PHYSICO-MECHANICAL PROPERTIES OF STABILIZED MUD BRICKS WITH PALM NUT FIBRES IN NDONG VILLAGE, MFOU DISTRICT, MEFOU-AFAMBA DIVISION IN THE CENTRE REGION OF CAMEROON

Amadou MOUNDOM [1, 5,*], Valentine YATO KATTE[2, 5],
Benjamin ABANDA NGONO [3, 5] and Benjamin AMBOKO MUHIWA[4, 6]
[1]Senior Lecturer in Civil Engineering
[2]Associate Professor in Civil Engineering
[3]Master's Student
[4]Assistant Lecturer in Civil Engineering
[5]Department of Agricultural Engineering, Faculty of Agronomy and Agricultural Sciences, University of Dschang, Cameroon
[6]Department of Civil Engineering, Faculty of Sciences and Applied Technologies, Free University of Great Lakes Countries, Goma, Democratic Republic of Congo
(*) – Corresponding Author: Email: moundomndi_amadou@yahoo.com

***ABSTRACT*: The objective of this work is the study of the physico-mechanical properties of stabilized mud bricks with palm nut fibres in Ndong Village, Mfou District, Mefou-Afamba Division in the Centre Region of Cameroon to reduce problems such as cracking and detachment of aggregates over time but also low compressive strength that barely reaches 2MPa.The Munsel colour code, particle size, Atterberg limits, bulk density, methylene blue, compression on mud bricks, water absorption and porosity tests were used. Also 0, 1, 2, 3 and 4% of palm nut fibres were used for stabilization of mud bricks. The results showed that the compressive strengths of bricks improved considerably for stabilized bricks than non-stabilized ones, up to 4.5 MPa for 4% fibre stabilization; For porosity, the more fibres are incorporated into the specimen, the more pores it had and the less dense it became, and the more strength the specimens acquired between the aggregates. However, for the non-stabilized specimens, they could not hold up to the end of the test and ended up being unrecoverable for the weighing and dimensional test. With regard to swelling for all specimens, the more fibres are incorporated in the specimens, the more the specimens tended to absorb water and swell, making the bricks brittle.**

Key words: Physico-mechanical properties, compressive strength, brick stabilization, palm nut fibres, water absorption, porosity, swelling.

I. INTRODUCTION

A. Context

Earth as a material is present in all Continents in general and in Africa in particular. This material is used for a variety of purposes, including construction. This building material has been used for a long time, long before the creation of elaborate materials such as cement and lime that are commonly used today. Indeed, many of the oldest buildings in the World are made of mud bricks. Moreover, a large population (one third) still lives in earthen dwellings today (Guérin, 1985). This is particularly the case in rural areas. Whether it is banked or rammed earth bricks, compressed earth bricks (earth compacted in a press), adobe (earth in a plastic paste state often amended with straw or other fibres, moulded into sun-dried bricks) or cob (clay soil, (clay soil, amended with straw or other fibres, covered in one or more layers with racks that frame a half-timbered structure), earthen architecture makes it possible to construct simple or monumental buildings in a variety of environments (Quoc-Bao, 2008). This construction technique has always been subject to improvement (Paulus, 2014).

Studies estimate that "at least 30% of the World's population lives in earthen buildings and 17% of the buildings inscribed on the UNESCO World Heritage List are earthen architectural works" (Anger et *al*, 2005) quoted by Paulus (2014).

Indeed, raw earth construction has many advantages. It is a natural product, available on site, directly usable and does not require any purchase, transformation and handling costs. Also, its implementation requires only elementary techniques, which favours self-construction, collective self-help and a visible reduction in costs

(Quoc-Bao, 2008). Apart from the ease and flexibility it allows at the building stage, the most appreciated characteristic of the earth material is the thermal comfort it generates (Quoc-Bao, 2008). Indeed, the earth wall has the property of ensuring a natural thermal regulation between the outside and inside temperatures, which is an invaluable advantage for populations that have limited means or possibilities to heat, or air-condition, their houses (Quoc-Bao, 2008).

Due to the importance of this abundant local raw materials for construction, numerous processes for stabilizing mud bricks are constantly being developed.

B. Problem statement

Today, a significant proportion of Cameroonians construct their buildings using materials produced from cement and lime. However, this is proving to be very expensive and not accessible to all classes of the society, especially those on low incomes who suffer from the high cost of living. This trend is spreading from the cities to the villages, as houses formerly made of earth are being abandoned for cinderblock houses, which are said to be synonymous with prestige and modernity. In addition, those who build with unstabilized mud bricks face problems such as cracking, low strengths of the bricks and loosening of the aggregates over time (see Figure I.B.a); this reduces the life span of these buildings but also the aesthetics. This is the case in NDONG Village, MFOU District, MEFOU-AFAMBA Division, and Centre Region of Cameroon.

However, the Cameroonian environment has enough soil that varies from one Region to another and can be used as construction materials for several types of buildings. In addition, there is a wide range of plant and animal products and by-products that can be used as soil stabilizers. Thus, after analyzing the properties of the soil, the cost and the maintenance, a suitable stabilizer can be found for the manufacture of earth bricks.

Among the products from plant species are palm nut fibres obtained after the extraction of palm oil. In fact, the Great South Cameroon Region is a suitable area for palm production; indeed, palm trees are regularly found in farmers' fields, as well as palm trees. However, after the oil has been extracted, these fibres are discarded or burnt (Figure I.B.b) whereas this by-product can be valorized.

Figure **Error! No text of specified style in document.**a: Degradation of mud brick walls

Figure I**Error! No text of specified style in document.**b: Dumping of palm fibres in a waste bin in the city of Yaounde

The present work aims to valorize the local materials close to home by developing a building material that is fairly durable, more resistant to cracking and less demanding to work with for the benefit of low-income people. This work focuses solely on the stabilization of mud bricks using palm nut fibres.

C. Objective

The objective of this work is to stabilize mud bricks with palm nut fibres for routine use in mud brick manufacture where the raw material is abundant.

D. Importance of the study

This study on the stabilization of mud bricks with palm nut fibres makes it possible to improve the mechanical properties of these bricks and to make the buildings and their inhabitants safer.

II. LITERATURE REVIEW

A. General informations on soil material

Soil is the loose, coherent or powdery material that forms a large part of the surface layer of the earth's crust. This surface layer is formed by the disintegration and decomposition of rocks and mineral constituents generally under the action of climatic phenomena, marine or fluvial erosion, or living organisms. It may have been formed locally or transported sometimes from a great distance by wind or water and form a layer of very variable thickness. (Guérin, 1985).

Soil consists of a mixture in varying proportions of four kinds of elements: gravels (5-20 mm), sands (0.08-5 mm), silts (2 µm-0.08 mm), and clays (< 2 µm). As shown, the soil is composed of inert materials (gravels, sands) and active materials (silts, clays). The former act as a skeleton and the latter as a binder, like a cement (Taallah, 2014). Soil therefore has a structure comparable to that of concrete with a different binder (Houben, 1996) as cited by Taallah (2014). The proportions of the elements constituting the soil will determine its behaviour and properties, for example, when subjected to moisture variations some change in volume (montmorillonites, illites), some swell, others do not (kaolinite, smectite) (P'kla, 2002). Gravels and sands are unstable while clays and silts are stable. This notion of stability, i.e. the ability to withstand alternating humidity and dryness without variations in properties, is fundamental for a construction material (Doat, 1979) as cited by Taallah (2014). These statements above indicate the importance of clays as a binder in the manufacture of compressed earth blocs (CEBs). A soil is characterized by its grain size (related to soil cohesion), porosity (permeability to water and air) and compressibility (compaction).

Throughout the world's heritage of raw earth building traditions, there are many building techniques with an infinite number of varieties adapted to the quality of the earth and the degree of elaboration of the know-how, reflecting the identity of the places and cultures. There are twelve techniques for using earth for construction established by the CRATERRE group (1986) cited by Taallah (2014). Eight of the twelve techniques are in common use and constitute the main techniques CRATERRE (1986) cited by Paulus (2014). These are:

- **Adobe**: earth in the form of a plastic paste often amended with straw or other fibres, moulded into sun-dried bricks.
- **Pisé**: the earth is compacted in mass in formwork, layer by layer and block by block, with a tamping machine.
- **Earth-straw:** earth is dispersed in water until a thick homogenous liquid is obtained which is mixed with straw to form a film on each strand. The resulting material retains the appearance of straw and is built into a monolithic wall that requires a supporting structure.
- **Torchis:** clay soil, amended with straw or other fibres, covers in one or more layers the racks that frame a half-timbered structure.
- **Shaped earth:** the earth, often amended with straw or other fibres, is shaped into walls in the same way as the pottery technique, without tools.
- **Extruded earth:** the earth is extracted by a powerful machine close to or derived from the equipment used for the manufacture of products intended to be fired.
- **Bauge**: earth, usually amended with straw or other fibres, is formed into coarse balls, which are piled on top of each other and lightly packed with the hands or feet to form shaped monolithic walls. In other cases, the cob is incorporated into a wooden structure.
- **Compressed earth**: the earth is compressed into a block in a mould. In the past, soil was compacted in a mould with a small pestle, or by forcefully pushing a heavy lid into the mould. Today, a wide variety of presses are used.

