Scientific Research Publishing

Journal of Materials Science and Chemical Engineering, 2022, 10, 16-29
https://www.scirp.org/journal/msce
ISSN Online: 2327-6053
ISSN Print: 2327-6045

Physico-Mechanical Properties of Bio-Based Bricks

Valentin Makomra[1*], Lionel Karga Tapsia[2], Benoit Ndiwe[3], Maxime Dawoua Kaoutoing[2], Noel Konai[4], Abel Njom[3], Tawe Laynde[5], Danwe Raidandi[5]

[1]National Advanced School of Publics Works, University of Yaounde1, BP 510 Yaoundé, Cameroon
[2]Department of Mechanical Petroleum and Gas Engineering, National Advanced School of Mines and Petroleum Industries of the University of Maroua, PO BOX 08 Kaélé, Cameroon
[3]Higher Technical Teacher Training College of the University of Douala, BP 1872 Douala, Cameroon
[4]Laboratory of Civil Engineering and Mechanical, National Advanced School of Engineering, University of Yaoundé 1, BP 8390, Yaoundé, Cameroon
[5]Laboratory of Materials, Architecture and Civil Engineering, National Advanced School of Engineering, University of Maroua, BP 46, Maroua, Cameroon
Email: *makomra@yahoo.fr

How to cite this paper: Makomra, V., Tapsia, L.K., Ndiwe, B., Kaoutoing, M.D., Konai, N., Njom, A., Laynde, T. and Raidandi, D. (2022) Physico-Mechanical Properties of Bio-Based Bricks. *Journal of Materials Science and Chemical Engineering*, **10**, 16-29.
https://doi.org/10.4236/msce.2022.104002

Received: March 11, 2022
Accepted: April 25, 2022
Published: April 28, 2022

Abstract

The aim of this work is to improve the high performance of mud bricks. The latter was reinforced with rice straws as stabiliser leading to an improvement of the physico-mechanical properties. Thus, the physical characteristics of the clay such as natural water content, density, atterberg limit, plasticity limit (Wp) and plasticity index (Ip) were determined. Their values are respectively 8.39%, 2025.73 Kg/m^3, 47.66%, 29.75% and 17.91%. The clay used is a low plastic organic silt. The normal proctocol provided an optimum dry density (ɣOP) of 1.28 Kg/m^3 at an optimum moisture content of 12.42%. The actual density of the straw is 464 Kg/m^3, its absorption rate reached 206% in 5 mins and stabilised at 385% at 480 mins of immersion. The maximum bending and compression strengths are respectively 1.52 and 0.164 MPa. The mud brick absorption coefficients obtained are between 4.875 at 0% straw and 20.573% at 3% straw.

Keywords

Mud Bricks, Physico-Mechanical Characteristics, Clay, Rice Straw

1. Introduction

For a long time, researches on the thermo-mechanical properties of mud material in the building of houses have been carried out using several ways of stabilization to improve its mechanical performance and its sensitivity to water, which has given rise to several mud products as: adobe, mud, cob, compressed earth block (CEB) [1]. This has been the subject of several researches, including: the Mechanical and Thermal Characteristics of Clay Stabilized by Gum Arabic and Reinforced by Rice Straw [2]; the Making of a brick based on sand dunes [3]; the studying of the mechanical characteristics of mud brick stabilized using sugar cane molasses [4]; the hygro-thermo-mechanical characteristics of structural materials for construction combining kenaf fibers with clay soils [5]; the Design, production and qualification of terracotta and raw earth bricks [6]; the Formulation and characterization of an earth-plant fiber composite: cob [7]; the Guide to good practices in raw earth construction [8]; the Analysis by dialogue test calculation of a 4-point bending test on a sandwich specimen for the compression characterization of long-fiber composites [9]; the geotechnical tests at the Orléans geotechnical laboratory [10]. Several natural fibers have been proposed as stabilizers, including hemp, flax, jute (in Europe) or even date palm, esparto, rice straw and saw palmetto (in Africa) [11].

Compared to the history of earthen construction, the adobe technic is an old one, which allows for a wide variety of block sizes in terms of masonry with a relatively low production cost.

In order to obtain high performance mud bricks, clay and rice straw were used as stabilisers. These bricks using local resources will contribute to the excessive degradation of the houses in the Pitoa area and the cracking of adobe bricks.

Rice straw is one of the most abundant agricultural resources in Cameroon (especially in the North and Far North) used to stabilise adobe bricks.

2. Materials and Methods

2.1. Preparation of Samples

The basic materials used to make the different test specimens are: clay soil and rice straw.

Rice Straw

Rice straw comes from the same place as the mud. For the manufacture of blocks of mud (adobes) rice straw is crushed to dimensions ranging from 1 to 4 cm.

2.2. Physical Characterization of Clay Soil

The physical characteristics were determined from geotechnical tests in order to propose a classification for clay soil from the district of Pitoa at a place called Langui. It is located in the North Cameroon region, Department of Bénoué, 15 km from Garoua. It is chosen on the basis of its availability and abundance in that area. It is extracted after stripping the topsoil to a depth of 10 cm using a hoe.

