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Effect of Cassava (Manihot *esculenta* Crantz: Euphorbiaceae) Starch on the Stabilization of Malagasy Lateritic Soil

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Abstract: *Laterite is one of the most widespread raw materials, especially in Madagascar. Its valorization as a building material would help to solve many socio-economic problems in Madagascar as well as in Africa. The use of this type of material fits well within the framework of high environmental quality, since the process uses an abundant material that does not require too much energy for its manufacture because it is dried in the open air. The aim of this work was to stabilize the laterite with cassava starch. The valorization of the latter would contribute to the development of new building materials. The study focuses on the mechanical characterization of specimens made with Vontovorona laterite in different proportions, which goes hand in hand with the determination of the physico-chemical parameters of the starch. To make specimens, we used techniques such as extraction, sieving, heating, laterite-stabilizing dosage, mixing, rotting, moulding, clamping, demoulding, drying. The results obtained show that the best stabilizing material is obtained if 15% of starch is mix to lateritic soil. The compressive strength in the dry state of the test specimens (samples) gave a significantly interesting result with a value of 54.8 bars (85% laterite with 15% starch). Thus the use of starch as a stabilizer in construction gave satisfactory results. This eco-friendly process, simple in its steps and practice, should be popularized among artisanal brick makers. Thus, replacing proportions of the Portland cement in soil stabilization with Cassava starch will reduce the overall environmental impact of the stabilization process.*

Keywords: *laterite; stabilization; starch; cassava; compressive strength; Madagascar*

I. Introduction

The population continues to grow in number and requires a reception infrastructure to avoid settlement in shantytowns and create a vulnerable layer when natural disasters occur. Today with clay from rice fields, bricks are still made with rudimentary ancestral techniques as in many African countries [1]. This problem always leads us to look for new or adequate materials, more reliable, cheaper, more resistant and even biodegradable.

Laterites, lateritic clays, or lateritic soils (Figure 1a) are a large family of soils (generally of red colour) which form in humid tropical and subtropical regions and which result from a particular weathering process [2]. To the soil engineer, the word "soil" means a material which is used in any kind of civil engineering job, either as foundation material to support the load exerted by structures, or as construction material itself, as in the case of highway constructions. For this reason, lateritic soils represent an alternative as building material and are widely used around the world mainly in Africa (Figure 1b). They are very different from other soils, because they have much higher content of iron and aluminum oxides (sesquioxide) and often contain some secondary minerals such as goethite and hematite [3-4], as well large amounts of quartz and kaolinite.

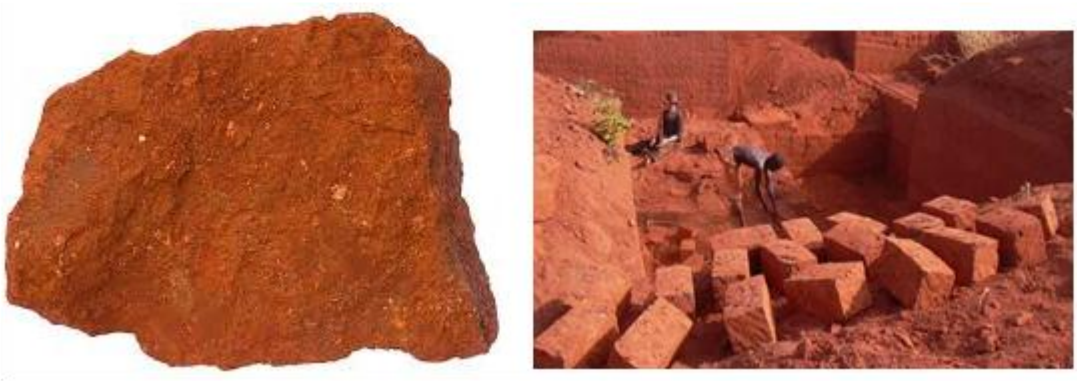


Figure 1**. Laterite **(a)** and House Foundation using Lateritic Bricks **(b)

There are numerous hypotheses on the genesis of laterites. Nevertheless, the most common hypothesis is that laterite can be formed from any type of rock (silicate, carbonate, etc), but only if the climate is hot and humid for an extended period **[5]**. During the weathering process which is very much dependent on the environmental conditions in which soils are occurring, the more unstable basic minerals disappear (e.g feldspars), and the more soluble ions escape in solution.