B. Some previous work on mud bricks

The United Nations Centre for Human Settlements has defined soil stabilization as the modification of the properties of a land-water-air system to achieve permanent properties compatible with a particular application (United Nations**,** 1992). However, stabilization is a complex problem as there are many parameters involved. One needs to know: the properties of the soil, the improvements envisaged, the economics of the project, the techniques for applying the soil chosen for the project and the maintenance of the project carried out (Houben, 2006) quoted by Paulus (2014).

There are several possible stabilization processes (mechanical, physical, chemical) depending on the type of stabilizer (inert, physico-chemical) in order to make the brick firmer and more resistant according to Guillaud et *al*. (1995)

As stated by Guérin (1985), stabilization can be used to: improve the mechanical characteristics of the soil (compressive strength, cohesion) by reducing voids between particles or by improving or creating links between them on the one hand, and to reduce water sensitivity (swelling and shrinkage) and permeability by sealing voids between particles on the other hand.

The improvement of the mechanical characteristics of the soil and the reduction of water sensitivity may be reversible (not permanent) or irreversible (permanent) and may or may not be combined. There is no universal (or miraculous) stabilizer that is suitable for all soils and fulfils both roles, nor are there "stabilization recipes" that are valid everywhere. Therefore, a choice will always have to be made between different possible stabilizers according to criteria of effectiveness, availability, cost, etc., and based on tests with the chosen soil and the chosen stabilizer (Guérin, 1985).

By compacting, the number of voids (and thus the volume) of the soil is reduced and the particles have more contact with each other, which increases internal friction. Soil compaction depends on the particle size, thickness, water content and compaction energy (Guérin, 1985).

For thin materials, drying causes some shrinkage which increases the cohesion of the material. Adobe bricks (sun-dried bricks) use this principle.

Stabilizers are natural (straw) or non-natural (cement, lime) materials which, when added to the soil, improve its qualities or give it new ones. They can have a purely physical action (straw which forms a reinforcement) or a chemical action, with modification of the material itself. Most stabilizers have a physico-chemical action, i.e. they combine these two modes of action (Guérin, 1985).

According to Guérin (1985), two stabilisation principles can be distinguished for chemically inert stabilizers:

- The change of granulometric composition where it is a question of improving the composition of the soil by adding elements (sand, clay) which are lacking and,
- The creation of a reinforcement where fibres are incorporated into the earth that will take up and distribute the stresses and strains that are exerted in and on the earth. This will reduce cracking and improve mechanical strength. Several types of plant fibres can be used for this purpose: straw, bark, wood chips, pine needles, rice husks, millet husks, sisal fibres, etc., the most common being straw.

The use of physico-chemical stabilizers aims, on one hand, to render irreversible the improvements obtained by stabilization through compression and, on the other hand, to obtain qualities that compression did not (or only slightly) provide to the soil (insensitivity to water and waterproofing). A distinction can therefore be made between binders (improvement of mechanical characteristics) and hydrophobic agents (waterproofing), but often physico-chemical stabilizers will play this double role; they are then distinguished according to their main action (Guérin, 1985).

Reinforced stabilization with fibres is widely used in earth construction worldwide. Fibres are mainly used for the production of kneaded blocks in clay soils, which often have a high degree of shrinkage. Artisanal production of straw-stabilized adobe bricks is very varied, but fibres are also known to be used for building in cob, straw earth, cob, as well as compressed blocks and adobe (Houben, 2006) cited by Paulus (2014). In the case of synthetic fibres, they are generally used in soil reinforcement to increase compressive and shear strengths (Estabragh, 2011).

Fibres are characterized by a length at least three times greater than their diameter. It can be said that the term "fibres" covers a large family of materials that have been introduced into the market as new applications. They are classified according to their origin (natural, synthetic and artificial), their shape (straight, wavy, needle), their size (macro or microfibre) and also by their mechanical properties. However, in order to make a choice of fibres to be used for a given application, it is necessary to take into account the compatibility of the fibre with the matrix, and the performance mode of the composite.

Several types of fibres are used in construction, which can be classified per family (Paulus, 2014):

Natural fibres can be divided into three main groups according to their origin (Baley, 2013):

- **Plant-based fibres:** The use of natural fibres, and in particular plant-based fibres, as reinforcement for composite materials has two main advantages. Firstly, these fibres are widely available at low cost and their use in construction constitutes new outlets for agricultural materials. Secondly, the use of plant fibres reduces the environmental impact compared to conventional composites as they are renewable, biodegradable, CO2-neutral raw materials that require little energy to produce. Plant fibres include :
    - Fibres from the seminal hairs of seeds (cotton, kapok),
    - Bast fibres extracted from plant stems (flax, hemp, jute, nettle),
    - Fibres extracted from leaves (sisal), trunks (palm), and fruit husks (coconut).
- **Animal fibres**: The most important and most used fibre is wool, known for its good thermal insulation qualities, its high absorbency (16-18%) and its high elasticity (45%). Animal fibres are classified according to their origin:
    - Hair: wool (obtained by shearing sheep), alpaca, angora, camel, cashmere;
    - Secretions: silk (Bombyx Mori), wild silk, spider threads.
- **Fibres of mineral origin**: Asbestos is the only natural mineral fibre. It has attracted the attention of industrialists for its resistance to heat, fire, electrical and chemical aggression and for its absorbency. It was

used in various industrial installations and even in construction before it was gradually banned because of the carcinogenic risks it presents (Service, 2004) as cited by Paulus (2014).

Synthetic fibres are made from synthetic polymers obtained from substances or compounds supplied by the petrochemical industry. They first appeared at the beginning of the 20th century, after the success of the Viscose fibre, and since then a large number of synthetic fibres have been developed, each with properties that meet a particular type of application. These fibres, like man-made fibres, are obtained by spinning. They are of interest to many industrialists because of their low cost, their availability and their independence from the seasons and above all the possibility of adapting them and modifying their properties. On the other hand, they are very much criticized for their behaviour towards the environment, both during the manufacturing process and after use, and the difficulties of recycling them. The main categories of synthetic fibres on the market are Polyamides (Nylons); Polyesters; Polyvinyl derivatives; Polyolefins: polyethylenes and polypropylenes are of increasing importance and their production now amounts to about 8% of all synthetic fibres (Quinn, 2002) quoted by Paulus (2014). This type of fibre is the most widely used in the industrial field in general and in the civil engineering field in particular. It includes glass fibres, carbon fibres, steel fibres and others. They are nowadays the most widespread in the construction industry (Paulus, 2014).

The addition of fibres to soil as a stabilizer is a technique widely used around the world. Straw, which reinforces the structure, is the most widely used because it can be adapted to the different ways of working the clay, i.e. plastic, viscous or in the case of compression. The fibres play several roles: to prevent cracking during drying by distributing the tensions due to the shrinkage of the clay throughout the mass of the material; to accelerate the drying process by draining out humidity through the fibre channels. Conversely, the presence of fibres increases absorption in the presence of water; lightening the material: the volume of straw is often very large, lightening the density of the material and improving its insulating properties (Paulus, 2014); increasing the tensile strength (Guillaud et *al*, 1995) as quoted by Paulus (2014).

Soil stabilized with fibres therefore has very good resistance to cracking and crack propagation because they oppose cleavage when the stress increases. Depending on the tensile strength of the fibres used, the shear strength will be increased by a certain degree (Paulus, 2014). Depending on the quantity of fibre used and its tensile strength, and depending on the compressive strength of the soil and the internal friction between the fibre and the soil, a good compressive strength can be achieved with the fibre reinforcement in place (Paulus, 2014). If one compares the strength of a material reinforced with fibres to the original material without fibres, one observes a strength that is about 15% higher for the material containing the fibres, except in the case of a material that is too sandy, where the fibres can have a negative effect. If we take the example of adding sheep wool fibres to soil, we observe an increase in compressive strength of about 37% (Paulus, 2014). In the case of deformations, there is also a greater capacity to absorb energy in the case of fibre-reinforced earth, which will be of great interest in earthquake-resistant regions. This is because the fibres modify the behaviour of the earth beyond the point of failure (Guillaud et *al*, 1995) as cited by Paulus (2014).