2.2.1. Test of the Water Content

The water content was determined by the method of weighing wet weight, then dry weight after oven drying according to the standard (NF P 94 050). Samples taken in the dry state and in powder form were placed in a tare and weighed (Pmh). Then they were introduced into the oven for drying. Once dry, they were weighed again (Pms). The mass of water was deduced and the water content of each tare of this sample was determined by the following relationship (1):

$$w(1\%) = 100 \times \frac{\text{Pmh} - \text{Pms}}{\text{Pms}} \tag{1}$$

With: Pmh: weight of wet material; Pms: dry material weight; w (%): water content.

2.2.2. Density of Solid Grains

The density of the soil was measured in accordance with standard NF P 94-054 using a water pycnometer. The pycnometer and its cap were weighed (m_1), then the sample was introduced into the pycnometer and weighed with the cap (m_2), then the pycnometer was filled with water, up to the mark. The whole was shaken to obtain a homogeneous mixture and weighed, after letting out all the air bubbles (m_3). Finally, the pycnometer was emptied, cleaned, dried and filled with water up to the stopper mark and weighed (m_4). The density is obtained from the expression in Relation (2). The density of the solid particles is obtained by taking the arithmetic mean of eight measurements on a soil sample

$$P_s = \rho_w \times \frac{m_2 - m_1}{m_4 + m_2 - m_1 - m_3} \tag{2}$$

2.2.3. Particle Size Analysis by Sieving

This test was carried out according to the NF P 94-056 and 057 standard. The dry sample taken for the study was soaked for one hour in a plastic bucket and washed with a 0.08 mm sieve. The sample was then dried in the sun and in an oven. Finally, it was sieved with interlocking square mesh sieve sets (5; 2; 1; 0.5; and 0.08) in mm and the accumulated rejects weighed.

2.2.4. Atterberg Limit

The tests defined by Casagrande are carried out on the floor mortar (d < 0.4 mm) according to the procedure of standard NF P 94 051.

- **Liquiditylimit (W_L)**

The liquidity limit of a soil (W_L) is determined using the Casagrande cup. The well homogenised mixture is placed in the cup and spread well with a spatula. The thickness in the centre of the material should be 15 to 25 mm. The end of the test is announced when the groove in the material closes to a length of approximately 12 to 13 mm. The number of strokes is recorded and samples are taken from the vicinity of the closure area to determine their water content. The test is repeated at least eight times while varying the water content in order to cover a range of 15 to 35 strokes. For this material, lip closure is obtained at 17, 19, 27 and 34 strokes.

- **Plasticitylimit (W_p)**

The sample is spread out on a wooden plate, to make it lose a certain quantity of water and then a roll is made. The plasticity limit is obtained when the breakage occurs during the preparation of the roll or during its lifting. The clay samples taken from these rolls are dried in an oven at 105˚C for 24 hours to determine their water content. The plasticity index, noted I_p, is expressed by the Relation (3):

$$I_p = W_L - W_p . \tag{3}$$

2.2.5. Determination of the Normal Proctor Optimum

The test was carried out in accordance with standard NF P94-093. The principle consists of weighing the empty Proctor mould, compacting three layers of soil sample in this mould and each layer receives 25 strokes of a 2.5 kg tamper. Then the mould is scraped with a metal ruler to remove the extra soil and weighed again. Finally a sample is taken from the top, middle and bottom of the mould for determination of their water contents.

2.3. Physical Characterisation of Rice Straw

2.3.1. Real Density

The density is determined indirectly in accordance with standard NF P 94-064. A sample of rice straw is dried in an oven at 105˚C for 24 hours and weighed. The sample is then placed in a container (tare) and impregnated with paraffin oil. The sample is then weighed in the open air when its temperature is closed to ambient temperature and then completed by hydrostatic weighing. The calculation of the density is determined as follows:

Mass of anhydrous sample (m_S)

$$m_S = m_{(s+ta)} - m_{ta} \tag{4}$$

With $m_{(s+ta)}$: Anhydrous and Tare Weight of sample

Paraffin mass:

$$m_p = m_{(S+P)} - m_P \tag{5}$$

With $m_{(S+P)}$: Anhydrous and Paraffin Weight of sample

Paraffin volum:

$$V_P = \frac{m_P}{\rho_P} \tag{6}$$

Hydrostatic weighing:

$$m_T = \frac{m_{(S+P)}}{1} - \frac{mh_{(S+P)}}{1} \tag{7}$$

With $mh_{(S+P)}$: Humid and Paraffin Weight of sample

Total Volum:

$$V_T = \frac{m_T}{\rho_W} \tag{8}$$

Sample volume:

$$V_S = V_T - V_p \tag{9}$$

The density of the sample:

$$\rho_s = \frac{m_S}{V_S} \tag{10}$$

2.3.2. Water Absorption Rate

Approximately 35 g of rice straw was oven-dried at 105˚C for 48 hours to obtain dry aggregate. The absorption rate of rice straw is calculated according to the formula (11):

$$A(T) = \frac{m_T - m_S}{m_S} \tag{11}$$

The oven-dried particles were immersed in water at ambient temperature within times of 5 minutes to 48 hours at ambient temperature.

2.3.3. Material Formulations

The soil is lightly crushed with a hammer and 5 mm sieves are used to prepare the specimens of dimensions 40 × 40 × 160 mm for three-point bending and 40 × 40 × 40 mm for compression and absorption by capillary action, which are made from local materials using several formulations. The rice straw is first immersed in water until saturation and then added to the soil in a dry state. Then the water is topped up. The dimensions of rice straw used for this work are: (length 1, 2, 3 and 4 cm and diameter 2 to 4 mm) obtained by manual cutting with scissors.