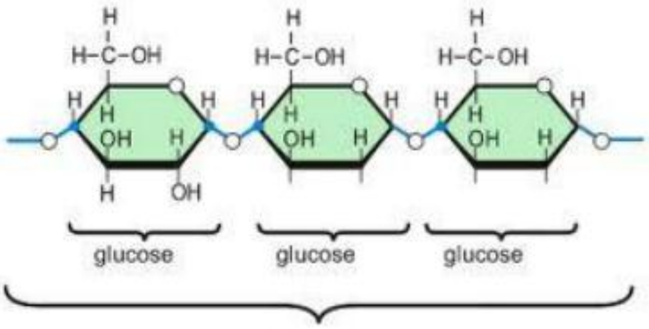
The stability of lateritic soils is a very important issue and depends essentially on the types of minerals that are contained in the soils. Some minerals such as halloysite and montmorillonite found in Hawaiian lateritic soils are known as being formed in the very early stages of weathering and they are not stables **[6].** The iron and aluminum oxides contained in lateritic soils play a crucial role for their stabilization and thus, in the formation and stabilization of large-size aggregates **[7].** To obtain a building material with better properties than the original soil, several products are mixed with the soil. The most commonly used are cement and lime, which are very expensive and luxury products. Thus, there is need to search for alternative methods of making use of cassava starch.

The valorization of natural substances such as cassava is one of the ideal solutions. Cassava (roots) is a product of agriculture in large quantities in several regions in Madagascar. The production of cassava in Madagascar is estimated in 2018 at more than 4.5 million tons [8]. It is generally practiced by peasants, in small plantations not exceeding 1 ha. The province of Fianarantsoa is the leading producer of fresh cassava at the national level, and supplies Antananarivo. It also supplies other regions such as the south of the island, which still has to bring in Tsiroanomandidy and Anjozorobe in times of drought. For this reason, we have chosen the theme "valorization of cassava used as laterite stabilizer". The aim of this research is to transform cassava starch into a stabilizer that can improve the mechanical resistance of the laterite brick and reduce the emission of CO_2 gas and consequently global warming in the world. This vision is in line with the meeting of the member states of the United Nations Framework Convention on Climate Change.

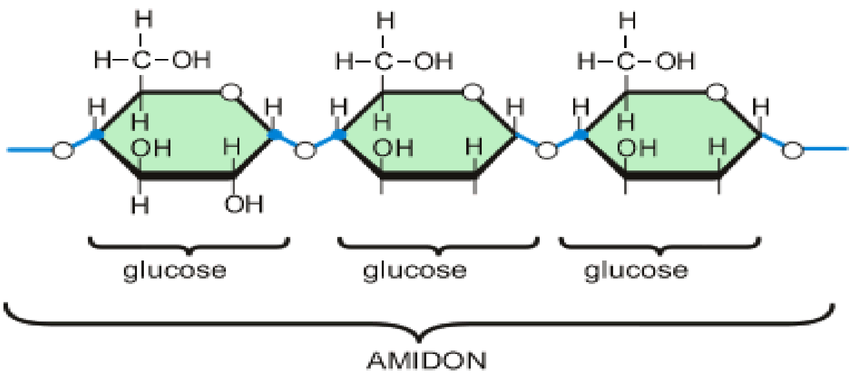
II. Material and Methods

2.1. Presentation of Cassava Starch

Starch consists mainly of glucidic fractions.



Complet ... molecules ($C_6H_{12}O_6$), so it



Fiber content	1.4

2.2. Vontovorona Laterite Data

The structure of the laterites is described as follows:

- Primary structure: iron oxide (Fe_2O_3)
- Secondary structure: clay
- Tertiary structure: magnetite (Fe_3O_4)
- Quaternary structure: quartz (SiO_2)

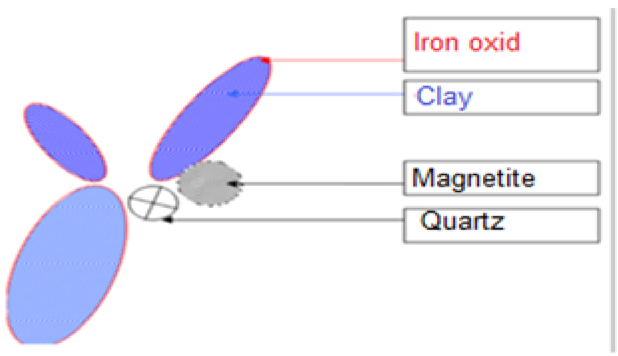


***Figure 3**. Structure of Laterite*

The chemical composition of the soil used in this study was performed by alkaline fusion method in order to determine the major elements according to NF ISO 14869-2 **[11]**. The chemical analysis reveals the presence of oxides of silicon, aluminium, iron, titanium, etc (Table 2).

