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Hydro Mechanical Properties of Cement and Cellulose Stabilized Compressed Clay Bricks

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Abstract: An experimental investigation is carried out in order to characterize the properties of new construction materials. Clay blocks stabilized with cement and recycled papers are successively tested. When these composite materials are utilized as finish for house envelops, they must have appropriate mechanical strength and water stability. Mechanical properties such as compression and tensile tresses of clay-cement and clay-cement-paper mixtures are found to be quite similar but are two to three times greater respectively for clay-paper and purely clay blocks. The former mixtures are also very stable regarding water. The above results give the optimum conditions for the utilization of these new construction materials.

Key words: Stabilized clay blocks, paper, cement, hydro mechanical properties.

Nomenclature

AC_w	Accessible porosity (%)
C_{ac}:	Coefficient of absorption by capillarity ($kg\cdot m^{-2}\cdot s^{1/2}$)
e:	Thickness of CCB (m)
F_c:	Applied force (N)
F_f:	Applied axial loading (N)
H_p:	Water content (%)
l:	Larger of compressed clay blocks (m)
L:	Length of compressed clay blocks (m)
m_a:	Mass of the specimen sitting in air (kg)
m_w:	Mass of the specimen sitting in water (kg)
m_h:	Mass of the wet specimen (kg)
m_d:	Mass of the dried specimen (kg)
R_c:	Compressive stress (MPa)
R_f:	Rupture flexure stress (MPa)
S:	Area upon which F_c is applied (m^2)
S_w:	Section of the specimen in contact with water (m^2)
t:	Time during which the specimen is in contact with water (s)
v:	Wave speed ($m\cdot s^{-1}$)
V:	Apparent volume (m^3)
ρ:	Apparent density of the specimen ($kg\cdot m^{-3}$)
υ:	Poisson's ratio, taken to be 0.15

1. Introduction

House conception in the traditional society was solely based on locally existing construction materials. Nowadays, new constructions especially in big town are erected based on foreign design. Consequently, the construction materials are imported up to the range of 45% [1]. However, due to the huge economical and social problems facing many developing countries, both researchers and leading non-governmental organizations (NGO) have put forth the idea of promoting local natural resources. As a matter of fact, local construction materials are available especially in the country side. Therefore, their use will make housing affordable for low income citizens. Unfortunately, pure clay materials lack mechanical resistance and are very sensible to water. Up to now, the stabilization process is proven to be one of the best

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solutions to these problems. This operation can be done based on physical means by mixing clay and natural or industrial fibers [2, 3]. It may also be done chemically by mixing clay with cement, pozzuolana or decoction of tree roots, selected grasses or other organic matters. For fact, the work of Meukam et al. [4] shows that adding cement or sawdust to clay improves the mechanical properties of bricks. It is also proven that the compression resistance increases with the addition of cement.

The aim of the actual investigation is to determine first of all the geotechnical properties of clay matter and second, characterize the properties of compressed clay blocs stabilized or not. The results obtained confirm the fact that the new materials are appropriate and reliable as they increase buildings strength and resistance.

2. Clay Matter as Construction Material

Clay is the main specimen utilized in this investigation either alone or stabilized with cement and/or recycle paper (cellulose).

2.1 Material Identification

Lateritic sols are found in many countries especially in Africa. The actual site is localized near Ouagadougou and is extensively exploited by construction companies. Clay is a complex heterogeneous matter. It must then be identified and analyzed throughout before deciding to use it as construction material. The identification process can be done by granulometric analysis. Soil granulometry is a good indication of the future quality of the crude bricks made from it. Asa matter of fact, good bricks are obtained when the soil smaller fractions (< 2 μm) are comprised from 5% to 30% while the size of the bigger fractions doesn't exceed 5 mm [5].