2.3.4. Preparation of the Mixtures

The samples are dried in the oven at 65˚C for 24 hours [12] (Hay. B, 2002). The rice straw is soaked in water for 1 hour and added to the soil. Then, the whole is mixed with water manually. The mass of the dry mixture to make a 40 × 40 × 160 mm test piece is 400 g and for 40 × 40 × 40 mm test piece is 100 g. The formulations F_j are obtained from the compositions: $F_j = B\,XAYPt$

B: mud brick; XA = percentage X of clay. The unit of X is the percentage (%).

YPt: Percentage Y of the straw of size t.

$$X = \{100; 99.5; 99; 98.5; 98; 97.5; 97\};$$

$$Y = \{0; 0.5; 1; 1.5; 2; 2.5; 3\} \quad \text{et} \quad t = \{0; 1; 2; 3; 4\}.$$

2.3.5. Preparation of Specimens

The prepared mixture was placed in a plastic bucket for about 1 hour for good impregnation. Then, the dough was placed by hand in a plastic mold and unmolded just after compacting by hand. After demoulding, the bricks were dried at ambient temperature.

2.3.6. Determination of the Apparent Density of the Test Specimens

The specimen is weighed after drying in an oven at a temperature of 105˚C to constant mass, M the volume of the specimen, V this volume expressed in m^3. The average dry density of the test piece is determined by the formula (12) expressed in kg/m^3 according to standard NBN B 24.206.

$$\rho = \frac{M}{V} \tag{12}$$

2.4. Determination of Mechanical Characteristics

2.4.1. Bending Test 03 Points

The specimen is placed in the characterisation device, which consists of two pistons. An upper piston with a 2.5 KN load cell and a displacement comparator attached. The lower piston rises with the specimen until it comes into contact with the upper piston. The force sensor records the forces exerted on the specimen. A camera films the operation and the video is stored directly in a PC for analysis. The measurement of the bending strength is given by the relation (13) according to the standard (XP 13-901)

$$R_f = \frac{3Ftmax \cdot L}{2 \cdot b \cdot h^2} \tag{13}$$

2.4.2. Compression Test

A brick sample of 40 × 40 × 40 mm according to standard XP P 13-901 is subjected to compression using the civil engineering press until it breaks. The principle consists of placing the brick sample in the press; applying the load in a continuous manner and at a regular speed until the sample breaks completely and recording the maximum load supported by the sample during the test. The machinery system made of camera and Computer records all the measurements of pressure and displacement of the blocks, it has a maximum capacity of 2.5 KN and a sensor. The compressive strength of the blocks is the arithmetic average of the strengths of eight tests carried out on samples from the same batch. It is given by the formula:

$$R_c = \frac{F}{S} \tag{14}$$

R_c: is the compressive strength of the blocks in mega pascal (MPa); F: is the maximum load supported by the two bricks in kilo newtons (N); S: is the average area of the test faces in square centimetres (mm^2).

2.4.3. Water Absorption by Capillarity

Water absorption by capillary action was measured by the detailed test according to the experimental standard NF XP 13-901. The principle is to partially immerse the brick at a 5 mm depth. The water absorption coefficient C_b corresponds to the rate of absorption rate after 10 min. The water absorption coefficient C_b is expressed by the following formula:

$$C_b = 100 \times \frac{m_h - m_s}{S\sqrt{t}} \tag{15}$$

$m_h - m_s$: is the mass of water, in grams, absorbed by the block during the test.

S: area of the submerged face, in square centimeters; t: is the immersion time of the block in minutes.

3. Results and Discussion

3.1. Physical Characteristics

3.1.1. Natural Water Content of the Clay

The average natural water content value of the clay is 8.39% compared to that obtained by ABAKAR [2] which is 10.90%, this clay is less moist.

3.1.2. Density of Solid Grains

The density values of solid particles whose size are not more than 2 mm are 2025.73 Kg/m^3 less than the value 2450 Kg/m^3 obtained by ABAKAR [2], mean this clay contain more void than theirs.

3.1.3. Particle Size Analysis by Sieving

The analysis was done on a sample of Ms = 361.27 g. The results of these analyses are given in Figure 1. For the different grain diameters, the soil was analysed by sieve opening between 5.00 mm and 0.08 mm or from sieve 38 to sieve 20. For sieve 38 with a sieve opening of 5 mm, no seeds were retained in the sieve, the cumulative sieving is therefore 100%, whereas for sieve 20 with an opening of 0.08 mm, 18.7% of the dry mass or 114 g was retained, also called cumulative refusal, and 81% of the cumulative sieving is also defined by the part passed through the sieve. From sieve 38 to sieve 20, the rate of cumulative refusal increases little by little contrary to the rate of cumulative sieving which decreases with each sieve. Thus, 81% represents the finer grains in the soil and 18.7% were rejected by the sieve due to their slightly larger size.

3.1.4. Atterberglimit

- **Liquiditylimit**

For this material, lip closure is obtained at 17, 19, 27 and 34 strokes and the result is given in Figure 2. From this diagram, the liquidity limit is deduced. It is worth 47.66% at 25 strokes.