Table 2. Results of the Analysis of the Chemical Constituents of Vontovorona Laterite

Constituents	**Content (%)**
SiO_2	31.54
Al_2O_3	25.94
Fe_2O_3	26.01
TiO_2	4.40
CaO	Trace
MgO	Trace
SO_3	Trace
K_2O	Trace
Cr_2O_3	Trace
MnO	0.21
Na_2O	0.09
P_2O_5	0.51
Loss of fire	11.29

2.3. Methodology

a. Stabilization Objectives

Stabilizing laterite means modifying the local soil so that it is best suited to the requirements involving modification of the properties of a land-water-air system to obtain permanent properties compatible with a given application.

The main objectives are to:

- Obtain better mechanical characteristics: increase dry and wet compressive strength, tensile and shear strength;
- Obtain better cohesion ;
- Improve resistance to wind and rain erosion: reduce surface abrasion and waterproof.

b. Types of Stabilization

Two possible ways to stabilize the lateritic soils are used in this study: mechanical stabilization and chemical stabilization.

1. *Mechanical stabilisation*

The properties of the earth were modified by intervening on its structure. It is the compaction of the earth that modifies its density, compressibility, permeability and porosity.

2. *Chemical stabilisation*

Laterite is added to other materials or chemicals that modify its properties. The modifications result from physico-chemical reactions between the active constituents of laterite and the materials, leading to the formation of new phases within the texture and maximum coating of the inert grains.

c. Test Tubes Manufacturing

1. Use of earth-stabilizer mixture

This step is very complex, since, on the one hand, the effectiveness of stabilization depends very strongly on the quantity of starch to be used, and on the other hand, the performance of the finished samples varies with its content. The different stages of stabilization are: laterite extraction, sieving, heating, laterite-stabilizer dosage, mixing, rotting, moulding, clamping, demoulding and drying, as can be seen in Figure 4.

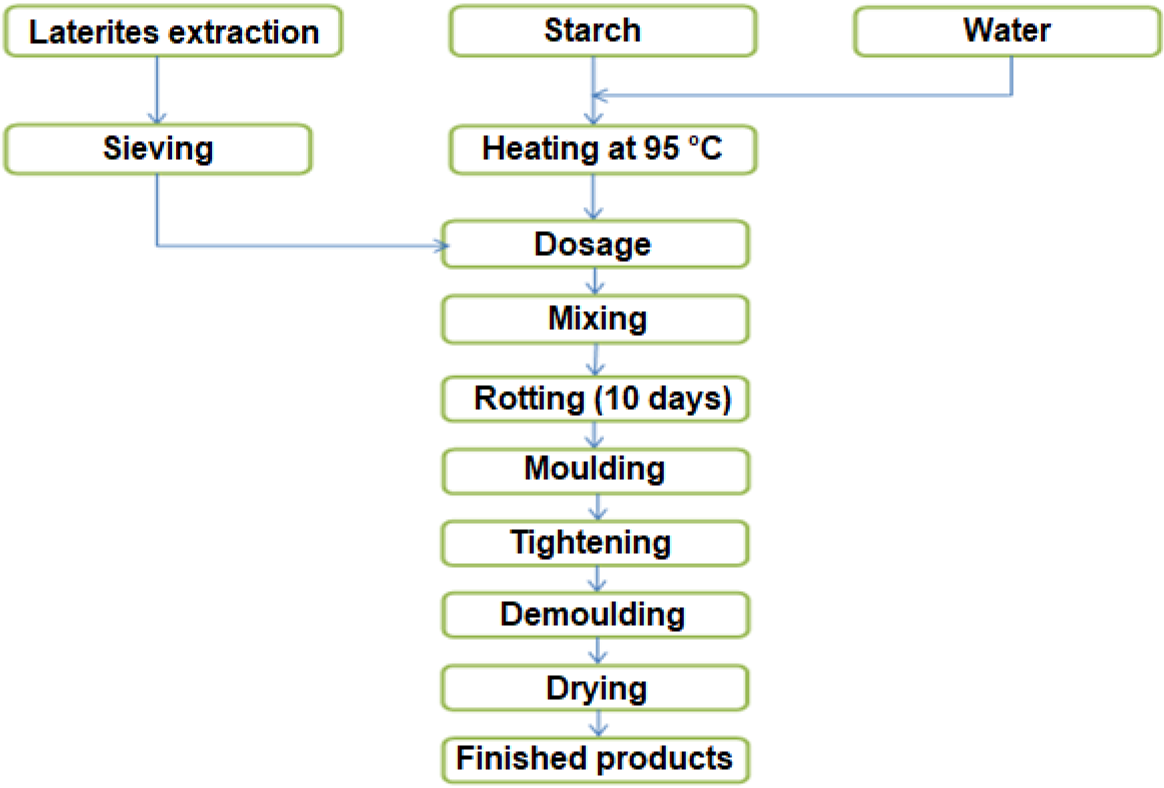


Figure 4. *Diagram of Laterite Stabilization by Starch*

- Laterite Extraction

Samples were collected from the Vontovorona Campus enclosure (Madagascar) at a depth of 1 m at Laborde coordinates; x = 791. 500; y =504.500. Laterite is extracted at a depth of 1 m with a shovel and manually. Attempts are made to clear the soil of any organic debris that may be with it and that may interfere with the implementation and composition envisaged for the bricks.

