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IMPROVEMENT OF THE MECHANICAL CHARACTERISTICS OF EARTH MATERIALS IN TRADITIONAL CONSTRUCTIONS IN NORTHERN CAMEROON

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ABSTRACT

Traditional constructions of the Sudano-Sahelian zones are mostly made from earth. However, these structures sometimes show early deterioration when they are not mixed with other materials. Mixing the earth material from termite mounds with straw *Hyparrhenia hirta* (L.) and suksuki) and snail shell powder after bringing it to a temperature of 700°C and sometimes with cow dung indicates the composition of our basic materials. Five mixtures were prepared with different percentages of its components: 2.5% straw or 62.5g for the first mixtures; 1.5% or 37.5g for the second mixture, 0% or 0g for the third mixture, 2.5% of straw, or 62.5g; 2.5% cow dung, i.e., 62.5g for the fourth mix and 1.5%, i.e. 37.5g snail shell combined with 1.5%, it's either are use that is 37.5g cow dung for the fifth mixed. The submission of all these mixtures to mechanical tests in order to study their behaviour have shown that the compressive strength varies from one mixture to another and could therefore constitute a means of improving the mechanical behaviour. Of the different samples for which the average compressive strength increased from 1.131542 MPa for the first mixture to 8.863744 MPa for the fourth mixture.

Keywords: Improvement, characteristics, mechanics, materials, buildings.

INTRODUCTION

Composite is defined as the assembly of two or more immiscible materials whose properties complement each other, forming a new material (Wendlamita, 2019). This material has several characteristics, the most interesting of which is the gain in mass, regarding its excellent mechanical characteristics. Similarly, this type of material is characterized by its high resistance to fatigue and its low rate of aging under the action of humidity, heat, and corrosion (Mahmoudi, 2010). The composite material is mainly made of a matrix and a reinforcement. The cohesion between them is that, by the interface, which ensures compatibility between the reinforcement and the matrix, and the transmission of forces from one to the other is without a relative displacement (Nouigues, 2021).

One of the materials commonly used in traditional constructions in the Sudano-Sahelian zone is clay soil resulting from prior treatment by termites, used in the construction of residential huts and granaries. While some use earthen materials taken from swampy areas, others, on the contrary, mix these materials with selected straw. We can then use the Coolati grass (*Hyparrhenia hirta* (L.)) for the construction of huts and granaries, and the "suksuki" for the huts in shells. Studies on the combination of stems, rice straws and néré decoction improves resistance to compression by 6% of the added decoction (Mariette, 2021).

Several studies on land stabilization have shown that 90% of the work concerns the use of mineral binders, 50% of which is with cement and the rest is shared between lime and other mineral additives or a mixture of several mineral binders (Humphrey *et al*., 2015; Ouedraogo, 2019). The use of snail shell in the prepared mixtures would be a means of studying the mechanical behaviour of the samples prepared for this purpose. In the present study, we analyzed quality of improved raw materials with five mixtures of various percentages of its components in mixing the main mixture and studied chemical and mechanical behavior of the product.

MATERIALS AND METHODS

Soil material is a set of constituents (water, air, organic matter, and solid matter) whose respective proportions characterize the structure of the soil. The one used in construction is obtained by a mixture of aggregates with elements of variable nature and proportions (gravel, sand,

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silt, and clay) (Guillaud *et al*., 2006). A study conducted on the construction of residential buildings showed that readily available building materials were used to construct houses and shelters. In hot, arid and temperate climates, the most common building material is earth. Today, almost a third of the world's population lives in mud houses and this number even reaches more than half in developing countries (Minke, 2006).

Within the framework of this experiment, the materials subjected to this study are soil samples taken from three different sites; Kani-Kaélé, Mayami-Garoua and Mourla-Pousse in the northern part of Cameroon (Table 1) where the climatic conditions are similar to the rest of the Sudano-Sahelian zone, delimited to guide our research and make it more optimal.

The study of the different samples taken aims to identify the material, analysing it and interpreting the results which are very important in the formulation of a resistant and durable material.