- **Plasticitylimit**

The average plasticity limit value is summarized in Table 1. The average plastic limit is 29.75%. From these measurements, it appears that this material is

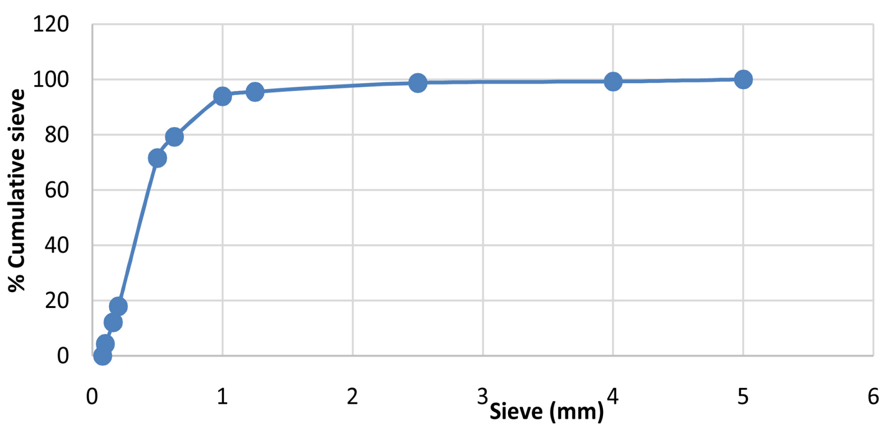

Figure 1. Particle size curve by sieving.

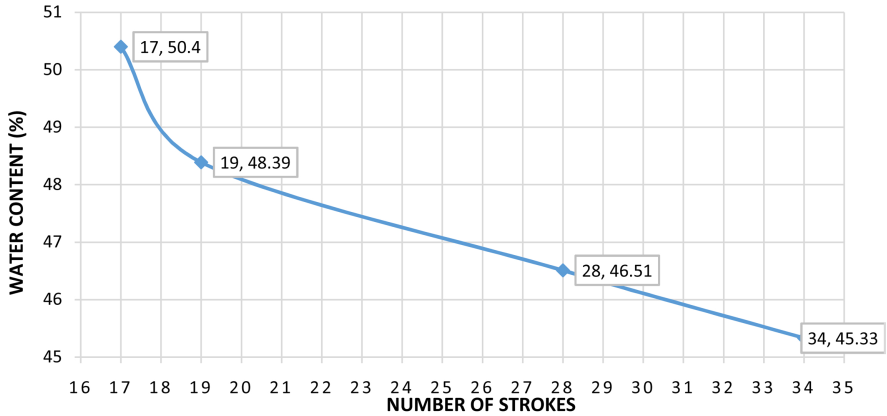

Figure 2. Diagram for determining the liquidity limit.

Table 1. The average plasticity limit value.

	Plaque	Tares (g)	Tare + Mh (g)	Tare + Ms (g)	Mw (g)	W (%)	$W_{average}$ (%)
	P1	31.94	33.23	32.94	0.29	29	
Plastic limit	P2	32.06	34.34	33.81	0.53	30.29	29.75
	P3	30.29	33.11	32.46	0.65	29.95	

an organic silt that is not very plastic. This rough classification is frequently used in the road sector (NF P11-300, 1992) and ensures that soils are not susceptible to significant dimensional variations in the presence of water. That value corresponds to the water content in the brick as it changes from plastic to semi-solid consistency and as it dries.

3.1.5. Normal Proctor

After analysis of the Proctor curves of **Figure 3**, we note that the percentage of water in the soil to be compacted was 13.54%. Thus, the maximum dry density of the soil sample is 1.21.

3.2. Rice Straw

3.2.1. Real Density of Rice Straw

The bulk density of rice straw is 464 kg/m^3. We note that the density lower than that of clay which is 2045 kg/m^3. This is due to the high porosity.

3.2.2. Water Absorption

The result of the water absorption of rice straw is summarised in **Table 2**. We find that the water absorption capacity of rice straw is 206% at 5 min. This is too high compared to most construction materials. After 48 hours of immersion, the two materials reach a relatively close absorption rate. In construction, the hydrophilic character is a major defect. Rice straw must be immersed in water until it is saturated before mixing it with the binder or soil, otherwise it will absorb all the mixing water, thus generating a product that is difficult to use.

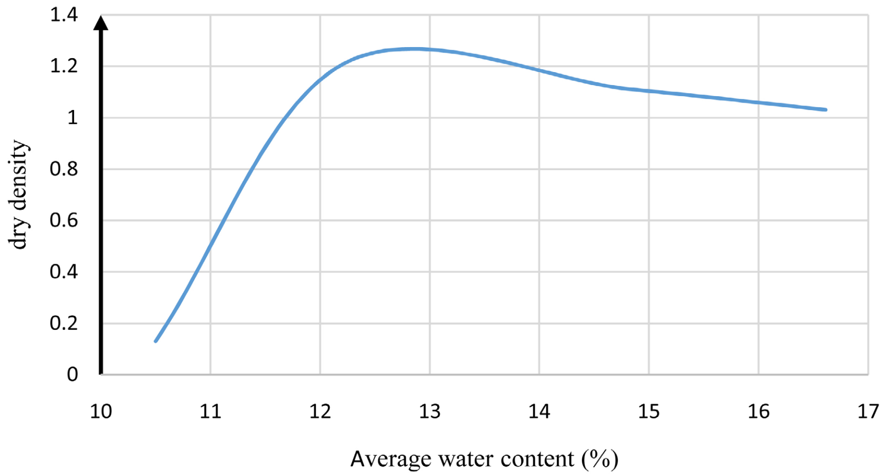

Figure 3. Proctor curve.