After being extracted from the quarry, the soil is unloaded and stored in a spacious and well-ventilated area for easy handling.

- Sieving

Before this operation, the laterite was dried in an oven at 120°C for two hours. Then it was sieved with an AFNOR sieve with a mesh size of 1 mm. The particles passing through the mesh of this sieve are collected.

- Drying

Starch can be heated with water at a temperature of 95°C to obtain the maximum viscosity of the starch.

- Dosage

This is the mixing of laterite with stabilizer and water. This method uses weighing equipment that must be accurate to within 10 to 50 g depending on the quantities weighed. The smaller the quantities, the more accurate the scale must be.

- Kneading

There are two ways to do the mixing.

- *Dry Kneading*

Dry mixing is intended to homogenize the soil-stabilizer mixture. Good dry mixing should be carried out and the minimum mixing time of 3 to 4 minutes should be respected, otherwise the effectiveness of the stabilization may be reduced. The decrease in performance can reach about 20%.

- *Wet kneading*

The mixture is then moistened to the optimum moulding water content. This water content also varies with the nature of the soil and the stabilizer to be used. An error in water content of 1 to 2% can lead to a decrease of 2 to 10% in the dry density of the blocks.

- Rotting

Rotting consists in letting the mixture rest for 10 days in order to increase the plasticity and homogeneity of the mixture by treating the pasta by exposure to humidity.

- Moulding

The dough is poured into a test tube (mould) and kneaded into the desired shape. The use of release oil is necessary to facilitate the demoulding process and to avoid sticking to the mould wall. This can be done using running oil or even water. Both sides of the specimens must be surface-prepared (flat side and bottom side of the mould). The crushing test shall be carried out on the flattened side, i.e. in the same direction as the specimens are made.

- Tightening

The purpose of clamping is to rearrange the soil particles so that they can bind together well. This leads on the one hand to an increase in the density of the compact assembly, and on the other hand to a decrease in its permeability, all three of which are very important characteristics in geotechnics.

- Demoulding

Demoulding is carried out after the dough has been tightened. This must be done carefully, meticulously and thoroughly.

- Drying

Drying is done in the shade but not in the sun: this is to limit the accelerated shrinkage of the laterite. In addition, the specimens or samples must be protected from all weather conditions to promote their maturation. A spacious and well-ventilated place must be found to dry them.

Figure 5. *Test Tubes Made of Stabilized Laterites*

d. Characterization of Finished Products

The purpose of these tests is to determine certain performances and properties of the materials in order to assign them appropriate and adequate uses.

The basic tests for the characterization of finished products are the withdrawal; the porosity and the crush resistance. In order to clearly distinguish the samples from each other, the following notations have been adopted, specifying the nature and proportion of the stabilizer used. LS X: Laterite with X% of starch (LS 00: L with 0% of starch; LS 05: L with 5% of starch; LS 10: L with 10% of starch; LS 15: L with 15% of starch; LS 20: L with 20% of starch).

III. Results and Discussion

3.1 Withdrawal

Shrinkage is expressed by the variation in length and diameter during the drying of the specimens. The length of the fresh shaped product is then measured. Another measurement is performed after 14 days of drying.

Either: $$R(\%) = \frac{d_h - d_s}{d_h} \times 100$$ or $$R(\%) = \frac{L_1 - L_2}{L_2} \times 100$$

With L_1: fresh product length; L_2: length of the completely dry product; d_h: fresh product diameter and d_s: diameter of the completely dry product. The linear shrinkage of the bricks was measured on day 14. The results obtained are presented in the figure 6.