2.2 Cement and Paper (Cellulose)

Cement is a hydraulic stabilizer suitable for soil with limited small fractionsand plasticity. Mixed with soil and with sufficient quantity of water, cement forms resistant stable crystals connected to soil grains. Because it riches its full resistance to water after 28 days of hydration, the blocks must remain humid during this period either by aspersing them with water or covering them with a plastic covert. As a matter of fact, Meukamand et al. [4] have shown an increase of compression strength with the increase of cement in the mixture. The actual paper is made from crushed biomass, transformed in past and then dried. Paper and paperboard wastes represent 21% of household wastes, 71% of office wastes and 29% of school wastes in France [6]. They represent only 9% of household's waste in Ouagadougou, Burkina Faso [7].

3. Experiments

After identifying the appropriate carrier, the clay is convoyed and then analyzed in laboratory in order to determine its geotechnical properties.

The compressed clay blocks (CCB) are stabilized by mixing 4% cement and/or 0.78% paper with clay on mass basis. The blocks are then analyzed to determine their mechanical strength.

3.1 Geotechnical Properties

The classification of soil is done based on the results of two specific laboratory analyses: they are the granulometry analysis and the Atterberg limits.

3.1.1 Granulometry Analysis

The aim of this analysis is to determine the fraction of grains and materialsize. It is done as follows:

(1) Disc screen with square shape for grains of diameter larger than 80 μm;

(2) Sedimentation for very small grains. It consists of letting a suspension of soil settles atthe bottom of the specimen filled with water. The smaller the grains, the slower (Stokes law) the speed of decantation. The measurement of the suspension density at variable time steps allows the calculation of the grainproportions for given diameters. The granulometry analysis trough disc screen and sedimentation are done according

respectively to the standards NF P18-560 [8] and NF P94-057 [9].

3.1.2 Atterberg Limits

The Atterberg limits are conventional geotechnical characteristics of soil which sets the limits of:

- Change in soil behavior from the liquid state to the plastic state: limit of liquidity (W_l);
- Change in soil behavior from plastic state to solid state: limit of plasticity (W_p).

The values of these limits are given by the water content of the soil during the actual transitional phase, expressed in percentage of the mass of its primary matters. The plastic index measured by the difference ($W_l - W_p = I_p$), defines the range of the plastic domain which is particularly important [10]. This index allows the appreciation of the quantity and type of clay within a specimen. The determination of the Atterberg limits is done according to the standard NF P 94-051 [11].

3.2 Mechanical Properties

Construction materials are subject to numerous stresses during loading either by compression or by traction. The primary quality of construction materials is to withstand these deformations. The resistance to compression is the most important mechanical properties when it comes to choosing construction materials for building walls [12]. There are of course other mechanical and hydrated properties that must be taken into account.

3.2.1 Saturationthrough Immersion

The absorption tests are realized according to the standard NF EN 14617-1 utilizing clay blocks of 9 × 14 × 14.5 cm, previously dried in a dryer (105°C, 24 h) [13]. The ponderable absorption (*Hp*) is written as:

$$H_P = \frac{m_h - m_d}{m_d} \times 100 \quad (1)$$

3.2.2 Compression and Three Point Flexural Stresses

The uniaxial compression and three point flexural tests are realized utilizing several blocks of variable dimensions according to the standards NF EN 14617-15 and NF EN 12372. The uniaxial compression tests are realized utilizing specimen of 9 × 14 × 14.5 cm equipped with hydraulic press. The axial stress is determined by the following equation:

$$R_c = \frac{F_c}{S} \quad (2)$$

where, R_c (MPa) is the compressive stress; F_c (N) is the applied axial loading; S (mm^2) is the area upon which F_c is applied.

The three point flexural resistance tests are realized upon blocks of 9 ×14 × 29 cm utilizing hydraulic press and applying the flexure force at the middle of the specimen. At the rupture, the maximum flexural stress is calculated utilizing the following equation:

$$R_f = \frac{3}{2} \cdot \frac{L - 100}{l \cdot e^2} \cdot F_f \quad (3)$$

where, R_f (MPa) is the rupture flexure stress; F_f (N) is the applied force; L (mm) is the length of CCB; l (mm) is the larger of CCB; e (mm) is the thickness of CCB.