The samples taken were studied in the laboratory of the Mission for the Promotion of Local Materials (MIPROMALO) in Yaoundé.

The materials used as adjuvants are selected straws (*Hyparrhenia hirta* (L.) and suksuki). The crushed snail shell heated to 700°C served as a hydraulic binder. The choice of these materials is justified by the impossibility or the difficulty of manufacturing cement without emitting greenhouse gases. The proposal of alternative binders such as our local materials available, economical and without environmental problems would be a solution to the problem (Abakar *et al*., 2018).

The specimens prepared are cylindrical in shape with standardized dimensions (Ø=10cm, H=20cm) and parallelepipedic in shape for the dimension compression and bending tests (B=4cm, H=3cm, L=16cm). Within the framework of the preparation of the samples, the materials below were used according to well-defined percentages and with the aim of identifying the threshold corresponding to the correct proportions of the components of the formulated material. Thus, straw, snail shell powder, termite mound clay, cow dung and sand were used according to the following distribution contained in Table 2.

a) Préparation of mixtures

After crushing the earth to improve the composition of the materials, it is weighed in order to determine the mass to be taken in the preparation of the sample using a precisise electronic balance KERN PNS-PNJ (Fig. 1-a). Then, the *Hyparrhenia hirta* (L.) is abounded and measured according to the various quantities (Fig. 1-b). Finally, the snail shell is cleaned and dried before (Fig. 1-c).

Fig. 1. Separate preparation of materials (a): weighing the soil, (b)Straw, (c): Snail shells.

b) Characterization

It consisted in carrying out on the earth material taken from different sites, a set of analysis aimed at identifying and analysing its granulometry, the relative curve of which presents the percentage of sieves and the diameter of the grains of the soils taken (Figs. 6 and 7). Traditional constructions, the earth material used is obtained by a mixture of aggregates with elements of variable natures and proportions (gravel, sand, silt, and clay). In addition, a study conducted on the construction of residential buildings showed that readily available building materials were used to construct houses and shelters. In hot, arid, and temperate climates, the most common building material is soil. Today, almost a third of the world's population lives in mud houses and this number even reaches more than half in developing countries (Guillaud *et al*., 2006).

The characterization of these earth samples taken therefore follows a precise methodology, which aims to identify the material, analyse it and interpret the results. These results can guide the choices of those involved in the construction of traditional buildings and structures. Within the framework of our study, we carried out the identification of soil samples, the granulometric analysis, the study of the Atterberg limits and tests with methylene blue. Mixing said materials according to the rates below allowed us to study the behaviour of the formulated composition. Each time we check the mechanical characteristics of the sample in order to orient ourselves on the materials that we can choose in order to improve it. The crushing and sieving of the materials were carried out separately (clay and snail shell). They were then combined using an appropriate mixer (Malanda *et al*., 2017), respecting the proportions described below. The mixture in figure 2 below is obtained by mixing the materials described (Fig. 1)

Fig. 2. Mixture of dry soil (earth), straw and provider snail shells.

Fig. 3. Decanting mixtures into test tubes (STOKES Law)

Fig. 4. Méthylène bleue test apparatus.

Fig. 5. Mechanical test apparatus, (a): Assembly of the parts, (b): Compression of the sample.

Table 1. Summary of material sampling sites.

No.	Designation of the site	Department	Architectural identity (use)
1	Kani- Kaélé	Mayo-kani	Clay box
2	Mourla-Pousse	Mayo-danay	Case in raw earth shells
3	Mayami-Garoua	Bénoué	Case in clay

Table 2. Distribution of the content of materials in the samples.

Mixtures		Materials				
		Straw	Snail Shell Powder	Clay	Cow Dung	Sand
1	%	2,5%	2,5%	95%	0%	0%
	Mass	62,5g	62,5g	62375g	0g	0g
2	%	1,5%	1,5%	97%	0%	0%
	Mass	37,5g	37,5g	2425g	0g	0g
3	%	0%	2,5%	97,5%	0%	0%
	Mass	0g	62,5g	2437,5 g	0g	0g
4	%	2,5%	2,5%	925%	2,5%	0g
	Mass	62,5g	62,5g	2312,5g	62,5g	0g
5	%	1,5%	1,5%	95,5%	1,5%	0%
	Mass	37,5g	37,5g	23x7,5g	37,5g	00

Table 3. Particle size distribution.

