Development and Characterization of Compressed Brick by Adding Ash Wood

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Abstract - **With the aim of valorizing local materials and contributing to the reduction of construction costs and energy consumed for heating or air conditioning, wood ash was used to stabilize compressed earth bricks (CEB). The general objective of this work is to valorize wood ash in the stabilization of compressed earth bricks. The results of the geotechnical characterizations show that the particle size analysis of laterite falls within the optimum range as recommended by CRATerre; the Atteberg limits used to calculate the plasticity index reveal that the plasticity index of laterite is 13.2%, which complies with the Cameroonian standard NC 102-114 2002-2006. The results of the physico-chemical characterizations reveal that Fourier transform infrared spectroscopy analysis of the base materials (laterite and wood ash) revealed that the Si-O-Si, Si-O-Al and Ca-O functional groups present on the surface of laterite and wood ash respectively are responsible for the chemical bonds involved in brick production. These results show that the base materials can be used for the production of compressed and stabilized earth bricks. Optimization of the production of compressed and stabilized earth bricks through implementation of the mixing plan shows that wood ash and laterite are the governing factors during production, and the brick produced under optimum conditions at respectively 5ml water, 15g wood ash and 80g laterite for a compressive strength of 6.11MPa, a value within the range recommended by the Cameroonian standard for compressed earth bricks. (RC= 4MPa). Evaluation of the hydration behavior of BTCS obtained under optimum conditions shows that the blocks absorb water by capillarity and total immersion. However, water absorption remains below 0.1g/mm^2 and below 15% for capillarity and total immersion respectively. They therefore comply with CRATerre recommendations for the use of a material in construction.**

Keywords: Stabilized compressed earth brick, wood ash, physicochemical characterization, mechanical characterization, soil.

I. INTRODUCTION

Having a home is an essential need for mankind, and this need has been met over the years with buildings made of animal skins and straw, but the problem has arisen that these constructions are not weather-resistant, so man has sought to develop new materials, and his interest has focused on earth. With the advent of cement, earth is increasingly being replaced by new materials. [1][2] [3]. This material, often criticized for its sensitivity to water and its lack of durability, nevertheless offers numerous advantages in its current form for the construction of sustainable, comfortable and economical housing. The characterization of clay materials must therefore be carried out in order to verify their suitability for the manufacture of mud bricks, [1] because the performance of BTC compressed mud bricks is largely influenced by the characteristics of the earth material, the type and content of stabilizer, and the production and hardening process. The transformation of earth into a building material for housing is relatively easy, requiring neither heavy materials nor equipment, let alone highly advanced technology. Even today, its almost immediate availability makes it an undeniable success. Numerous efforts have been made in this field to improve the physico-mechanical performance of BTCs in dry and wet conditions, as well as their durability. The operation mainly involves stabilization with chemical binders such as cement, lime or even geopolymers [4] [5] as well as industrial and agricultural by-products [6]. Compressive strength, considered an appropriate indicator of stabilized BTC performance, should be at least 4 MPa and 2 MPa, respectively, in dry and wet conditions for use in load-bearing wall construction [7]. However, for building construction [8], refer to the Turkish standard (TS 704 1983, 1985) which recommends a minimum strength of 1 MPa when [9] suggests a minimum of 2 MPa for cement-stabilized blocks. Today, rammed earth is arousing renewed interest in the wake of the housing crisis that is perpetuating itself, especially in developing countries (DCs) and Cameroon in particular. It offers numerous environmental, social, cultural and economic advantages.

In the particular case of wood ash, it is generated by the combustion of domestic wood, which produces large

quantities of ash. It is generally used to spread soil and, in the kitchen, to soften certain foods. However, there are still huge quantities of ash, and we need to find a way of recovering it, which has proved its effectiveness in stabilizing earth bricks. To this end, the work carried out on the incorporation of wood ash for soil brick stabilization is carried out in a randomized manner with a variable, i.e. the proportions of soil and water are maintained, but the proportions of wood ash are varied. This method of working does not allow us to take into account the simultaneous effects of water volume, laterite proportion and wood ash on the compressive strength of earth bricks. It is therefore necessary to use mix design methodology to determine the interactions between the factors and the optimum conditions for producing wood ash-stabilized compressed earth bricks. So this study was initiated to understand the effect of wood ash on the mechanical properties of the material. This work consists in making BTC stabilized with wood ash and studying the mechanical properties of these bricks. The aim is to demonstrate and confirm that wood ash is a stabilizer that improves the mechanical properties of compressed earth bricks. The overall aim of this project is to use wood ash to stabilize compressed earth bricks.

II. MATERIALS AND METHODS

2.1 Material

The main materials used to carry out this work are laterite, wood ash and laboratory equipment.

2.1.1 Base materials

▪ **Laterite**

The laterite used in this work was collected in the Ngaoundéré 3rd arrondissement, 600m from the University of Ngaoundéré, with geographical coordinates: Latitude 7° 19' and Longitude 13° 20'. It will be used as a matrix for the production of compressed and stabilized earth blocks throughout this work**.**

▪ **Wood ash**

The ash used in this work was taken from a grill in Bini-Dang (Ngaoundéré 3th); it is obtained by burning wood. It is a powdered material with a grain size of less than 1mm and a gray color. It will be used as a stabilizer in compressed earth bricks and will be noted CB.