There is an optimum quantity of fibre to add beyond which there is a loss of strength. If too much fibres is added, the density will be too low and there will be insufficient contact points between the fibres and the soil. This means that the deformations will no longer be transmitted correctly, which will reduce the resistance of the earth. Good results are already obtained with a dosage of 4% by volume. The fibres are preferentially placed in all directions in order to obtain better results. To further improve the results, the fibres can be combined with a second stabilizer such as cement, lime or bitumen. The fibres can be of plant, animal or synthetic origin. Straw of all kinds, cereal husks, hemp, coconut fibres, palm fibres, etc. are generally used for vegetable fibres; cattle hair and mane for animal fibres; steel, glass fibres and cellophane for synthetic fibres.

The change from a brittle matrix to a ductile fibre composite exhibiting a softening post-peak behaviour is noted by all authors. However, this change in behaviour does not necessarily go hand in hand with an improvement in flexural strength (Kriker, 2005) cited by Paulus (2014), which is why the most important parameter to account for the contribution of fibres in the behaviour of the composite is its toughness, which represents the ability of the material to absorb a certain amount of energy before failure (ACI, 1996).

The work done by Sreekumar et *al.* (2013) on lateritic blocks stabilized and reinforced with coconut fibres proceeds by characterising the properties of the lateritic soil as presented in Table II.B.a:

Table II.B.a : Properties of lateritic soils used by Sreekumar et *al*. (2013)

Properties	Values
Bulk density (%)	**2,55**
Liquidity limit (%)	**58**
Plasticity limit (%)	**35**
Shrinkage limit (%)	**19,79**
Plasticity index (%)	**23**
pH	**4,73**
Clay (%)	**27,6**
Silt (%)	**6,9**

Fine sand (%)	22,5
Average sand (%)	25
Coarse sand (%)	18
Dry density (g/cm3)	1,64
Optimal water content (%)	21

Sreekumar et *al.* (2013) subsequently determined the physicochemical properties of coconut fibres as presented in Table II.B.b:

Table II.B.b: Physico-chemical properties of coconut fibres used by Sreekumar et *al*.

Physical		Chemical	
Diameter	0.32mm	Lignin	39,62%
Density	1.35g/cm^3	Cellulose	22,99%
Tenacity	14 ,85	Ash	2,99%
Elongation failure	26,53%	Pectin	2,40%
Swelling with water	88,35%		

The block dimensions used by Sreekumar et *al* (2013) for making the blocks are 190mm x 110mm x 100mm and the added materials are: sand in three percentages (10%, 20% and 25%), cement at 8% and coconut fibre (0.5%, 1% and & 5%). After compression, flexural and absorption tests at days 7 and 28, the values obtained are presented in Table II.B. c:

Table II.B. c: Compressive forces, bulk density, dry density and water absorption of blocks obtained by Sreekumar et *al*. (2013)

Designation	Bulk density (g/cm3)	Dry density (g/cm3)	Compression force (MPa)	Water absorption (%)
S25C8	2,06	1,75	2,12	14,13
CF 0.5	2,11	1,79	2,43	14,17
CF1	2,01	1,71	2,23	20,46
CF 1.5	1,86	1,58	2,14	24,32

Where S25C8: sand 25%+cement 8%;
CF0, 5: sand 25%+cement 8%+0.5% fibre ;
CF1: sand 25%+cement 8%+1% fibre ;
CF1, 5: sand 25%+cement 8%+1.5% fibre ;

The Cameroonian Standard on compressed earth blocks CEB, (NC 102-114, 2002-2006) has defined the following thresholds for the said blocks: 20-35% for the average plasticity limit, 35-50% for the liquidity limit and finally 20-30% for the plasticity index. (%). The same Standard presents in table II. B.d the recommendations on the granularity for CEB.

Table II.B.d: Granularity recommended for CEB by the CEB standard, (NC 102-114, 2002-2006)

Granularity	Diameter (mm)	Percentage (%)
Gravel	>2mm	0-25
Sand	0,02-2	55-75
Silt	0,02- 0,002	10-25
Clay	< 0.002mm	10-15

The results presented by Sreekumar et *al* (2013) showed an increase in compressive strength in the range of 3.01-4.28N/mm² compared to stabilization with cement only. With regard to absorption, the blocks with fibres absorb more water but remain stronger.

Malanda et al (2017) worked on the stabilization of an earth brick using sugarcane molasses and determined compressive strengths that varied from 2 to 4.65 MPa. The same authors determined the compressive strength with the molasses plus bagasse mixture which varied between 2 and 5 MPa.

Katte et al (2017) investigated the use of dried sewage sludge, in varying proportions, in the manufacture of burnt clay bricks and obtained compressive strengths ranging from 2.81 to 16.03 MPa.

Bruno et al (2015) achieved high compressive strengths of mud bricks by using a high-pressure compaction method.

The classification of soils based on the methylene blue test is presented in Table II.B.e., according to NF P 94-068:

Table II.B.e: Classification of soils based on the methylene blue test for the manufacture of blocks according to NF P 94-068

Value of VBS	Classification
0,1	Water-insensitive soil
0,2	Onset of water sensitivity
1,5	Threshold distinguishing sandy-loam soils from sandy-clay soils

2,5	**Threshold for distinguishing low plasticity from medium plasticity silty soils**
6	**Threshold for distinguishing silty from clayey soils**
8	**Threshold for distinguishing clay soils from very clay soils**

From the above, the state of the art presents work on stabilized mud bricks without addressing the case where the stabiliser is palm nut fibre, a construction method widely used in several regions of Cameroon and in the World, hence the interest of this work.

III. MATERIALS AND METHODS

A. Location of the study area

We will briefly present the site where the soil samples and fibres were collected and where the analysis was carried out.

The soil used for this study was collected in NDONG village, MFOU district, MEFOU-AFAMBA division in the Centre Region of Cameroon. The sampling site is located at 03°49.426'N and 011°32.982'E. The climate is equatorial with a bimodal season. The vegetation is forest and the relief of the site is steep, with cassava and plantain being the main crops grown on the soil surface.

The palm nut fibres were collected in the Centre of SANGMELIMA Town, division of DJA and LOBO, SOUTH Cameroon Region.

The palm oil tree, whose scientific name is *Elaesis guineensis*, is a tropical perennial plant originating from the Gulf of Guinea. It grows spontaneously throughout the forest zone of Cameroon where it has long been the subject of artisanal exploitation.

The analyses were carried out at MIPROMALO (Mission for the Promotion of Local Materials) located in the NKOLBIKOK district of the 6th arrondissement of YAOUNDE, MFOUNDI division. It is located at 03°52.417'N and 011°29.957'E. Its main aim is to promote the use of locally manufactured materials in order to reduce the costs of building national equipment.

B. Experimental Protocol

- *Collection of materials*
  - *Collecting soil samples*

The sampling procedure was as follows:

- Determining the boundaries of the field: this involves identifying the various boundaries as well as obstacles that could hinder sampling (soil discharge points, high concentration of organic matter, termite mounds, etc.);
- Mark the various sampling points (05 in total) (here the points are named X, Y, Z, W and C respectively) with stakes;
- Measure each distance using the decameter and the double step;
- Dig holes with a section of 50 cm x 50 cm and a depth of around 50cm reaching the B horizon of the soil (the passage from the A horizon to the B horizon is visible by a change in colour). The materials used to do this are: machete to clean around, pickaxe and planter to dig, shovel to remove the soil from the hole and a template graduated at 50cm and a decameter of maximum length of 15m to measure the dimensions of the hole;
- Then load each soil sample into its own jute bag using shovels;
- The samples are then transported to the laboratory. The depth of each sample is presented in Table III.B. a:

Table III.B.a: Variation in depths dug for each sample

Sample	Top soil thickness (cm)	Max. depth dug (cm)
X	25	48
Y	23	50
Z	19	49
W	20	45
C	21	49

- **Collection of palm nut fibres**

Palm nut fibres were obtained by the following process:

- Sorting of palm nut fibres by hand at the pressing plant while separating palms;

- The fibres are collected with a bucket and put into a jute bag;
- Manual washing of the fibres at the LOBO river several times in basins in order to extract a maximum of oil from the fibres;
- Transport and sun-drying of the fibres in the open air to significantly reduce the water content (Figure III.B);


Figure III.B. a : Fibres packed in the bag after collection


Figure III.B. b: Sun drying of the fibres

- *Laboratory analysis*

Dry particle size analysis test (EN 933-1 and EN 933-2) and wet particle size analysis (by sedimentometry) test (NF P 94-057)

Prior to the sieve analysis tests, the Munsel colour code is used to determine the colour of the soil as it moves from one horizon to another.