Ref Sample	% gravel Φ>2 mm	% surcel 2>Φ>0.02 mm	% Silt 0.02>Φ>0.002 mm	% Clay Φ<0.002 mm
Clay of kaele	0,9	51,5	21,5	26,5
Clay of Garoua	2,7	54,1	11,6	31,6
Clay of Mourla Pouss	0,6	37,2	16,0	46,2

Table 4. Determination of ωL, IP per sample.

Ref Sample	Liquidity Limits	Plasticity Limits	Plasticity index
Clay of kaele	34,3	16,7	17,6
Clay of Garoua	44,6	20,7	23,9
Clay of Mourla Pouss	54,3	21,7	32,6

Table 5. Methylene blue test results.

Réf Sample	Ms (g)	Volume of aqueous methylene blue solution introduced (ml)	VBS
Clay of kaele	20	130	6,5
Clay of Garoua	20	135	6,75
Clay of Mourla Pouss	20	145	7,25

Table 6. Presentation of densities.

Ref Sample	apparent density (g/cm^3)	Real density	Porosity(ŋ)
Clay of kaele	1,96	2,59	24,33
Clay of Garoua	1,69	2,61	35,47
Clay of Mourla Pouss	2,04	2,57	20,73

Table 7. Mechanical characteristics.

Ref	Fc(KN)	Rc(MPa)	Moy	Observations
C10	0,8	1,131542	1,131542	weak resistance
	0,8	1,131542		
	0,8	1,131542		
C20	4,4	6,223479	6,977841	Average resistance
	6	8,486563		
	4,4	6,223479		
C30	4	5,657709	7,732202	Average resistance
	6,2	8,769448		
	6,2	8,769448		
C40	5,2	7,355021	8,863744	High resistance
	6,8	9,618105		
	6,8	9,618105		
C50	3	4,243281	5,374823	Average resistance
	4,2	5,940594		
	4,2	5,940594		

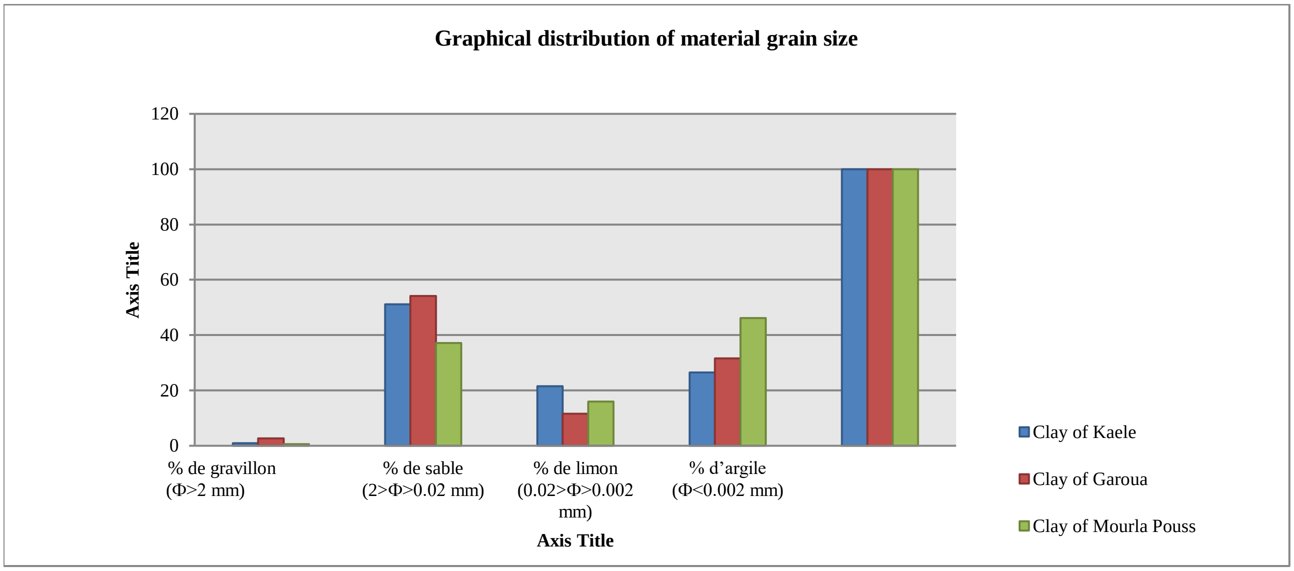

Fig. 6. Particle size distribution in the sample.