3.3.3 Absorption by Capillarity

The absorption test is met to determine the quantity of water absorbed by capillarity by the blocks. It consists in measuring the mass increase of the specimen sitting inside a vessel containing water up to 5 mm of the specimen's height. The coefficient of absorption by capillarity is determined after 5 nm of immersion. The blocks are prepared and kipped for 24 h in a dryer at 105 °C in order to determine the dry masses. The absorption by capillarity is measured by weighting the specimenas time passes. It is expressed by the following equation:

$$C_{ac} = \frac{m_h - m_d}{S_w \cdot \sqrt{t}} \quad (4)$$

where, C_{ac} (kg·m^{-2}·s$^{1/2}$) is the coefficient of absorption by capillarity; m_h (kg) is mass of the wet specimen; m_d (kg) mass of the dried specimen; S_w (m^2) is section of the specimen in contact with water; t (min) is the time during which the specimen is in contact with water.

3.2.4 The Porosity Accessible to Water

The open porosity or porosity accessible to water AC_w (%), is the ratio of the total open pore volume of a porous media to its apparent volume. Open pores are those accessible to water whereas closed pores are inaccessible to water. The test itself consists in determining the weight of the dry and saturated specimen and finally their apparent volume utilizing hydrostatic weighting [14]. The saturated and dried specimens are obtained respectively after 96 h immersion time and 24 h time span in a dryer at 105 °C. The porosity accessible to water is expressed as:

$$AC_w(\%) = \frac{m_a - m_d}{V} = \frac{m_a - m_d}{m_a - m_w}.100 \qquad (5)$$

where, m_a (kg) is mass of the specimen sitting in air; m_w (kg) is mass of the specimen sitting in water; m_d (kg) is mass of dried specimen; V (m^3) is apparent volume; AC_w (%) is the accessible porosity.

3.2.5 The Dynamic Young's Modulus

When an isotropic solid is subjected to reversible traction or compression loading, we observe an elongation or reduction of its length (ΔL) along the loading direction. The solid undergoes relatively small deformation involving only straight-line portion of the corresponding stress-strain diagram. For that initial portion of the diagram, the stress σ is directly proportional to the strain ε and we may write:

$$\sigma = \varepsilon \cdot E_D \qquad (6)$$

where, σ ($N \cdot m^{-2}$)is the stress; ε is the strain; E_D (N/m^2) is the dynamic Young's modulus.

This relation is known as Hooke's law, after the English mathematician Robert Hooke (1635-1703). The coefficient E_D is called the modulus of elasticity, the Young's modulus or the dynamic Young's modulus. It is obtained with 9 × 14 × 19.5 cm specimen dimensions utilizing ultrasonic measurement method. An ultrasonic wave going through the granular medium will have a propagation speed function of the dimensionof the medium pores. We then measure the time elapses when the wave goes through the medium. Knowing its length, we deduce the speed of the wave packet. The dynamic Young's modulus is given by the following equation [14]:

$$E_D = v^2 \rho \frac{(1+\upsilon)(1-2\upsilon)}{1-\upsilon} \qquad (7)$$

where, v ($m \cdot s^{-1}$) is the wave speed; ρ ($kg \cdot m^{-3}$) is apparent density of the specimen; υ is the Poisson's ratio, taken to be 0.15; ED ($N \cdot m^{-2}$) is the dynamic Young's modulus.

4. Results and Discussion

4.1 Geotechnical Characteristics

From the results shown in Table 1, we can infer that the clay medium is of class A-2-6 according to US HRB. It is of lateritic grave clayey origin and sandy limestone in sense of Taylor triangular classification. Based on the results of the granulometry and the Atterberg limits, it can be utilized for the fabrication of crude bricks which can be stabilized incorporating hydraulic stabilizers [5].

4.2 Dry and Wet Compressive Resistances

The dry and wet compressive resistances are plotted in Figs. 1 and 2.