Dry particle size analysis is performed to determine the distribution of soil grains of at least 90µm in the present work.

The particle size analysis by sedimentometry is carried out on the sieve of each sample after the particle size analysis by dry method for maximum dimension of 90µm.

Atterberg limits and plasticity index test (NF P 94-051)

They are used to determine the water content threshold between liquidity and plasticity of the soil.

The Atterberg limits test is carried out in two phases: Research of the liquidity limit wl, the water content at which a groove of standard size, made in the soil placed in the Casagrande cup, closes under the action of 25 shocks applied in a standard manner; Research of the plasticity limit wp, the water content at which a manually made soil cylinder of 3mm diameter cracks when lifted. At the end of the two phases, the plasticity index Ip is determined by the relation 1:

$$I_p = W_l - W_p \quad (1)$$

Bulk density test of soil

The apparent density of a soil (ρ_a) , described by the French standard NF X31-503 (1992), is the ratio of the mass of the wet soil to the apparent volume (V) and is expressed by the expression 2:

$$\rho_a = \frac{M_2 - M_1}{V} \quad (2)$$

ρ_a is the bulk density in g/cm3 ;
M_1 is the mass of the empty container in g;
M_2 is the mass of the container full of soil and flattened in g;
V is the net volume of the container measured in cm^3.

Methylene blue test, known as the stain test (NF P 94-068)

The methylene blue test is used to determine the cleanliness of a soil and the type of clay it contains (water sensitive or swelling). The water content of the sample (w), the dry mass of the test sample M_o, the mass of blue introduced B (10 g/l solution), the value of blue for particles with a maximum size of less than 5 mm (VBS_1) and the value of blue for particles with a maximum size of more than 5 mm (VBS_2) are given respectively by the relations 3 to 7:

$$w = \frac{M_{h2} - M_{s2}}{M_{s2}} \quad (3)$$

$$M_O = \frac{M_{h1}}{1+w} \quad (4)$$

$$B = 0,01\,V \quad (5)$$

$$VBS_1 = \frac{B}{M_o}\,x\,100 \quad (6)$$

$$VBS_2 = \frac{B}{M_o}\,x\,C100 \quad (7)$$

Mh_1 is the mass of the first test sample used to determine the methylene blue value;
Mh_2 is the mass of the second test sample used to determine the water content of the sample;
Ms_2 is the dry mass of the second test sample used to determine the water content of the sample;
Mh3 is the mass of the third test sample to cope with the possibility of a second determination of the blue value;
C is the weight proportion of the 0/5 mm fraction for Dmax $< 5\,mm$ or 0/50 mm for Dmax $> 50\,mm$ contained in the material.

- **Characterization of palm nut fibres**

The characterization of the palm nut fibers for average diameter, average length and density was determined as follows:

- The average length, diameter and volume of several fibers (15 in total) are determined using the caliper;
- With regard to the density of the fibres(ρ_{fibre}), the quantity of fibres whose average volume V_f is known is weighed and its mass M_f obtained. This density is given by expression 8 :

$$\rho_{fibre} = \frac{M_f}{V_f} \quad (8)$$

- **Compression test on mud brick specimens**
  - **Manufacture of 4 cm x 4 cm x 16 cm mud bricks (NF P18-400 and EN 12390-1)**
    - **Method of making unstabilized specimens**

- Take and weigh 400g of soil sample;
- Take and weigh 10% of water (i.e. 40g of water) for each 400g of soil; the quantity of water taken is not far from the plasticity limit;
- Then mix (knead) the soil and water evenly in a sieve;
- The resulting mixture (in the shape of a paw) is then put into the 4cmx4cmx16cm crate mould and compacted by hand;
- The mixture is then pressed at 7kN in a hydraulic press to form the specimens;
- Remove the formed specimens from the mould and place it in a secluded area.

Method of making stabilized specimens

- Take and weigh 400g of soil sample;
- Take and weigh the mass corresponding to the percentage of fibre (4g for 1%, 8g for 2%, 12g for 3% and 16g for 4%);
- Substitute the fibre mass for the corresponding fibre mass in the 400g above;
- Mix the soil with the fibres in a (kneading) bowl
- Take and weigh out 10% of water (i.e. 40g of water) for every 400g of soil.
- Then mix the soil + fibre + water together homogeneously in a sub-sieve;

The resulting mixture (in the form of a paw) is then placed in the 4 cm x 4 cm x 16 cm section of the crate mould and compacted by hand;

- The mixture is then pressed at 7kN in a hydraulic press to form the specimens
- Remove the formed specimens from the mould and place it in a secluded area.

  - **Compression test of mud bricks (standard NF P 18-400, EN 12390-1, EN 12390-2 and EN 12390-3);**
  - **The surfacing of the specimens according to EN 12390-4;**
  - **Equipment required according to EN 12390-4;**
  - **The breaking load (F), is the maximum load recorded during the test and the compressive strength at d day (f_{cd}) is determined by the relation 9:**

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

F= breaking force of the specimen in Meganewtons (MN) ;
S= surface area of the specimen in m^2, 0.04 m x 0.04 m (0.0016 m^2)
f_{cd} compressive strength at d day in MPa.

From a calculation, the tensile strength on day d (f_{td}) is given by the relation 10 :

$$f_{td} = 0,06 f_{cd} + 0,6 \quad (10)$$

where f_{td} and f_{cd} are in MPa.

- **Water absorption and porosity test**

It was done after the 14th day of drying according to the following operations:

- Take one specimen of each percentage of each stabilized and non-stabilized sample (i.e. 5x3=15 stabilized specimens and 5x1=5 non-stabilized specimens) and determine the water content (w_1) after 24 hours in the oven at 105°C, and determine the initial volume Vi ;
- Remove the specimens after 24hrs and allow to cool for 24hrs at room temperature to avoid cracking of the specimens
- Weigh each specimen, read its mass, record and measure the dimensions (length, width and thickness)
- Soak and gradually remove the sides of each specimen in warm water, then immerse the specimen completely in water for 24 hours, remove specimens, weigh and record the dimensions and determine the final volume V_f and the water absorption content (w_{AB}).

- The swelling (G) is given by relation 11 :

$$G = \frac{V_f - V_i}{V_f} \quad (11)$$

- The porosity p, where d_a is the bulk density of the soil, is given by relationship 12 :

$$p = d_a \, x \, (w_{AB} - w_1) \quad (12)$$

IV. RESULTS AND DISCUSSION

A. Particle size composition of soil samples

The particle size compositions by dry method and by sedimentometry are presented in Figure IV.A.a:

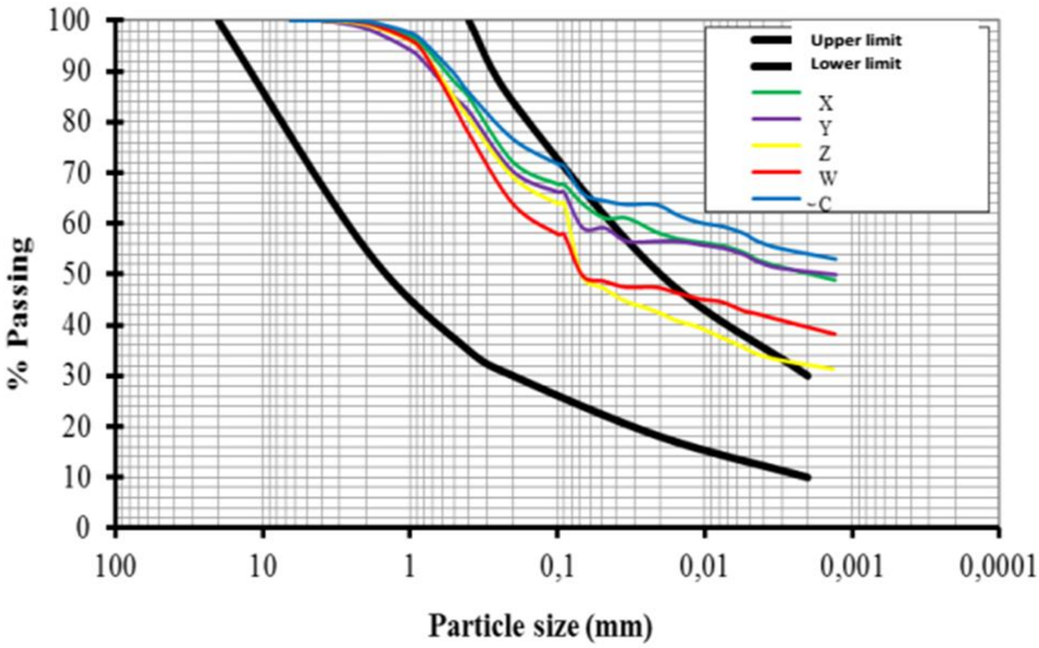

Figure IV.A.a: Particle size distribution curves of each sample of soil collected