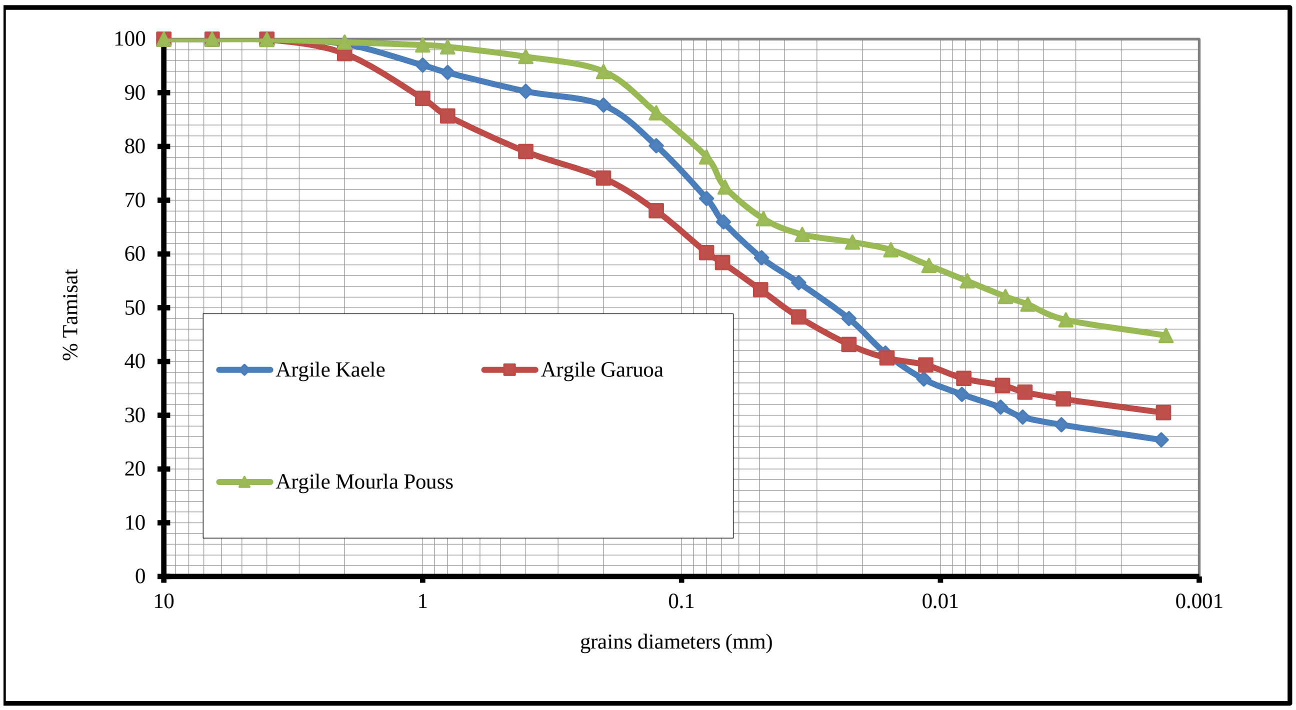

Fig. 7. Particle size curves.