Table 2. Absorption rate of rice straw.

Duration (min)	0	5	30	60	120	150	240	360	480	1400	2800
Mass (g)	35	107	117	127	130	140	148	150	151	154	157
Absorption (%)	0	206	234	263	271	300	323	329	331	340	348

3.3. Physical and Mechanical Testing of Specimens

3.3.1. Apparent Densities

Figure 4 gives the results of the apparent densities of the specimens. This table shows that for each size, the apparent density decreases as the percentage of fibres increases. These masses are between 1082.57 and 1420.05 Kg/m^3.

3.3.2. Three-Point Bending Test

The Figures 5-9 show that the bending strength drops as a function of the straw intake percentage. For adobe without straw, the maximum strength is 1.52 MPa. For straw of 1cm length (Figure 5), the resistance is 1.04 MPa at 1% straw, 0.97 MPa at 0.5% straw to finish at 0.63 MPa with 3% straw while passing through the other percentages (Figure 6). Strength drops from 0.90 MPa at 0.5% straw to 0.42 MPa with 3% straw with a slight increase to 2.5% straw. Figure 6 has a resistance which varies between 0.61 and 0.73 MPa and that of Figure 8 varies between 0.57 and 0.84 MPa. Figure 9 gives the maximum resistance of each size. Apart from the simple clay formulation, the maximum strength is 1.04 MPa corresponding to the B99%A-1%P1 formulation (adobe made up of 99% clay and 1% straw of 1 cm size). This resistance is beyond the minimum resistance underlined by Doat [13].

3.3.2. Compression Test

The compression results are synthetized in Figure 10-14. The compressive strength drops. The maximum compression strength of Simple clay adobes is

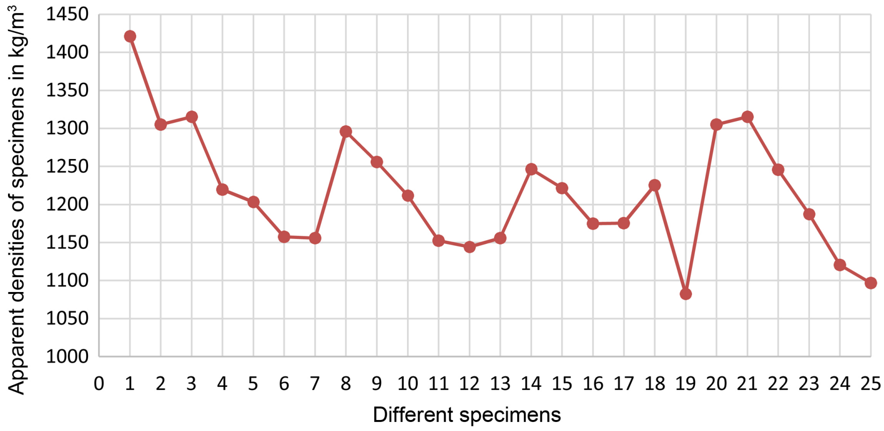

Figure 4. Apparent densities of the specimens.

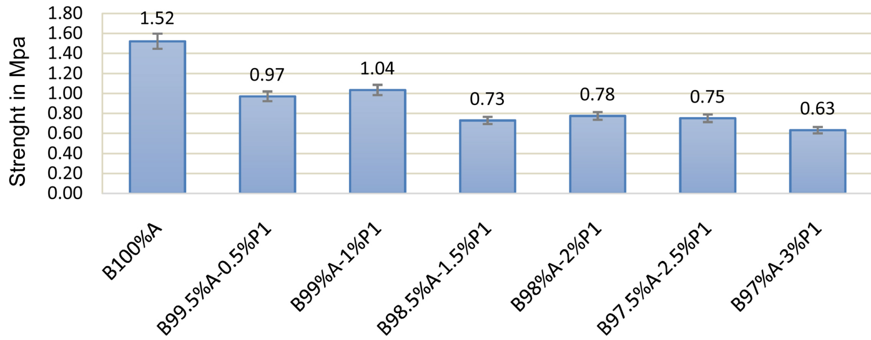

Figure 5. Bending strength of adobes with 1 cm long straw.

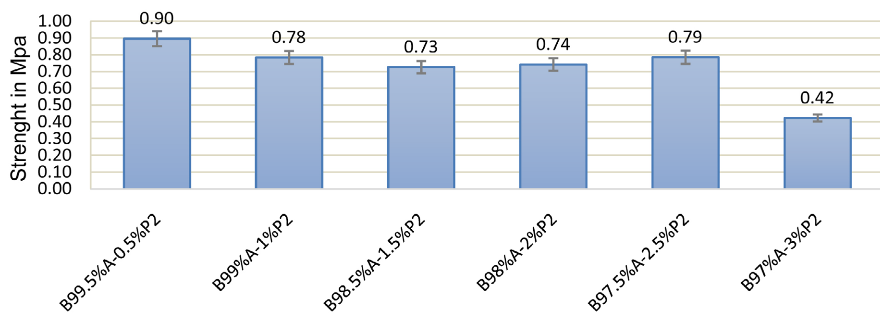

Figure 6. Flexural strength of adobes with 2 cm long straw.