The Munsel colour code and grain size after the sieve analysis tests are presented in Table IV.A.a:

Table IV.A.a: Summary of colour coding and granularity of soil samples

Sample	Coordinates	Code	% of gravel Ø>2 mm	Sand % 2>Ø>0.02 mm	% of silt 0.02>Ø>0.002 mm	% clay Ø<0.002 mm
X	**P, 79**	**10 Y R 5/8**	**0,46**	**41,17**	**6,79**	**48,87**
Y	**N, 65**	**7.5 Y R 6/6**	**1,53**	**41,96**	**5,26**	**49,95**
Z	**R, 77**	**10 Y R 4/4**	**0,74**	**56,39**	**9,6**	**31,35**
W	**N, 85**	**5 Y R 6/7**	**0,44**	**52,08**	**6,37**	**38,22**
C	**L, 57**	**7.5 Y R 8/6**	**0,16**	**36,07**	**8,6**	**53,02**

The results of the colour analysis in Table IV.A.a show that they are mainly yellow, brown and red, characterizing lateritic soils. As for the particle size analyses obtained by dry sieving and by sedimentometry presented in Table 4.1 and the curve in Figure 4.1, they reveal that samples X, Y, Z, W and C have a high percentage of clay (respectively 48.87; 49.95; 31.35; 38.22 and 53.02) and sand (respectively 41.47; 41.96; 56.39; 52.08 and 36.07) and a low percentage of silt (respectively 6.79; 5.26; 9.6; 6.37 and 8.6) and gravel (respectively 0.46; 1.53; 0.74; 0.44 and 0.16).

The lower and upper limits of the spindle (shown in black lines) are established according to the Cameroonian Standard on BTC (NC 102-114, 2002-2006).

It can then be seen that the curves of the samples move more quickly out of the limits of the standard when these samples have a high percentage of clay in relation to the sand (ranked in descending order of clay content). Thus for the curve to return to the normal BTC spindle, the percentages of the different grains must be 0-20 for gravel, 55-75 for sand, 10-25 for silt and 10-15 for clay.

The liquidity and plasticity limits and the plasticity index of the studied soils are presented in Table IV.A.b:

Table IV.A.b: liquidity and plasticity of soil samples

Sample	Plasticity limit (%)	Average plasticity limit (%)	Liquidity limit (%)	Plasticity index (%)
X	10,759	9,455	64,36	54,909
	9,396			
	8,209			
Y	6,061	7,791	56,91	49,121
	10,596			
	6,716			

Z	11,18	10,505	38,54	28,034
	9,091			
	11,243			
W	11,382	10,268	63,26	52,99
	9,957			
	9,465			
C	10,345	9,161	59,73	50,568
	7,692			
	9,444			

As shown in Table IV.A.b, the results of the plasticity and liquidity test obtained on material fractions below 400µm show that for samples X, Y, W and C plasticity indices are greater than 30 indicating a very high plasticity and that of Z between 20 and 30 which indicate a high plasticity. Therefore, only Z meets the conditions presented by the Cameroonian Standard on BTC in terms of plasticity. This plasticity is explained by the high presence of fine particles (clay).

B. Methylene blue values

The Methylene blue values are presented in Table IV.B:

Table IV.B: Soil Methylene blue values for clay content

Sample	VBS	Observation
X	2,23	Threshold distinguishing sandy loam from sandy clay soils
Y	2,20	Threshold distinguishing sandy loam from sandy clay soils
Z	1,86	Threshold distinguishing sandy loam from sandy clay soils
W	2,27	Threshold distinguishing sandy loam from sandy clay soils
C	2,33	Threshold distinguishing sandy loam from sandy clay soils

The **Methylene** blue values of Table IV.B refers to Dmax < 5mm (as 90µm sieve used). It can be seen that the soils are predominantly sandy-clay and therefore sensitive to water. This means that a certain quantity of water must be used to make the test material.

C. Characteristics of palm nut fibres

The density, diameter, length and moisture content of the palm nut fibres are presented in Table IV.C:

Table IV.C: Characteristics of palm nut fibres

Fibre mass (g)	Fibre volume (cm^3)	Fibre density (g/cm^3)	Diameter (mm)	Length (cm)	Water content (%)
19,68	**120**	**0,164**	**< 0,5**	**3 à 4**	**7,14**

According to table IV.C, the physical properties of the fibres (with very low values) show that they can be incorporated directly into the bricks.

D. Characteristics of stabilized mud brick specimens

- *Compressive strengths*

The compression tests are carried out on palm nut fibre stabilized mud bricks and the results for samples X, Y, Z, W and C are presented in Table IV.D.a and Figure IV.D.a for sample X, Table IV.D.b and Figure IV.D.b for sample Y, Table IV.D.c and Figure IV.D.c for sample Z, Table IV.D.d and Figure IV.D.d for sample W and Table IV.D.e and Figure IV.D.e for sample C.

Table IV.D.a: Compressive strengths of mud bricks of sample X stabilized with palm nut fibres

		Percentage of palm nut fibre in the bricks in the sample X				
		0%	**1%**	**2%**	**3%**	**4%**
Time (Days)	**7**	1,41	2,5	3,28	2	1,14
	14	1,75	3	2,63	2,41	2,19
	21	1,47	3,04	2,38	2,72	3,06
	28	1,79	2	3,25	3,55	4

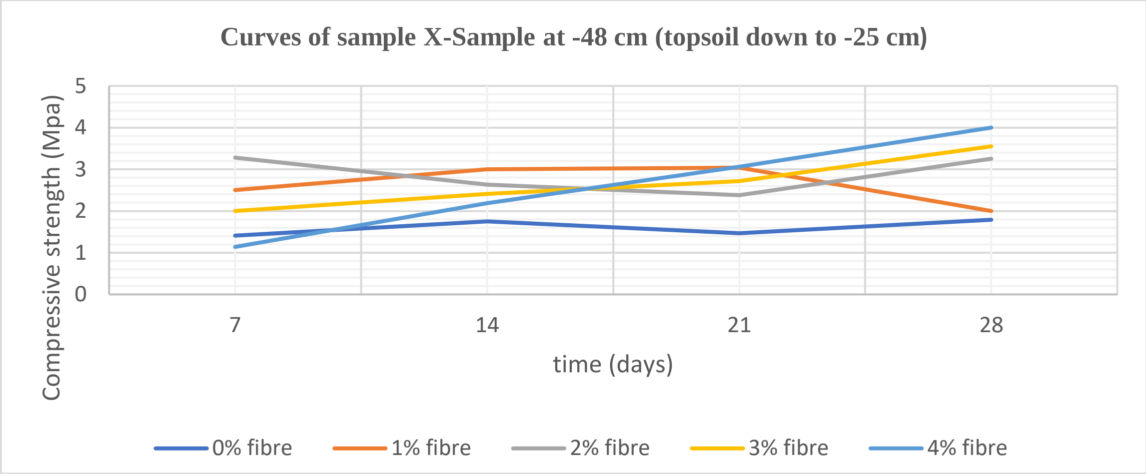

Figure IV.D.a: Compressive strength curves of mud bricks of sample X stabilized with palm nut fibres

From Table IV.D.a and Figure IV.D.a, an improvement in compressive strengths is noted with the strengths of stabilized bricks globally higher than those of non-stabilized bricks.

Table IV.D.b: Compressive strengths of mud bricks of sample Y stabilized with palm nut fibres

		Percentage of palm nut fibre in the bricks of the sample Y				
		0%	**1%**	**2%**	**3%**	**4%**
Time (Days)	**7**	0,28	1,41	2	1,8	1,69
	14	0,31	1,63	2,25	3,05	3,75
	21	0,23	2,81	2,91	2,85	2,81
	28	0,32	4,35	1,75	2,5	3

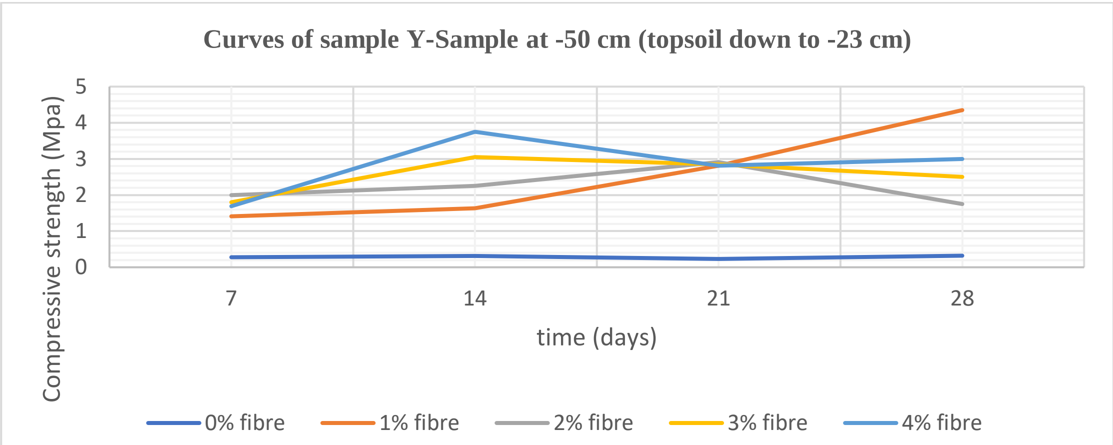

Figure IV.D.b: Compressive strength curves of mud bricks of sample Y stabilized with palm nut fibres

From Table IV.D.b and Figure IV.D.b, an improvement in compressive strengths is noted with the strengths of the stabilized bricks significantly higher than those of the non-stabilized bricks.