c) Equipment used

The mixture is decanted into the test tube according to STOKES' law. The diameter is gently inserted into the suspension to avoid creating turbulence. Densitometer and thermometer readings are taken after 30s, 40s, 1mn, 2mns, 10mns, 20mns, 40mns, 80mns, 2h, 4h, 24h. The values obtained are used to calculate the equivalent diameters of the grains remaining in suspension at each instant, as well as their percentage (Table 3). The following relations (2) and (3) are used for this purpose:

$$\mathbf{D} = \sqrt{\frac{18\eta H}{(\gamma_s - \gamma_w)t}} \qquad (2)$$

$$\mathbf{Q}(\%) = \frac{V\gamma_s\gamma_w}{P(\gamma_s - \gamma_w)}(\mathbf{r} - \mathbf{1})$$

H/t= is the speed of the particles located at the depth H. In these relations we have:

D= diameter of the grains still in suspension

η= dynamic viscosity

t= time H the depth of the fall of the grains

γ_w= the specific weight of the water

γ_s= the density of the olid grains

r= the density of the suspension P the weight of dry soil in the suspension
V=: the volume of the suspension

The apparatus used for this methylene blue test is an equipment consisting of the following parts:

- A rotary stirrer with adjustable speed (from 400 to 700 rpm) with analogue display with its static and pale stirring.
- An additional status
- 50ml to 0.1ml glass burette with stopcock and stand
- A 2 liter plastic beaker
- A plastic container 200mm*150*80mm
- A glass rod Ø 8 mm - L 300 mm
- 1 pack of 100 Ø90 mm filters
- 100g dose of methylene blue
- 1 dose of 500g of material blue
- A 0-10ml – 0.1ml vending machine
- 1 liter amber glass bottle ref E036-01-D005

RESULTS

a) Granulometry

The results of the tests carried out on the materials based on the equipment mentioned above are recorded in Table 3. These results are presented according to the percentage of gravel, sand, silt, or clay with regards to the following diameters: greater than 2 mm, between 2 mm and 0.002 mm, between 0.02 mm and 0.002 mm and less than 0.002 mm.

b) Atterberg limits

These are water contents by weight corresponding to particular states of a soil. In this case, they are determined on the fraction of soil mentioned in table 4 below, passing through the 400 µm sieve and are expressed as a percentage. It is: • Liquidity limit (ωL), • Limit of plasticity (ωP): • The plasticity index (IP) being the difference between the liquid limit and the plastic limit. This index defines the extent of the plastic domain of the soil (figure a). Its formula is: IP = ωL - ωP.

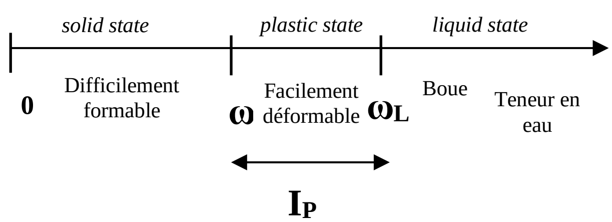

Figure (a): State of plasticity of soils

c) Methylene blue test

The methylene blue tests on the clay samples were carried out according to standard NF P 94-068. The results obtained are contained in Table 5.

d) Détermination of the relative density and absolute density

The actual density (dr) is determined by the following formula:

$$\mathbf{dr} = \frac{(M2 - M1)}{(M2 - M1) - (M3 - M4)}$$

With:
M1=vacuum pycnometer mass,
M2= mass of Pycnometer with sample
M3= mass of Pycnometer, sample, and water
M4 = mass of Pycnometer with water
dr= Actual density
NB: For each sample, three (03) tests are carried out as presented in Table 6.

Results obtained after mechanical test

The five samples of materials formulated and dosed progressively at 10%, 20%, 30%, 40% and 50% snail shell to which we assigned the codes C10, C20, C30, C40 and C50 respectively allowed us to appreciate the evolution of the resistance of the various samples tells that summarized in Table 7 opposite. This allows us to know if the resistance is weak, average, good or very good.

DISCUSSION

Particle size

According to the description of the different samples, the soils taken at Kani-Kaélé and Mayami-Garoua are extracted from termite mounds, while that of Mourla-Pouss is taken from a marshy area. The choice of laterite from a termite mound justifies the prior treatment carried out by termites on the clays.