0.19 MPa, that made with 1cm straws long is 0.16 MPa (Figure 10). The compression strengths of the bricks using straw of size 2, 3 and 4 cm are respectively 0.14 MPa; 0.2 MPa and 0.14 MPa (Figures 11-13). These characteristics allow us to conclude that the brick can be used to build houses [12]. The brick B98.5A1.5P3 made with 1.5% of 3 cm straw has maximum compression strength (Figure 14). The adobe brick reinforced with rice straw absorbs a lot of water when the percentage of straw is high (Figure 15). The absorption coefficient is 4.875% at 0% straw and 20.57% at 3% straw. This can also be explained by the void left by the straw in the adobe (Figure 16). The pores existing within the matrix of the brick influence the absorption of water by capillarity action and

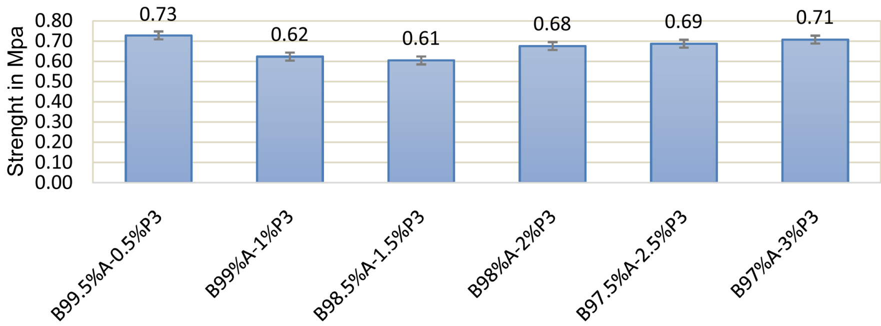

Figure 7. Flexural strength of adobes with 3 cm long straw.

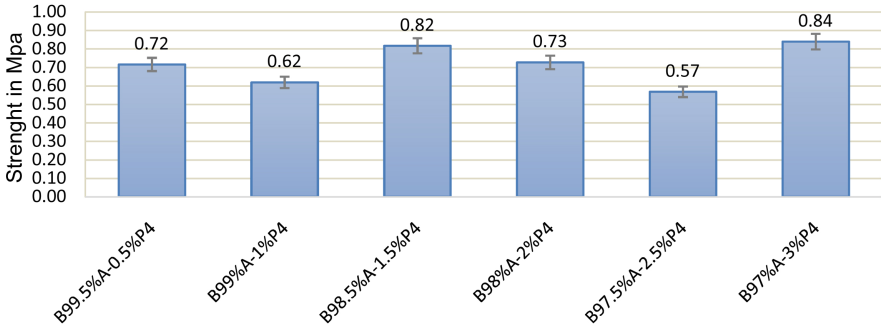

Figure 8. Flexural strength of adobes with 4 cm long straw.

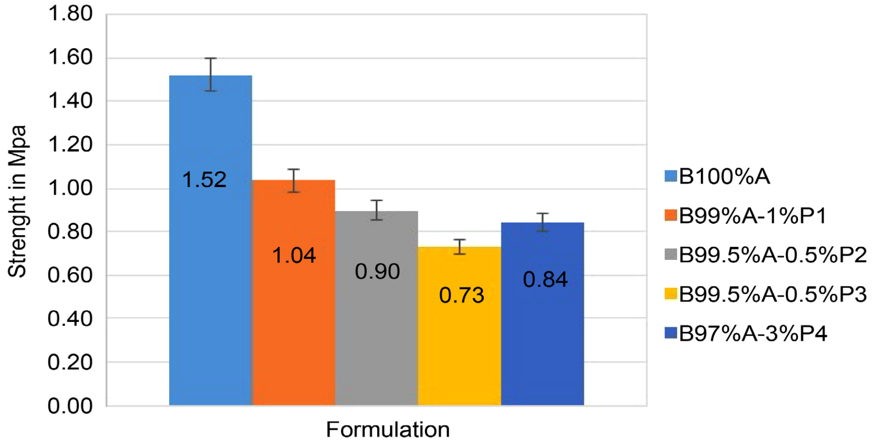

Figure 9. Influence of rice straw on the bending strength of adobes.

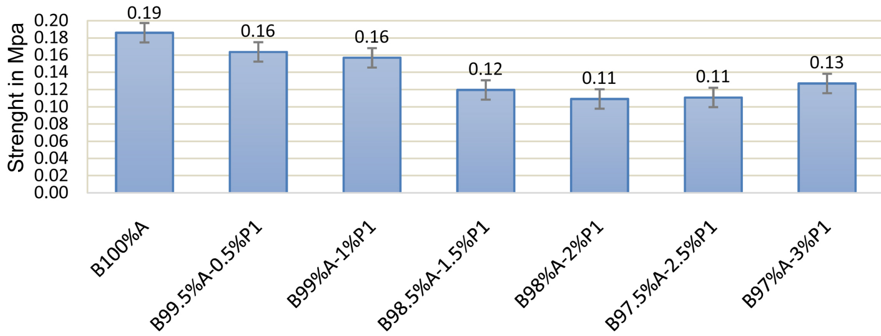

Figure 10. Compressive strength of adobes with 1 cm long straw.