Table IV.D.c: Compressive strengths of mud bricks of sample Z stabilized with palm nut fibres

		Percentage of palm nut fibre in the sample bricks Z				
		0%	**1%**	**2%**	**3%**	**4%**
Time (Days)	**7**	1,91	1,66	1,78	1,99	2,17
	14	2	2,75	1,94	2,63	3,44
	21	1,03	2	2,78	3,6	4,16
	28	2,08	3	3,2	2,6	1,5

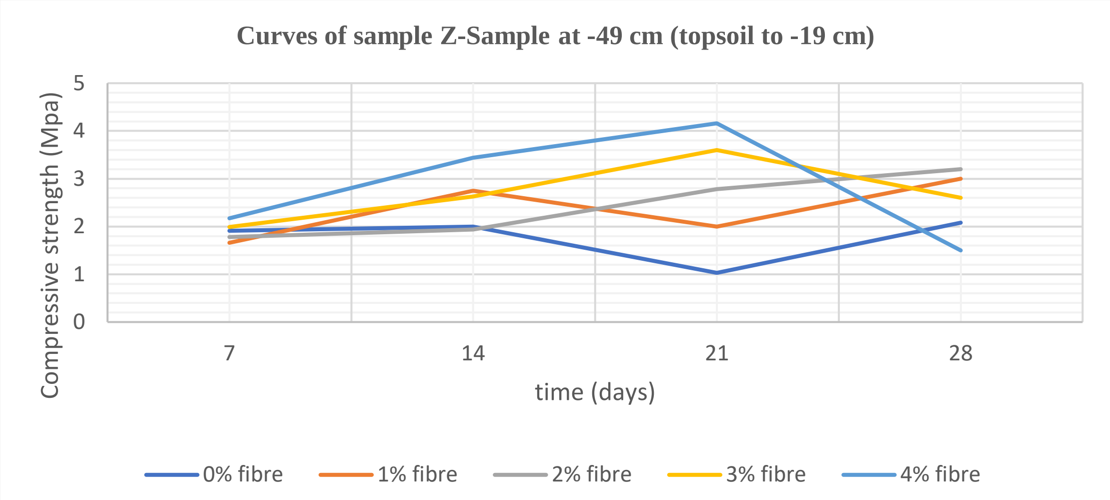

Figure IV.D.c: Compressive strength curves of mud bricks of sample Z stabilized with palm nut fibres

From Table IV.D.c and Figure IV.D.c, an improvement in compressive strengths is noted with the strengths of stabilized bricks globally higher than those of non-stabilized bricks.

Table IV.D.d: Compressive strengths of mud bricks of sample W stabilized with palm nut fibres

		Percentage of palm nut fibre in the sample bricks W				
		0%	**1%**	**2%**	**3%**	**4%**
Time (Days)	**7**	1,83	2,61	2,03	2,33	2,5
	14	1,81	2,31	1,94	2,36	2,94
	21	0,97	2,19	2,69	2,18	1,94
	28	1,68	2,8	2,9	3,5	4,5

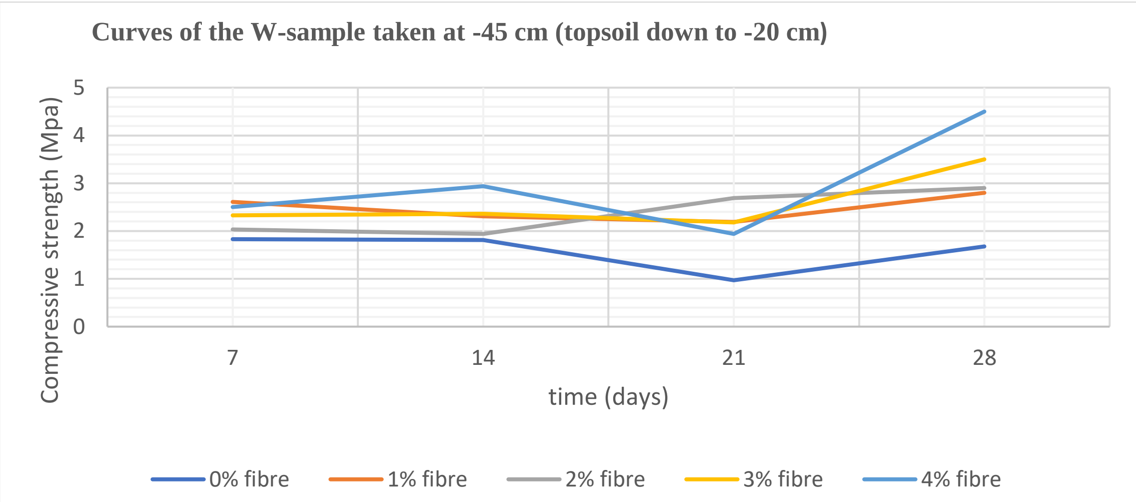

Figure IV.D.d: Compressive strength curves of mud bricks of sample W stabilized with palm nut fibres

From Table IV.D.d and Figure IV.D.d, an improvement in compressive strengths is noted with the strengths of the stabilized bricks significantly higher than those of the non-stabilized bricks.

Table IV.D.e: Compressive strengths of mud bricks of sample C stabilized with palm nut fibres

		Percentage of palm nut fibre in the bricks in the sample C				
		0%	**1%**	**2%**	**3%**	**4%**
Time (Days)	**7**	2	2,21	2,22	2,23	2,25
	14	1,75	2,19	2,38	3,18	3,56
	21	1,22	2,19	2,78	3,22	3,94

	28	2,13	1,4	2,54	2,66	2,8

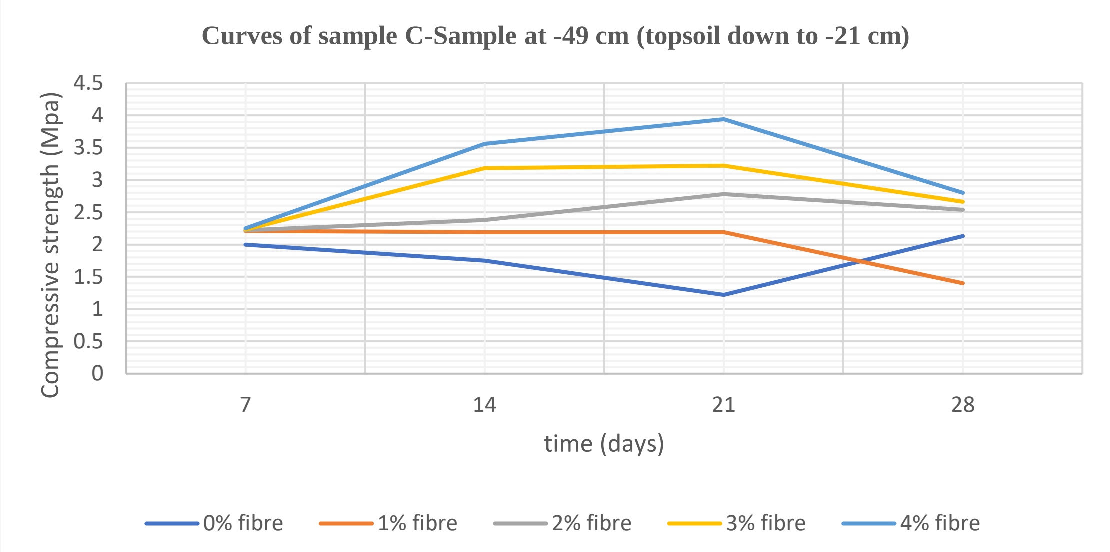

Figure IV.D.e: Compressive strength curves of mud bricks of sample C stabilized with palm nut fibres

From Table IV.D.e and Figure IV.D.e, an improvement in compressive strengths is noted with the strengths of stabilized bricks globally higher than those of non-stabilized bricks.