The study of the particle size distribution shows that the highest rate of gravel (Φ>2mm) in the samples is found in the samples taken at kani kaélé 0.9% and garoua 2.7%. Considering from the fact that these samples have undergone prior treatment, we can deduce that termites played a role in the supply of granular materials in the clay. As for the rate of sand whose grain size is between 0.02mm and 2mm, it is 51.5% for the clays of Mayami-Garoua and 37.2 for the soil of Mourla Pouss.

In addition, we note that the soils from the termite mounds contain more sand than that taken from the marshy area. The activity of termites during the construction of termite mounds would have favored the transportation of these grains of sand in the clay. Knowing the relationship between binders and aggregates, we understand that termites establish a bond between the grains of sand with the clay.

Regarding silt; its rate is 25.5% for kani kaélé soils. And from 11.6% for the soils of Mayami-Garoua, to 16.0% for the soil of Mourla-Pouss.

The low rate of silt in building materials is explained by the fact that a building material is resistant if there are aggregates and binders within it that will play the role of cement.

Landing limits

The Free Encyclopedia specifies that in geotechnics, the Atterberg limits define both an indicator qualifying the plasticity of a soil, and also the test which makes it possible to define these indicators (Duboisset, 2003),

With regards to the various samples of materials subjected to the study, we note that those resulting from the termites' present limits of liquidity (between 34.3 and 44.6), limits of plasticity (between 16.7 and 20.7) and indices of plasticity (between 17.6 and 23.9). As for the soil of Mourla-pouss, they are respectively 54.3; 21.7 and 32.6 above the limits of the samples which were previously subjected to pretreatment by termites.

It is deduced that the Atterberg limits and the plasticity index of soil samples vary not only with the importance of its clay fraction but also with the nature of the clay minerals and adsorbed cations. This is how the highest values of this index are obtained with montmorillonites and more particularly those charged with the sodium cation (Na^+).

Apparent density and real porosity

The results of the analysis, subject of the apparent density and real porosity, which is the capacity of a material in the solid state to allow itself to be penetrated by a fluid, reveal that the soil samples of Kani-kaélé and Mayami-Garoua from termite mounds have the following results apparent densities (between 1.69 and 1.96), real densities (between 2.59 and 2.61) and respective porosities (24.33 and 35.47). As regards the samples taken at Mourla Pouss, they are respectively 2.04; 2.57 and 20.73). This implies that the preliminary treatment of the soil by termites increases the apparent density and decreases the porosity. As for the real mass of the material, it is substantially equal to those relating to the soils of Kani Kaélé and Mayami Garoua.

Methylene blue test

This analysis shows that for twenty (20) grams of each sample (kani-kaélé clay, Mayami-Garoua clay and Mourla-Pouss clay), the respective volumes of aqueous solutions of methylene blue below were introduced (130 135 and 145) milliliters for this, the respective VBS results below were obtained: (65; 675 and 725).

The results of the methylene blue test as practiced in the laboratory, show the possibility of assessing the clay content of the soils of the various sampling sites and particularly the determination of the degree of pollution of the sands and gravels. It is therefore conceivable to widen the possibilities of using neglected or underestimated materials, or even to limit the refusals of good materials as much as possible.

To do this, we define the threshold of the blue value from which we can decide with better knowledge of the facts to reject or accept one of the three materials studied. Consequently, if one does not plan to improve the soil sample taken at Mourla-Pouss, it will be difficult to obtain a resistant material. We therefore understand why cow dung and suksuki straw is added to make shell hutches.

CONCLUSION

Traditional constructions occupy a considerable place in the Sudano-Sahelian zone. However, the implementation techniques vary from one locality to another depending on the availability of materials and the weather conditions. Nevertheless, the construction of a durable and resistant structure requires knowledge and the choice of good materials. The characterization and the definition of the indicators of clay, considered as raw materials, constitute here, an answer to the subject matter. Earth samples were taken from Kani-Kaélé, Mayami-Garoua and Mourla-Pouss in order to experiment and characterize the materials commonly used in these types of construction. Particle size analysis, determination of Atterberg limits, limits of liquid and plasticity, as well as methylene blue tests have essentially constituted the adequate paths to facilitate the choice of materials by builders in the area of the study.

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