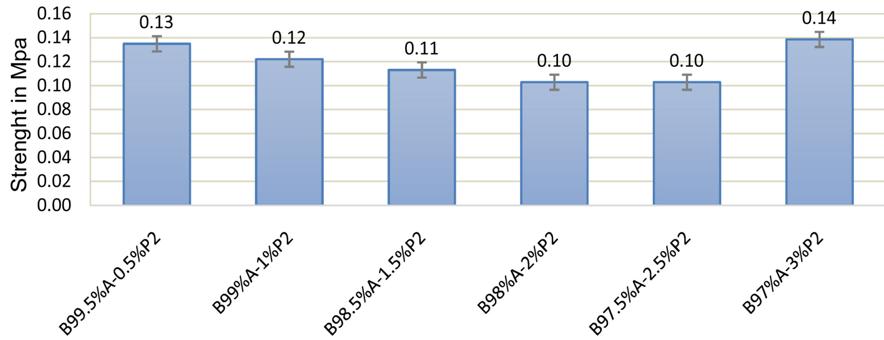

Figure 11. Compressive strength of adobes with 2 cm long straw.

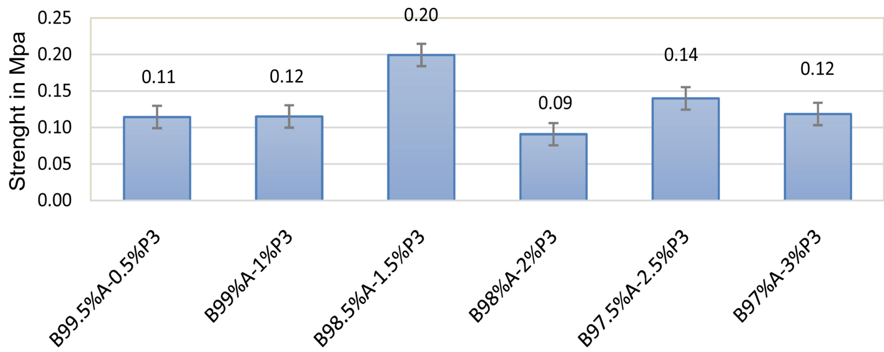

Figure 12. Compressive strength of adobes with 3 cm long straw.

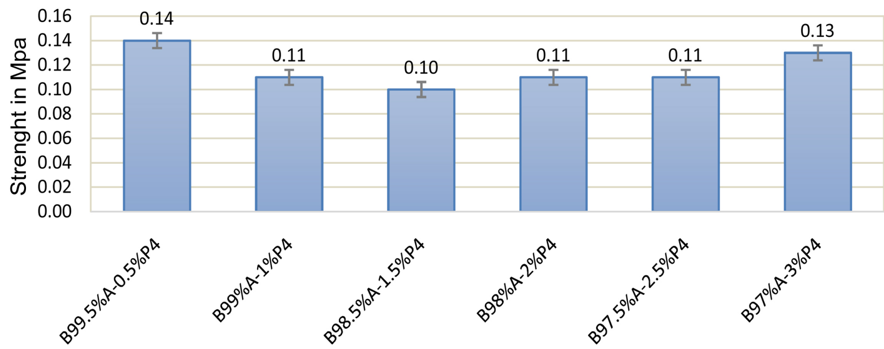

Figure 13. Compressive strength of adobes with 4 cm long straw.

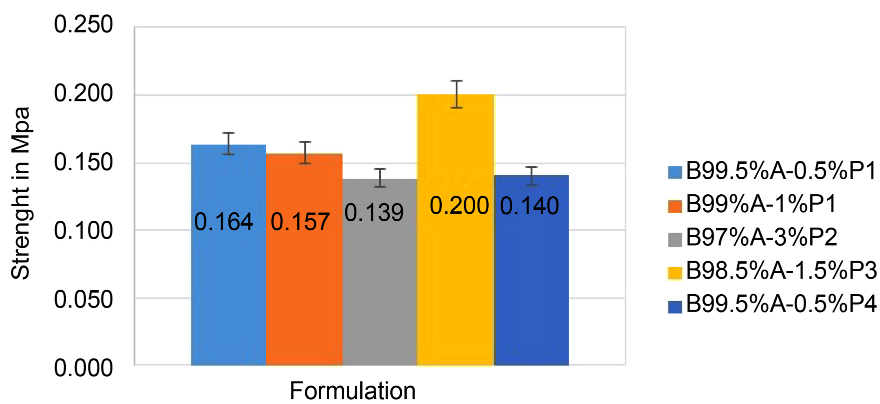

Figure 14. Influence of rice straw on the compressive strength of adobes.

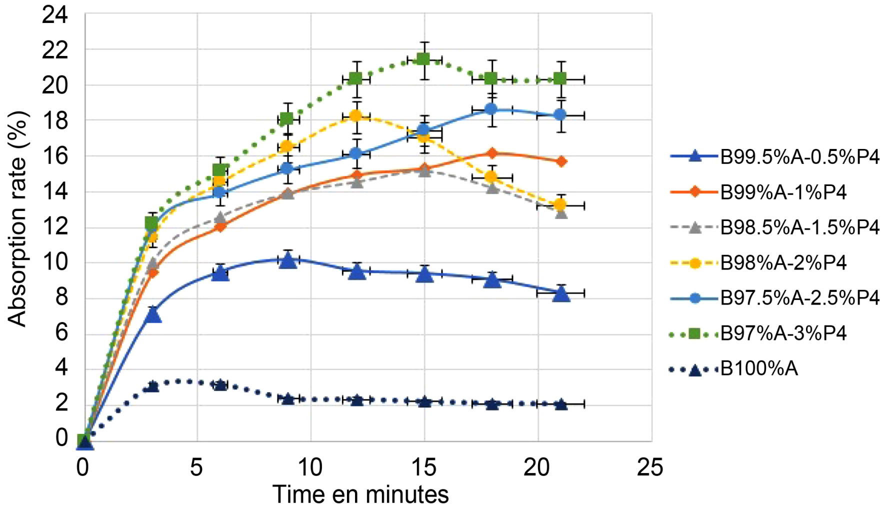

Figure 15. Influence of rice straw on water absorption rate.