The recapitulation of the compressive strengths of mud bricks stabilized or not with palm nut fibres is presented in Table IV.D.f:

Table IV.D.f: Recapitulation of compressive strengths between stabilized and non-stabilized samples

Drying time	**Percentage of palm nut fibre**				
	0%	**1%**	**2%**	**3%**	**4%**
7 days	**0.28-2 MPa**	**1.41-2.61 MPa**	**1.78-3.28 MPa**	**1.8-2.33 MPa**	**1.14-2.5 MPa**
14 days	**0.31-2 MPa**	**1.63-3 MPa**	**1.94-2.63 MPa**	**2.36-3.18 MPa**	**2.19-3.75 MPa**
21 days	**0.23-1.47 MPa**	**2-3.04 MPa**	**2.38-2.91 MPa**	**2.18-3.6 MPa**	**1.94-4.16 MPa**
28 days	**0.32-2.13 MPa**	**1.4-4.35 MPa**	**1.75-3.25 MPa**	**2.5-3.55 MPa**	**1.5-4.5 MPa**

Table IV.D.f shows that the compressive strengths for the 0% specimens barely reach 2 MPa (varying from 0 to 2.13 MPa considering all the specimens) while those of 1% (varying from 1.4 to 4.35 MPa), 2% (varying from 1.75 to 3.28 MPa), 3% (varying from 1.8 to 3.6 MPa) and 4% (varying from 1.14 to 4.5 MPa) are in most cases around or even above 2 MPa. According to the same table, the drying time improves or even increases the compressive strengths of the specimens, mainly for those where palm nut fibres have been incorporated. These values are in line with and similar to the compressive strength values determined by Malanda et al (2018) on earth bricks stabilized with sugarcane molasses, but globally lower than the values varying between 2.81 and 16.03 MPa determined by Katte et al (2017).

- **Swelling and porosity of stabilized mud bricks**

The swelling and porosity of stabilized mud bricks are presented in Table IV.D.g:

Table IV.D.g: Swelling and porosity of stabilized mud bricks

Sample	**Fibre (%)**	**$(w_{AB}-w_1)$ (%)**	**Bulk density da of soils (g/cm3)**	**Porosity p (%)**	**Swelling G (%)**
X	**1**	**9,93**	**2**	**19,86**	**4,02**
	2	**10,78**	**2**	**21,56**	**6,61**
	3	**11,05**	**2**	**22,21**	**8,07**
	4	**11,295**	**2**	**22,59**	**10,08**
	1	**16,0048309**	**2,07**	**33,13**	**12,91**
	2	**18,599**	**2,07**	**38,5**	**14,27**

Y	**3**	**29,09**	**2,07**	**69,2**	**17,12**
	4	**40,39**	**2,07**	**83,6**	**20,53**
Z	**1**	**11,299**	**1,77**	**20**	**7,66**
	2	**19,92**	**1,77**	**35,26**	**11,53**
	3	**24,94**	**1,77**	**44,14**	**15,11**
	4	**30,435**	**1,77**	**53 ,87**	**17,68**
W	**1**	**18,49**	**1,5**	**27,73**	**8,2**
	2	**30,02**	**1,5**	**45,03**	**9,05**
	3	**32,23**	**1,5**	**48,34**	**9,20**
	4	**35,3267**	**1,5**	**52,99**	**9,46**
C	**1**	**21,4**	**2,01**	**43,05**	**6,53**
	2	**27,3**	**2,01**	**54,95**	**10,57**
	3	**29,88**	**2,01**	**60,06**	**11,17**
	4	**31,46766**	**2,01**	**63,25**	**11,45**
X	**0**	**-**	**2**	**-**	**-**
Y		**-**	**2,07**	**-**	**-**
Z		**-**	**1,77**	**-**	**-**
W		**-**	**1,5**	**-**	**-**
C		**-**	**2,01**	**-**	**-**

These results in Table IV.D.g on porosity show that the more fibres are incorporated into the specimen, the more pores it has and the less dense it becomes, and the more strength the specimen acquire between the aggregates. However, for the non-stabilized specimens, they could not hold up to the end of the test and ended up being unrecoverable for the weighing and dimensional test.

With regard to swelling, the same Table IV.D.g shows that for all specimens, the more fibres are incorporated in the specimen, the more the specimen tends to absorb water and swell, making the bricks brittle.

V. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

The objective of this work is the study of the physico-mechanical properties of stabilized mud bricks with palm nut fibres in Ndong Village, Mfou District, Mefou-Afamba Division in the Centre Region of Cameroon to reduce problems such as cracking and detachment of aggregates over time but also low compressive strength that barely reaches 2MPa.The Munsel colour code, particle size, Atterberg limits, bulk density, methylene blue, compression on mud bricks, water absorption and porosity tests were used. Also 0, 1, 2, 3 and 4% of palm nut fibres were used for stabilization of mud bricks. The results showed that the compressive strengths of bricks improved considerably for stabilized bricks than non-stabilized ones, up to 4.5 MPa for 4% fibre stabilization; For porosity, the more fibres are incorporated into the specimen, the more pores it had and the less dense it became, and the more strength the specimens acquired between the aggregates. However, for the non-stabilized specimens, they could not hold up to the end of the test and ended up being unrecoverable for the weighing and dimensional test. With regard to swelling for all specimens, the more fibres are incorporated in the specimens, the more the specimens tended to absorb water and swell, making the bricks brittle.The study was not carried out on several sites in the area in order to better observe the trend of the results and chemical analyses were not carried out in order to show the chemical action of the stabilizer on the brick and also the mineralogical properties of the soil.

B. Recommendations

Given the importance of palm nut fibre stabilization of mud bricks in the study area, it is appropriate to conduct further studies on the chemical and mineralogical composition (pH, minerals present, etc.) of the soil but also of the fibres (lignin, cellulose, ash, pectin, etc.) and experiment with other percentages of fibre incorporation to determine the most appropriate percentage for this stabilization.

REFERENCES

ACI, 1996. *State-of-the-art report on fibre reinforced concrete. Reported by ACI Committee. Disponible sur http://indiafiber.com/Files/ACI%20report.pdf. Consulté le 21 avril 2017.*

AMCO, 2009. Rénovationdurable.Disponiblesur http://www.renovationdurable.eu/IMG/pdf/2009_2010_AMCO_2387_partie2_chap_4.pdf. Consulté le 29 mars 2017.

***Association le village, 2015**. Fiche technique BTC. Disponible sur http://associationlevillage.fr/Association-le village/Publications/fiche_technique_BTC_LeVillage_2015.pdf.*

***Bachir T., 2014**. Étude du comportement physico-mécanique du bloc de terre comprimé aux fibres. Disponible sur http://thesis.univ-biskra.dz/1173/1/Geni_civil_d4_2014.pdf . Consulté le 15 avril 2017.*

***Badour S., Hamza S., Ha Phong N., Bourassi Y., Blanco D., Weill F., Eddamanhoury M., Moraru A., 2010**. Rapport de maçonnerie. Disponible sur http://aegc.epfl.ch/files/content/sites/aegc/files/shared/R%C3%A9sum%C3%A9,%20examen_HPN_HS_JER/Mat%C3%A9riaux%20I/TP_ma%C3%A7onnerie.pdf consulté le 30 avril 2017.*

***Baley C, 2004.** Fibres naturelles de renfort pour matériaux composites. Disponible sur https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwjF7JXarK7mAhWy6uAKHRkuDxkQFjAAegQIAhAB&url=https%3A%2F%2Fwww.techniques-ingenieur.fr%2Fbase-documentaire%2Farchives-th12%2Farchives-materiaux-fonctionnels-tian0%2Farchive-1%2Ffibres-naturelles-de-renfort-pour-materiaux-composites n2220%2F&usg=AOvVaw2cwViO2cBMl3SpKJPVpz3I. Consulté le 30 avril 2017.*

***Bock-Hyeng C., Andrea N., Ofori B., Yamb-Bell, Musibau A., Shofoluwe, 2016**. Mechanical Properties of Sustainable Adobe Bricks Stabilized with Recycled Sugarcane Fiber Waste. Journal of engineering Research and Application, 6: 50-59. Aussi disponible sur http://www.ijera.com/papers/Vol6_issue9/Part-3/G0609035059.pdf. Consulté le 30 avril 2017.*

***Bruno A. W., Gallipoli D., Céline Perlot C., Mendes J., Salomon N., 2015**. Briques de terre crue : procédure de compactage haute pression et influence sur les propriétés mécaniques. Rencontres Universitaires de Génie Civil, May 2015, Bayonne, France. HAL-01167676.*