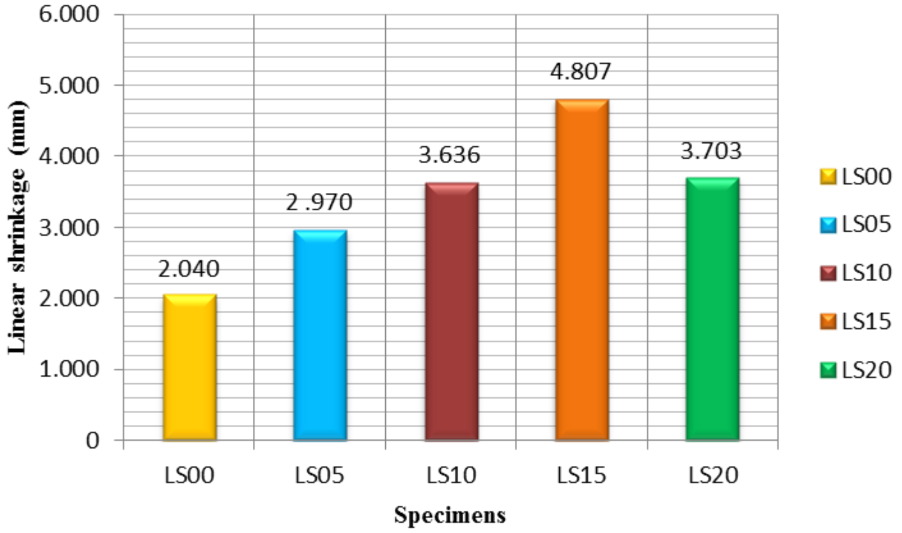


Figure 6. *Variations in Linear Shrinkage of Specimens*

3.2. Porosity

It is the percentage of the amount of water absorbed by the material during its immersion for 24 hours (Figure 7). It is defined by the relationship:

$$p = \frac{M_h - M_s}{M_s} \times 100$$

with p = porosity; M_h = wet material mass and M_S = dry material mass.

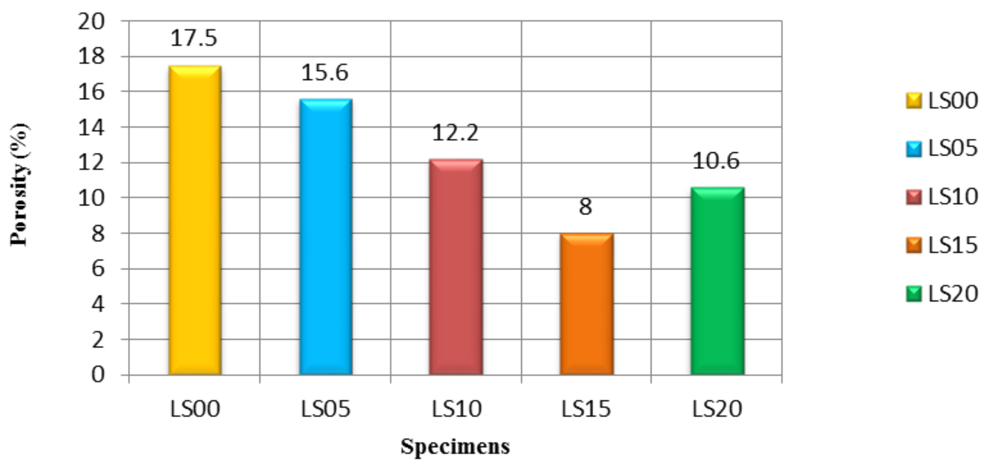


Figure 7. *Porosity Value*

3.3. Resistance to Crushing or Dry Compression

It is expressed as the limit load per unit area that the specimen can withstand without being crushed (Figure 8). It is expressed by the following formula:

$$R_c = \frac{F}{S_b}$$

with F: maximum load supported by the test piece and S_b: average gross cross-sectional area of the specimen.

The results of the compression tests carried out on all samples are given in the figure 8 below; the compression tests were carried out on days 7, 14 and 28 for each composition.

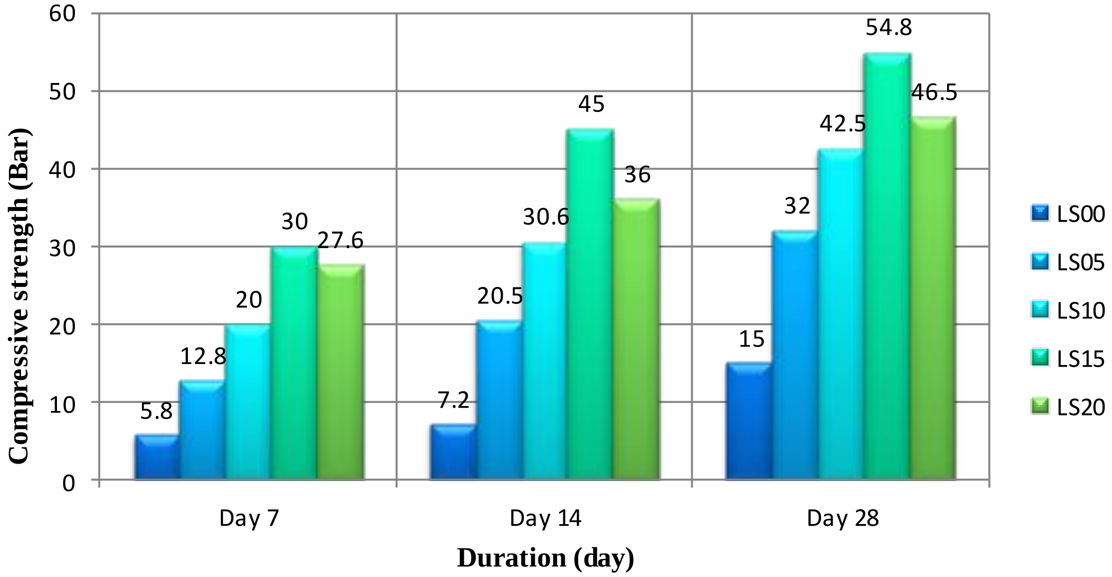


Figure 8. *Change in Dry Compressive Strength*

3.4. Wet Compressive Strength

The wet compressive strength of investigated laterites is gathered in Table 3.

