption coefficients are low because all these values are less than 20 $g/cm^2.s^{1/2}$, below which the element is classified as low capillarity according to NF P 554. According to the mechanical stabilization of sub-paragraph 2.2.3, a low capillarity is synonymous with a good compactness. Also, when the determination of the cement content increases, we notice that the water absorption of the blocks decreases. The excessive consumption of water by cement does not have a negative effect on the water qualities of the blocks because the absorption coefficients of the blocks are very low (maximum 5.02 $g/cm^2.s^{1/2}$).

Table 8. Capillary absorption coefficient.

Cement dosage	M1 (g)	M2 (g)	Area (cm^2)	Cb ($g/cm^2.s^{1/2}$)
4%	6450	6985	435	5.02
6%	6500	6980	435	4.50
8%	7699	7988	392	3.01
10%	7628	7866	392	2.48

3.2.4. Economic Discussion

According to Table 9, our study shows that the costs of blocks made from lateritic soils stabilized by simple compression after the addition of CPJ 32.5 cement and fine particles vary from 77.65 F CFA to 175.05 F CFA. The prices of blocks made of fired clay reinforced with vegetable fibbers or animal waste (straw, rice bran, beef dung, etc.) currently produced and sold in the city of N'Djamena vary from 75.00 FCFA to 175.00 FCFA. Compared to these two production processes of the blocks, the costs are roughly the same because 1000 blocks costs 175,000 FCFA. However, to avoid deforestation, we believe that the production of blocks with laterite by simple compression, which is the subject of this study, is an appropriate solution to all ecological and global warming problems, the main source of which is the massive use of firewood.

Table 9. Economic balance sheet of the blocks.

Cement (%)	Fines (%)	Number of blocks	Unit price (FCFA) (F CFA)	Total price (FCFA) (F CFA)
0	30	1000	77.65	77650
	35	-	77.83	77830
	40	-	78.04	78040
4	30	-	126.12	126120
	35	-	126.33	126330
	40	-	126.54	126540
6	30	-	142.32	142320
	35	-	142.53	142530
	40	-	142.74	142740
8	30	-	158.53	158530
	35	-	158.74	158740
	40	-	158.95	158950
10	30	-	174.59	174590
	35	-	174.80	174800
	40	-	175.05	175050

4. Conclusion

The mechanical resistance tests performed on the blocks show that the cement increases the RC throughout the cure time while an appropriate percentage of fine particles causes a good compactness of the blocks. This study reveals that the optimal dosage of fine particles is in turn 30% and that a 10% dosage of CPJ 32.5 cement is sufficient to exceed the limit resistances of 4.0 MPa recommended for a load-bearing wall by the International Centre for Earth Architecture, CRAterre. The highest value of the compressive strength obtained is 7.9 MPa after 28 days of dry cure and the lowest value is 0.76 MPa at 4% cement and 50% fine particles. Also, moisture causes a decrease in compression resistance (between 22 and 28%). This loss does not have a major impact on wet block RC. However, we may consider further research to reduce this rate of RC loss from blocks after block immersion. Finally, this work leads us to conclude that lateritic soil blocks stabilized by simple compression with fine particles and cement have many advantages over clay soil blocks stabilized by cooking with vegetable fibbers or waste animals.

Acknowledgments

We thank the Director General of NHSPW and all laboratory technicians for their financial and technical support. It is through you that this modest research work has come to an end.

References

[1] Youdjari Djonkamla, Characterization and Numerical Simulation of the Volumetric Behavior of N'Djamena Clay Soils, Memoir 2010, 115 p.

[2] H. Houben, H. Guillaud, 1995. Treaty on Earth Construction. parenthesis edition, Marseille, France, 355 p.

[3] Bozabe Renonet Karka and Bassa Bruno, 2021. Experimental study of the behavior of clay blocks stabilized with lime by simple compression for the construction of walls. Journal of Materials and Engineering B 11 (4-6) 64-75. DaviD Publishing Company.

[4] Bruno Bassa, Renonet Karka Bozabe and Adoum Issak, 2021. Main engineering properties of stabilized earth block bricks formulated with soils from N'djamena - Chad. International Journal of Advanced Research (IJAR) 9 (05), 1132-11140. Research Communications.

[5] BCEOM-CEBTP, 1972. Manual on Roads in Tropical and Desert Areas: Road Maintenance and Operation.

[6] Imoh Christopher, A. et al., 2021. Understanding the Effect of Compaction Energies on the Strength Indices and Durability of Oyster Shell Ash-Lateritic Soil Mixtures for Use in Road Works. Engineering and Applied Science Research 48 (2): 151-60.

[7] Abalo P'kla, 2002. Characterization in Simple Compression of Compressed Earth Blocks (CEB): Application to Masonry CEB - Earth Mortar. Doctoral Thesis, 234 p.

[8] CRAterre, 1985. Building in Earth. Alternative ed., Paris, 286 p.

[9] Kinet Ouinra and Tomtebaye Ngakoutou Fulbert, 2016. Comparative study of bricks in lateritic and sandy soils stabilized with cement by simple pressure, Memoir of end of studies to obtain the diploma of master, 93p.

[10] Cédric Flament, C. 2003. Refinement of Granular Washing Fines: Application to Raw Earth Construction. PhD thesis, 227 p.

[11] Bozabe Renonet Karka, 2013. Contribution to the physic-mechanical characterization of micro-concrete tiles locally made from cement, gum Arabic and sand (CGS) composites, Unique Doctoral Thesis, University of Abomey-Calavi, Cotonou, Benin.

[12] Mahamat Saleh Ibrahim Yacoub, 2010, Comparative Study of the Improvement of Compressed Earth Bricks Stabilized by Cement and Lime Off, Memory 46 p.

[13] M. Olivier and A. Mesbah, 1986. The earth material: static compaction test for the production of compressed earth bricks. Bull. lab liaison.

[14] M. Olivier, and A. Mesbah, 1997. Earth building mechanics: procedure for conducting resistance tests on compressed earth blocks.

[15] AFNOR, 2001. Compressed earth blocks for walls and partitions, Paris.

[16] AFNOR NF EN 13286-53, 2005. Treated and untreated mixtures with hydraulic binders, Part 53: method of axial compression preparation of specimens of materials treated with hydraulic binders.

[17] BS 1924, 1990. Methods of testing for stabilized soil. London, British Standards Institution.

[18] BS 1377, 1990. Methods of testing soil for civil engineering purposes. London, British Standards Institution.

[19] American Society for Testing and Materials (ASTM), 1992. Annual book of standards volume 04.08, Philadelphia.

[20] Hubert Guillaud et al., 1995. Compressed earth blocks, Volume II. Design and Construction Manual, 151p.