The tests are realized 30 d after the confection of the blocks which contain 1.3% water. The values of the compressive strength vary from 2.399 to 7.765 MPa.

Table 1 Soilgeo technical characteristics.

Soilgeo technical characteristics	Content (%)
Limit of liquidity	40
Limit of plasticity	19
Index of plasticity	21
Clay fraction ($d \leq 2$ μm)	8

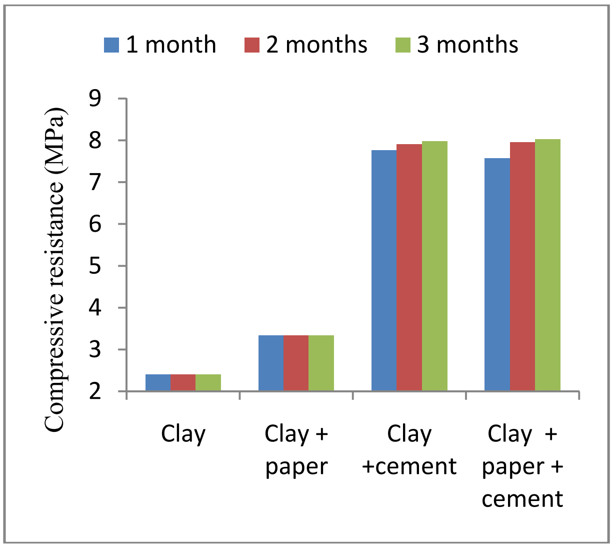

Fig. 1 Compressive resistance function of the age of CCB.

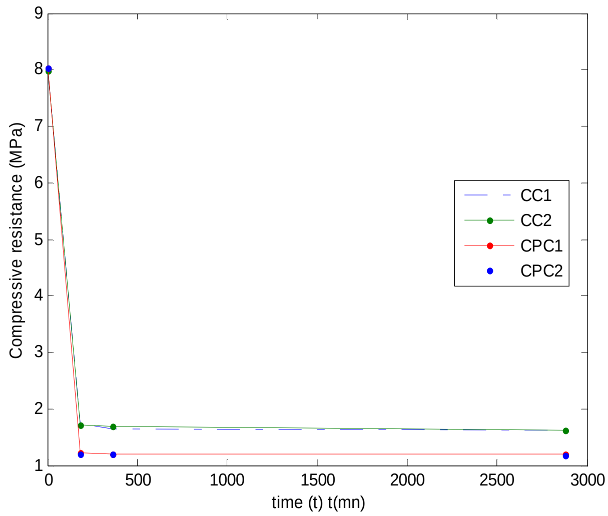

Fig. 2 Compressive resistance of the CCB function of time of immersion

When we incorporate paper (cellulose), cement and cement-paper successively into clay matter, the percent amelioration values of the strength are: 38.7, 223.5 and 215.5. We notice, Fig. 1, that adding paper increases the hardening time of cement during the first period but starting from the second month, it improves the strength of the blocks. In the other hand, the relative small increase of the resistance of the blocks containing cement is essentially due to the fact that the pozzuolanic reaction with its slow kineticsis still in progress [15]. After 28 d the evolution of the properties of the blocks is not noticeable. These results are similar to those published by Millogo [15] and Meukam et al. [4].

The CCB been sensible to water, we have investigated the impact of water content on their resistances. The tests are done on blocks stabilized with cement, cement-paper having 60 d of age. The results, Fig. 2, show a net decrease of the values of the resistances. The smallest values of the resistance of the blocks made of clay-paper-cement (CPC) and clay-cement (CC) are respectively 1.227 MPa and 1.618 MPa. They are all greater than 1 MPa, the standard value [16]. The blocks made of CPC1 and CPC2 are more sensible to water than CC1 and CC2. After 3 h of immersion, the CC and the CPC loose respectively an average of 78.9% and 84.97% of their strength. These values remain constant after 6 h of immersion. The dry compression strength of clay blocks stabilized with cement-paper (CP) which is greater than the compression strength of the blocks stabilized with pure cement have however, the smallest compression strength when humid. This is due to the fact that the CPC absorbs more water than the CC and we know that the compression resistance decreases when the water content of the blocks increases [4, 17].