Table 3: Average wet compressive strength of studied laterites

Duration (day)	Wet compressive strength (bar)				
	LS00	LS05	LS10	LS15	LS20
Day 7	Disaggregation	Disaggregation	Disaggregation	Disaggregation	Disaggregation
Day 14	Disaggregation	Disaggregation	4.8	8.5	8.5
Day 28	Disaggregation	4.2	6.0	18.0	10.0

3.5. Resistance to Traction

The limit load per unit cross-section that the material can support without breaking is given in figure 9. It can be deduced from the compressive strength by the formula:

$$R_t = \frac{1}{10} R_c$$

with R_t : Resistance to traction and R_c : Resistance to compression.

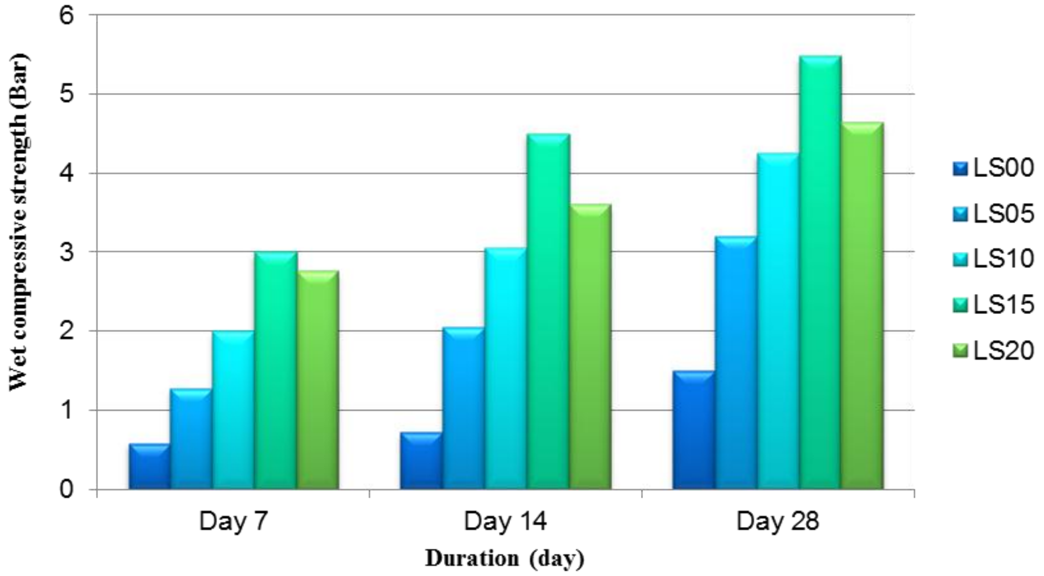


Figure 9. *Variation of Tensile Strength*

3.6. Resistance to Shear

This is the conventional load corresponding to the failure of the specimen subjected to a bending test (figure 10). It is deduced from the compressive strength by the following formula:

$$R_{sh} = \frac{10}{3} R_c$$

with R_{sh} : Resistance to shear and R_c : Resistance to compression.