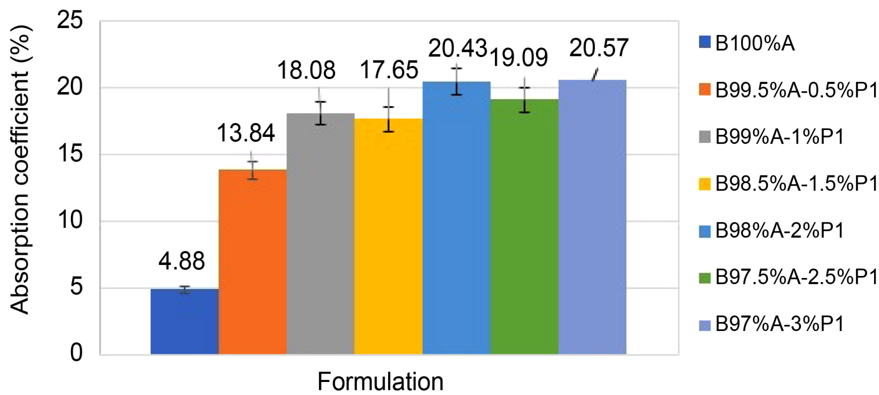

Figure 16. Influence of rice straw on the water absorption coefficient.

absorption rate increases with void rate.

4. Conclusion

The study of the mud and rice straw from the Pitoa area in the North Cameroon Region and the analysis of the physical and mechanical characteristics of the adobe type Mud bricks reinforced with rice straw presented quite interesting results. The water content of the mud is 8.39%. The liquidity and plasticity limits are respectively 47.66% and 29.75%, which gives a plasticity index of 17.91%. Thus, for this study we selected the formulation B98.5%A-1.5%P3 (adobe made of 98.5% clay and 1.5% straw of size 3 cm) for the construction of the habitat in this locality. As perspective, a comparative analysis between these bricks and those made from the biohardeners will be done.

Conflicts of Interest

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

References

[1] Houben, H. and Guillaud, H. (2006) Traité de construction en terre,Centre de recherche et d'application pour la construction en terre. EAN13; 9782863641613, ISBN 978-2-86364-161-3, Ed. Parenthèse, Marseille, Collection: L'Encyclopédie de la construction en terre, 360 p.

[2] Abakar, A. (2018) Caractérisations mécanique et thermique de l'argile stabilisée par la gomme arabique et renforcée par la paille de riz. PhD thèse, Université de Lorraine, France. https://hal.univ-lorraine.fr/tel-01920664

[3] Djouhri, M. (2007) Confection d'une brique à base de sable de dunes mémoire de. Master's Thesis, Université KASDI Merbah de Ouargla, Algeri.

[4] Malanda, N., Louzolo-Kimbembe, P. and 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 RAMReS—Sciences Appliquées et de l'Ingénieur*, **2**, 1-9.

[5] Laibi, B. (2017) Comportement hygro-thermo-mécanique de matériaux structuraux pour la construction associant des fibres de kénaf à des terres argileuses. Chimie Inorganique. PhD Thesis, Normandie Université; Université d'Abomey-Calavi, Bénin.

[6] El Fgaier, F. (2013) Conception, production et qualification des briques en terre cuite et en terre crue. Thèse de doctorat, Ecole centrale de Lille. https://tel.archivesouvertes.fr

[7] Phung, P.A. (2018) Formulation et caractérisation d'un composite terre-fibres végétales: la bauge. Thèse de doctorat, Université de Caen Normandie, Caen, 179 p.

[8] Areso (2018). Guide des bonnes pratiques de la construction en terre crue.

[9] Mejdoub, A., Bois, C., El Yagoubi, J., Lorriot, T. And Wargnier, H. (2019) Analyse par dialogue essai calcul d'un essai de flexion 4 points sur éprouvette sandwich pour la caractérisationen compression de composites à fibres longues. 21ème Journées Nationales sur les Composites, École Nationale Supérieure d'Arts et Métiers (ENSAM)—BordeauxTalence, France.

[10] Atlan, Y. (1978) Catalogues des essais géotechniques exécutés au laboratoire géotechnique d'Orléans. 78 SGN 178 GEG, 240-270.

[11] Hejazi, S.M., Sheikhzadeh, M., Abtahi, S.M. and Zadhoush, A. (2012) A Simple Review of Soil Reinforcement by Using Natural and Synthetic Fibers. *Construction and Building Materials*, **30**, 100-116.

[12] Hay, B., Filtz, J.R. and Batsale, J.Ch. (2004) Mesure de la diffusivité thermique par la méthode flash. *Techniques de l'Ingénieur*, R2955, 1-12. https://doi.org/10.51257/a-v1-r2955

[13] Doat, P., Hays, A., Houben, H., Matuk, S. and Vitoux, F. (1979) Construire en terre. Editions Alternatives et parallèles, Paris, 265 p.