4.3 Three Point Flexural Stress and Young Modulus

The values of the three point flexural strength are small because the bricks have small elasticity. Stabilization tends to improve the values of the clay blocks resistance. Adding paper and cement to clay respectively decreases and increases the blocks strength. We observe a decrease of the Young modulus when the density of the blocks decreases except for the CPC blocks. These results are similar to the values published by Nicot [14].

The greater values of the blocks Young modulus are indications that their rupture will not be reached quickly with reasonable loading. Thus the blocks do not have ductile behavior.

4.4 Accessible Porosity and Absorption by Immersion

The values of the accessible porosity are equal to 28.914% and 31.766%, respectively for the CC and CPC blocks. Adding cement which is made of fine grains reduces the number of open pores then inducing small values of accessible porosity for material stabilized only with cement. Contrary to cement, the addition of paper considerably increases the porosity which in turns increases the absorption of the material. This time the number of open pores increases enabling water to migrate easily inside de medium structure.

Fig. 3 shows the variation of the absorption function of time of immersion. The blocks which are mixed with paper present the greatest water content because paper tends to increase open pores.

For the entire blocks, the absorption is quick during

Table 2 Young modulus and density of blocks.

Specimens	E_D (MN/m^2)	Strength at three points flexure (MPa)	Density (kg/m^3)
Clay (C)	2,548.881	0.205	1,835.45
Clay-paper (CP)	2,478.776	0.248	1,745.34
Clay-cement (CC)	7,029.192	0.689	1,959.76
Clay-paper-cement(CPC)	4,443.503	1.132	1,820.47

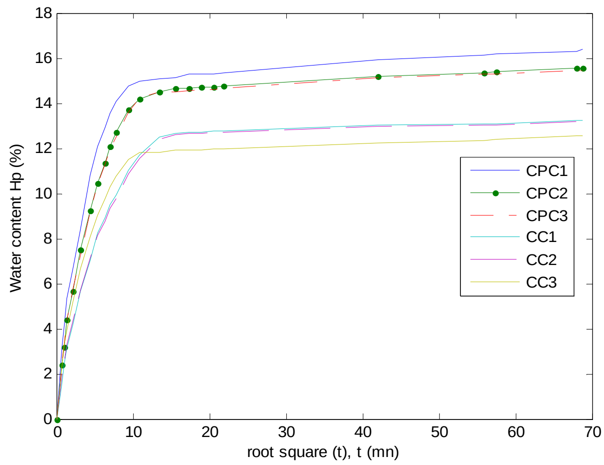

Fig. 3 Water content of blocks with immersion time.

the first 180 nm of immersion time except for the CC3 and CPC1 blocks where the time is shorten to 120 nm. Past this period, the absorption becomes slow up to the saturation, observed after three days and 5 h. The values of the water content at saturation of the CC blocks are the smallest, varying from 12.54% to 13.22% compare with the 15.47% and 16.40% range for the CPC blocks. After 3 h of immersion time, the CPC2, CPC3 and CC1, CC2 water content at saturation have the following respective values: 93.20%, 93.62%,94.31% and 93.68%. These values are 91.84% and 94.34 for the CPC1 and CC3 blocks but for 2 h immersion time. Because they need small quantity of water to get saturated, the CC blocks are found to saturate quickly.

4.5 Blocks Capillary Absorption

Fig. 4 shows that the stabilization reduces the upward flow of water due to capillarity. The blocks of clay-cement reduce water absorption by 50% due to the fact that cement penetrates the material void space reducing the number of open pores and hence, the porosity. Adding paper helps to increase the coefficient of capillary absorption by 9.55% but the blocks remain sensible to water while cement increases considerably the stability to water. The water content by capillary absorption of the CC and CPC blocks function of time is shown in Fig. 5.