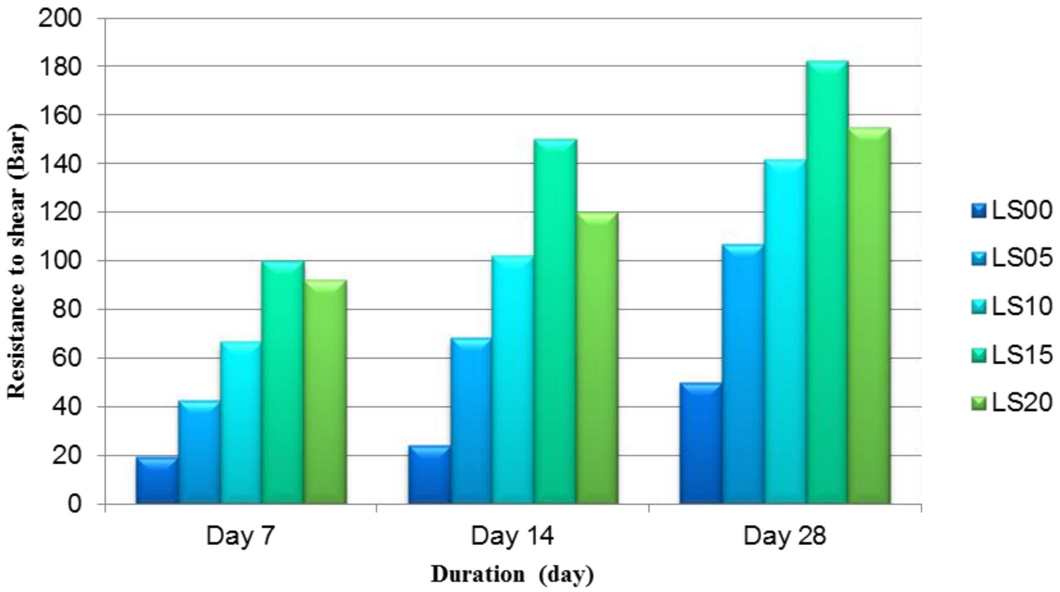


Figure 10. *Variation of the Resistance to Shear*

3.7. Determination of Density

Density is the ratio of the total mass of a certain amount of soil to its volume. It is expressed by the following formula:

$$\rho = \frac{M}{V}$$

with $$V = \frac{\pi d^2}{4h}$$

M= Total mass
d= specimen diameter

h= specimen height

The density of the finished products was measured on day 28. The results of the measurements are shown in the following figure 11.

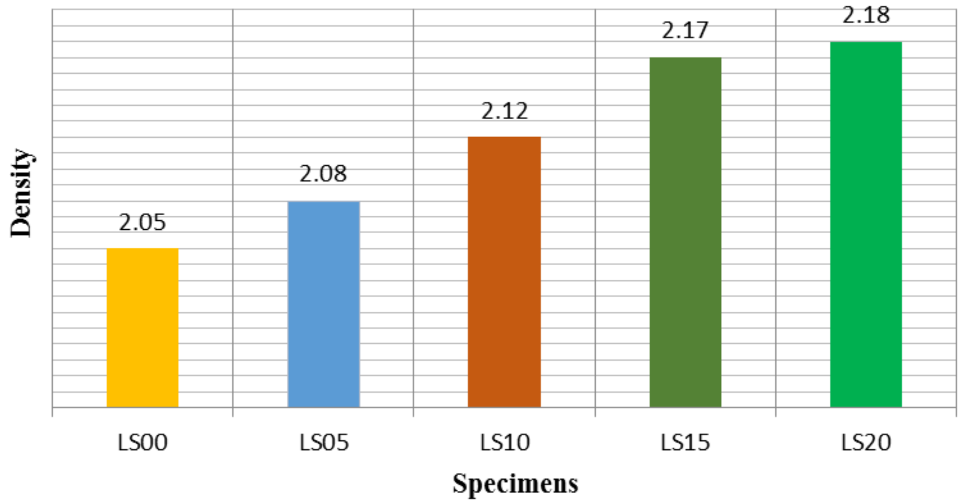


Figure 11. *Variation of the Density*

This research is dedicated to the valorization of the Malagasy ancestral construction materials not yet referenced, and then to qualify the physical state of the specimens was done by referring to the Cameroonian standards (Table 4). Referring to the Cameroonian standards, the 15% starch sample with laterite 85% is in class B "Good", it has a high dry and wet compressive strength compared to the other samples. Samples LS05, LS10, LS20 are in class C "Average", concerning the values of porosity, dry compressive strength and wet compressive strength. Sample LS00 is in class D: "Low". It does not resist after 30 minutes of immersion. After the various manufacturing tests, we were able to determine the best composition of our sample; it is 15% starch with 85% laterite. We found that the resistance to dry compression is 54.8 bars; we also know that the resistance to wet compression is 18 bars. During the manufacturing trial, there is the rotting time of 10 days to get the plasticity of the mixture and its homogeneity to obtain the high compressive strength. In the chemical stabilization, we must emphasize that the microbial reduction during the rotting time contributes to the mechanical stabilization of laterites.