***Bureau International du Travail Genève, 1985**. Construction à faible coût dans les programmes spéciaux de travaux publics. Principes directeurs pour l'emploi de la terre crue. Disponible sur http://staging.ilo.org/public/libdoc/ilo/1985/85B09_272_fren.pdf. Consulté le 29 mars 2017.*

***CRATerre, 1991**. Le bloc de terre comprimé: éléments de base. Disponible sur http://www.craterre.org/terre.grenoble.archi.fr/documentation/downloads/BTC-Elementsdebase.pdf. Consulté le 4 jullet 2017.*

***Degoutte G., Royet P., 2009**. Aide-mémoire des mécaniques du sol. Disponible sur http://www.umc.edu.dz/coursbiologie/cours%20mecanique%20des%20sols%20p%C3%A9dologie.pdf. Consulté le 4 juillet 2017.*

***Delot P., 2015.** Les adobes : production et mise en œuvre. Disponible sur http://associationlevillage.fr/Association-le-village/Publications/formation-adobes-2015.pdf . Consulté le 29 mars 2017.*

***Doat P, Hays A, Houben H, Matuk S, Vitoux F, 1979.** Construire en terre. Editions Alternatives. Disponible sur : https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=2ahUKEwiwr5Tznq7mAhUixoUKHUq1AN4QFjABegQIAxAB&url=https%3A%2F%2Fwww.abebooks.fr%2Frechercher-livre%2Ftitre%2Fconstruire-en-terre%2Fauteur%2Fcraterre%2F&usg=AOvVaw2GFryR-5JFORjIgXDnH4wW. Consulté le 29 mars 2017.*

***Estabragh A R, Bordbar A T, Javadi A A, 2011.** Mechanical behavior of a clay soil reinforced with nylon fibers. Disponible sur https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwjXm9TSoK7mAhWR0eAKHRGHDAEQFjAAegQIBRAB&url=https%3A%2F%2Fwww.researchgate.net%2Fpublication%2F225501461_Mechanical_Behavior_of_a_Clay_Soil_Reinforced_with_Nylon_Fibers&usg=AOvVaw3bh8UcJRfrUC7kmRt_3bfh. Consulté le 30 mars 2017.*

***Houben H, Rigassi V, Garnier P, 1996.** Blocs de terre comprimée : équipements de production. Disponible sur https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwj7z-Hvoq7mAhXE2eAKHQd_ClsQFjAAegQIBBAC&url=http%3A%2F%2Fdocumentation.2ieedu.org%2Fcdi2ie%2Fopac_css%2Fdoc_num.php%3Fexplnum_id%3D663&usg=AOvVaw2sI9lpNz8RF4zEcFAyqXUV. Consulté le 27 mars 2017.*

***Institut Internationale de l'Ingénierie de l'Eau et de l'Environnement (2iE), 2013**. Écomateriaux de construction: pilier de la croissance verte en afrique ?. disponible sur http://www.2ie-edu.org/assets/collection_acte_conference_eco_materiaux_2iE_2013.pdf. Consulté le 29 mars 2017.*

***Katte V.Y., Seukep J.F.N., Moundom A., Wouatong A.S.L. and Kamgang K.B.V., 2017.** The effect of partial replacement of waste water treatment sludge on the the properties of burnt clay brick. International Journal of Civil Engineering and Technology, 8(6), pp. 567-583.*

***Laboratoire central des ponts et chaussées, 1973**. Essais de laboratoire et en place de mécanique des sols. Disponible sur http://media.lcpc.fr/ext/pdf/ifsttar/librarie/fonds_ancien/NITESSMEC.pdf consulté le 15 avril 2017.*

***Laboratoire central des ponts et chaussées, 1987**. Analyse granulométrique par sédimentométrie. Disponible sur http://www.ifsttar.fr/fileadmin/user_upload/editions/lcpc/MethodeDEssai/MethodeDEssai-LCPC-ME18.pdf consulté le 30 avril 2017.*

***Malanda N., Louzolo- Kimbembe P., Tamba-Nsemi Y. D., 2017**. Etude des caractéristiques mécaniques d'une brique en terre stabilisée à l'aide de la mélasse de canne à sucre. Revue Cames-Sci. Appl. & de l'Ing., Vol. 2(2), pp. 1-9. ISSN 2312-8712.*

***NC 102-114, 2002-2006.** Bloc de Terre Comprimé, MIPROMAMO, ANOR, Yaoundé, Cameroun.*

***Ndjogui T. E., Ndip Nkongho R., Rafflegeau S., Levang L. F. P., 2014**. Historique du secteur palmier à huile au Cameroun. Disponible sur http://www.cifor.org/publications/pdf_files/OccPapers/OP-109.pdf consulté le 30 avril 2017.*

***Nithiya, R., Chris A., Vinodh L. K. R., Anbalagan, C., 2016.** Experimental Investigation on Bricks by using various waste materials. Journal of Latest Trends in Engineering and Technology, 6: 395-402.*

***Ohimain E. I., Izah S. C., Obieze F., 2013**. Material-mass Balance of Smallholder Oil Palm Processing in the Niger Delta, Nigeria. Disponible sur http://maxwellsci.com/print/ajfst/v5-289-294.pdf. Consulté le 30 avril 2017.*

***Olivier, M., Mesbah A., El Gharbi, Z., Morel J., 1997**. Mode opératoire pour la réalisation d'essais de résistance sur blocs de terre comprimée. Disponible sur http://www.rilem.org/images/publis/120303.pdf. Consulté le 30 avril 2017.*

***P'kla A., 2002**. Caractérisation en compression simple des Blocs de Terre Comprimés (BTC) : application aux maçonneries « BTC- mortier de terre ». Disponible sur http://theses.insa-lyon.fr/publication/2002ISAL0037/these.pdf. Consulté le 30 avril 2017.*

***Paulus, J., 2014**. Construction en terre : dispositions qualitatives, constructives et architecturales-application à un cas pratique : Ouagadougou. Disponible sur http://www.sbd.ulg.ac.be/research/Files/Thesis/2015_Paulus_Jehanne_MSc_Thesis.pdf. Consulté le 23 mars 2017.*

***Quo-Bao B., 2008**. Stabilité des structures en pise : durabilité, caractéristiques mécaniques. Disponible sur http://theses.insa-lyon.fr/publication/2008ISAL0093/these.pdf. Consulté le 15 avril 2017.*

***Serratrice J., 1996.** Les essais de gonflement. Disponible sur http://www.ifsttar.fr/collections/BLPCpdfs/blpc__204_65-85.pdf. Consulté le 30 avril 2017.*

***Sreekumar M. G., Deepa N., 2013**. Stabilized lateritic blocks reinforced with fibrous coir waste. International Journal of Sustainable Construction Engineering & Technology (ISSN: 2180-3242), 2: 23-32. Aussi disponible sur http://penerbit.uthm.edu.my/ojs/index.php/IJSCET/article/download/610/474. Consulté le 30 avril 2017.*

***Talla A. P., 2010.** Etude des constructions en briques de terre stabilisées à l'aide du parkia Biglobosa. Disponible sur http://documentation.2ie-edu.org/cdi2ie/opac_css/doc_num.php?explnum_id=646. Cconsulté le 15 avril 2017.*

United Nations, 1992. *Earth Construction Technology. United Nations Centre For Human Settlements, Disponible sur https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&uact=8&ved=2ahUKEwj53bOnqq7mAhXR5AKHdwTCRIQFjACegQIARAC&url=https%3A%2F%2Fwww.un.org%2Fruleoflaw%2Fwpcontent%2Fuploads%2F2015%2F10%2Fistanbul-declaration.pdf&usg=AOvVaw3o2Eea9kxC9bhVw2m2tgOf. Consulté le 04 mai 2017.*

Vissac, A., Fontaine, L., Anger, R., 2012. *Recettes traditionnelles et classification des stabilisants d'origine animale ou végétale. Disponible sur http://craterre.org/diffusion:ouvrages telechargeables/download/id/d8c1e3f89ee43e459d0e292fc9610798/file/2012_04_paterre_recettes_traditionnelles_stabilisants.pdf. Consulté le 23 mars 2017.*

Weill F., Radi M., Phong H., Hamza N., Ilias N. S., 2010. *Rapport d'identification des sols. Disponible sur http://aegc.epfl.ch/files/content/sites/aegc/files/shared/R%C3%A9sum%C3%A9,%20examen_HPN_HS_JER/M%C3%A9canique%20des%20sols%20et%20%C3%A9coulement%20souterrains/TP1.pdf. Consulté le 15 avril 2017.*