The investigations have lasted 26 h, time during which the blocks get saturated at more than 96%. The water migration curve is quasi-linear for the CPC blocks and linear for the CC when the investigation time is less than 6 h. This period corresponds to the time that is necessary for water to get to the blocks' height (14 cm), which gives an average migration speed of 6.481×10^{-3} m·s^{-1}. After 6 h, we observe quasi-horizontal lines indicating reduced water absorption, hence a decrease of water migration because the bricks have reached more than 91% saturation. Furthermore, the CC blocks absorb less water than the

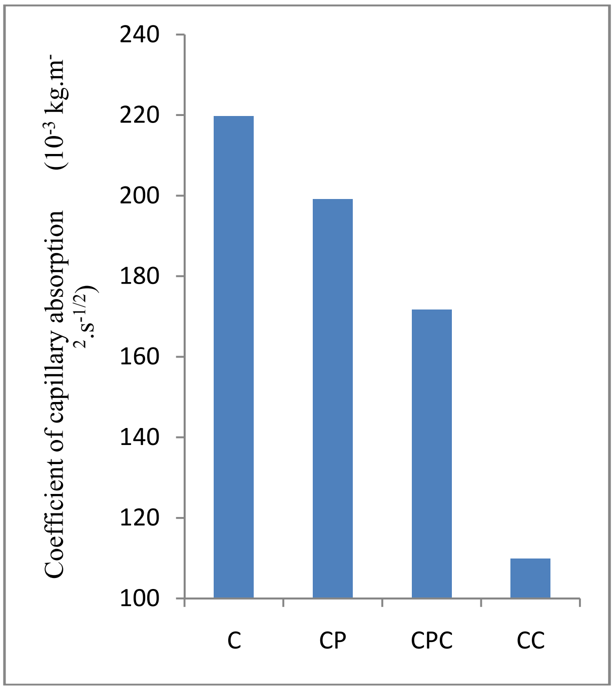

Fig. 4 The coefficient of capillary absorption of different types of CCB.

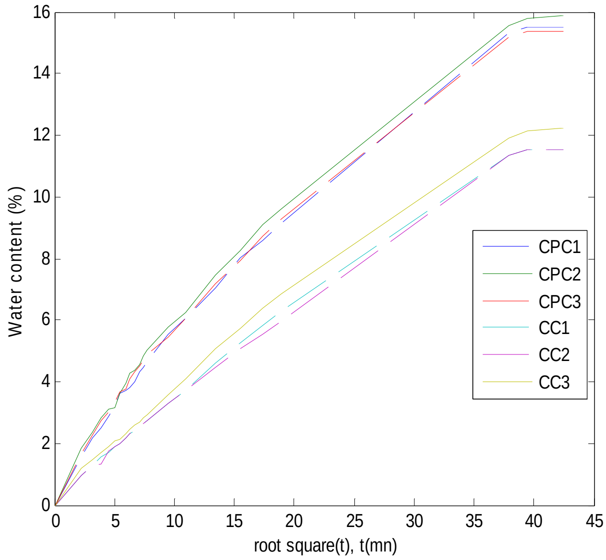

Fig. 5 The water content of the CCB function of time.

CPC which validates the precedent results.

5. Conclusions

The stabilization of clay with paper or cement or paper-cement has a noticeable influence on the strength of the blocks and on their behavior in contact with water. The compressive resistance and the three point flexural strength are improved and we even notice an important increase for blocks in which cement and cement-paper are incorporated. The blocks water stability has increased with the addition of cement which allows the values of the humid compressive resistance to be higher than 1 MPa. Based on these results, we can conclude that the entire blocks have acceptable mechanical properties and hence, may be utilized as construction material. If we take the hydro mechanical properties as criteria, the blocks stabilized with cement-paper have the best construction advantage. Their humid and dry compressive resistances are superior respectively to 1.2 MPa and 8 MPa and have also small densities.

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