Table 4. Classification of Specimens According to Cameroonian Standards

Characteristics	S (age)	U (unit)	Class A: Excellent	Class B: Good	Class C: Medium	Class D: Low
Total absorption : p (24 hours dipping)	28 days	% weight	< 5 %	[5, 10]	[10, 20]	>20
				LS15 : p= 8 %	LS05 : p=15.6 LS10 : p=12.2 LS20 : p=10.6	LS00 : Disaggregation
Dry compressive strength: R_C^{dry}	28 days	bar	>120	[50, 120]	[20, 50]	< 20
				LS15 : R_c =54.8	LS05 : R_c= 32 LA10 : R_c=42.5 LA20 : R_c=46.5	LS00 : R_c=15
Wet compressive strength: R_C^{wet} (24 hours dipping)	28 days	bar	>20	[10, 20]	[5, 10]	< 5
				LS15 : R_c =18	LS05 : R_c=5.2 LS10 : R_c=6 LS20 : R_c=10	LS00 : Disaggregation

3.8 Comparison of Brick Manufacturing Process

Table 5. Comparison between Two Bricks from Two Manufacturing Processes

Method of manufacture	Clay brick stabilized with starch	Terracotta brick
Raw materials	Cassava, laterite	Clay
Fuel	No cooking	Wood fuels (biomass)
Advantages of the method	Available products to farmers, bets easy work	Bons comportements à l'eau, utilisation simple avec la moule.
Cooking temperature	Heating to 95°C for cassava starch	1200°C for brick firing
Mechanical resistance at 28 days	54.8 bars	27.3 bars
Sustainability	Bricks do not show cracks	Bricks are more easily exposed to cracks.
CO_2 emissions	The brick emits a low level of CO_2	The brick emits a high level of CO_2 during firing.

According to the comparison of used methods, the laterite brick stabilized with starch is easy to manufacture, does not pollute the atmosphere, and respects the environment.

3.9. Environmental Approach

a. Socio-economic Impacts

- Creation of decent work for villagers by recruiting local labor ;
- Improvement of accessibility to goods and services;
- Valorization of available and accessible local products.

If such an activity could be formalized as a source of income, then environmental protection would be better managed. And since it is a source of income, the villagers will be able to send their children to school, to consult a doctor and to buy medicines if they are sick.

b. Negative Impacts during Manufacturing

- Laterite excavation from mining;
- Disturbance and accident due to laterite extraction holes;
- Pollution with unused material and waste;
- Need to manufacture starch from dry cassava;
- Heating of starch before use.

c. Mitigation of Negative Impacts

Mitigation measures must be taken to ensure that negative impacts are mitigated and perhaps even reversed, such as:

- Compliance with work safety rules;
- Sensitization of brick craftsmen to environmental protection;
- Management of liquid pollutants and solid waste;
- Installation of a starch production unit;
- Management of unused materials;
- Cheaper choice of fuel for heating starch by recycling cassava peels for a green and circular economy;
- Planting cassava over larger areas.

This process, simple in its steps and practice, should be popularized among artisanal brick makers.

The inclusion of this concept and the manufacture of artisanal cement [12] in the training program in technical or vocational schools is essential for a country like Madagascar. Indeed, over the years, cement and lime have been the main materials used for stabilizing soils. By definition, soil modification is the addition of a modifier like cement or lime to a soil to change its index properties, while soil stabilization is the treatment of soils to enable their strength and durability to be improved such that they become totally suitable for construction beyond their original classification. The modifier materials have rapidly increased in price due to the sharp increase in the cost of energy and their high demand. It has been also shown that Portland cement, by the nature of its chemistry, produces large quantities of CO_2 for every ton of its final product which contributes to the melting of the ozone layer covering the earth surface. Therefore, replacing proportions of the Portland cement in soil stabilization with Cassava starch will reduce the overall environmental impact of the stabilization process [12, 13].

In both Africa and Madagascar, it was reported that the use of alternative raw materials could help to bring the opportunity to solve many socio-economic problems [14-16]. This is particularly the case of Gbado-Lite city (Nord-Ubangi Province) in Democratic Republic of the Congo where lateritic soil is widely used as Brick Manufacturing raw material [1]. The present study revealed thus that *Manihot esculenta* Crantz could help people to combat deforestation linked to the process of clay brick manufacturing in Nord-Ubangi eco-region which is a subgroup of Northeastern Congolian lowland forests. This eco-region displaying a climate better adapted to the cassava culture, is one of the 200 globally priority terrestrial eco-regions known as the "G200" [17-21].

IV. Conclusion and Suggestion

The aim of this work was to study the stabilization of laterite by starch in order to develop a new process for laterite stabilization, without cement or fat lime and at lower cost using cassava. According to the laboratory test results, it was proved that the value of the dry compressive strength of the test specimens (samples) carried out gave a higher result of 54.8 bars (85% laterite with 15% starch) confirming thus that new materials can be produced in the field of civil engineering. The stabilization of laterite by starch is a very interesting choice because cassava is cultivated in all regions of Madagascar, and it is also technically, economically leading compared to other stabilizers, and environmentally feasible for sustainable development.

Further in-depth studies are still necessary, in particular, the implementation of large scale trials to be able to conclude on the reliability of this method. The protection of the environment is a vital duty worldwide, so it is important to raise public awareness.

Acknowledgement

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