Figure 1: Raw materials: a) laterite b) wood ash

2.1.2 The hydraulic press

The press in photo 1 used in this work is a type 769YP-24B hydraulic press, with pressures ranging from 0 to 60 MPa. This press is used for the compression stage in the production of compressed and stabilized earth blocks and in the characterization of optimized bricks.
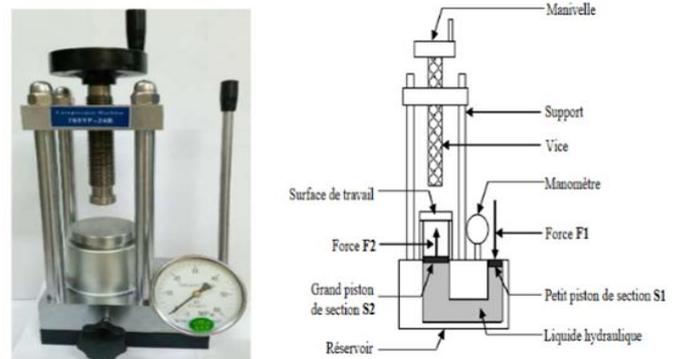

Figure 2: hydraulic press diagram and photo

2.2 Methods

2.2.1 Geotechnical characterization of base materials

2.2.1.1 Determining soil texture: jar test

This test shows the proportion of each soil constituent. It involves placing a sieved soil sample in a jar. After shaking it and leaving it to stand for 24 hours or more, the height of each sedimented layer is measured through the wall, with sand at the bottom, silt in the middle and clay above. The percentages are then determined as shown below:

% sand: (thickness of sand layer*100) / total thickness of soil in jar

% silt: (thickness of silt layer*100)/ total thickness of soil in jar

% clay: (thickness of clay layer*100) / total thickness of soil in jar

The results obtained are placed in the texture triangle.

2.2.1.2 Particle size analysis

- **Particle size analysis by dry sieving after washing**

Particle size analysis is carried out in accordance with French standard NF P 94-056. The material to be tested is first steamed at 105°C for 24 hours. After being soaked in water, the material is washed using a 90 μm sieve. The reject from the 90 μm sieve constitutes the coarse fraction, which, after steaming at 105°C for 24 hours, is dry-sieved using an Endecotts EFL 2000 electric sieve shaker. Different sieve mesh sizes are used. The mass of rejects accumulated on each sieve is compared with the total dry mass of the sample. The percentages of accumulated rejects thus obtained are used to deduce the sieve mesh percentages required to plot the particle size distribution curve. In addition, the fine fraction, made up of particles smaller than 90 μm, is used for particle size analysis by sedimentometry.

- **Granulometric analysis by sedimentometry**

Its purpose is to determine the weight distribution of soil particles with a diameter of less than 90 μm. The test, which is carried out in accordance with French standard NF P 94-057, is based on the fact that in a liquid medium at rest, the settling velocity V of a solid particle is a function of its diameter. It is based on Stokes' law, which gives, in the case of spherical grains of the same density, the relationship between grain diameter and settling velocity. The determination of grain diameter is based on the dispersion and precipitation of clay grains within the liquid. Stokes' law is given by the equation:

$$V = \frac{(\gamma_s - \gamma_w)}{18\eta} D^2 \text{(cm.s}^{-1}) \qquad (1)$$

With:

γ_s Volumic weight of particle in gf.cm^{-3}

D: particle diameter in cm

γ_w : Volumic weight of liquid (Water) gf.cm^{-3}

η: dynamic viscosity in poises

40 g of dry particles smaller than 90 μm, separated from the rest of the soil by sieving, are mixed with 30 ml of a solution incorporated with sodium hexa-metaphosphate. The mixture is left to stand for around 15 hours. Then, using a mixer, the mixture is stirred for at least 3 minutes and poured into a 1-liter glass test tube. This mixture is topped up to 1000 ml with distilled water. The test tube is rigorously homogenized for a few minutes. The mixture then settles in the test tube according to Stokes' law. The densimeter is gently inserted into the suspension to avoid creating turbulence. Densimeter and thermometer readings are taken after 30s, 1mn, 2mn, 10mn, 20mn, 40mn, 80mn, 2h, 4h and 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. The following relationships (2) and (3) are used for this purpose:

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

$$Q(\%) = \frac{V\gamma_s\gamma_w}{P(\gamma_s - \gamma_w)}(r - 1) \quad (3)$$

Où $\frac{H}{t}$ is the velocity of particles at depth H. In these relationships we have:

D: diameter of grains still in suspension

H: depth of grain fall

$\boldsymbol{\gamma_w}$: water's weight by volume

r: suspension density

Q: the percentage of grains remaining in suspension at a given time

t: the time

V: suspension volume

$\boldsymbol{\gamma_s}$: the weight by volume of solid grains

η: dynamic viscosity

P: the weight of dry soil in the suspension

The results obtained from these two analyses are plotted on a semi-logarithmic graph representing the complete particle size distribution curve.

2.2.1.3 Determination of Atterberg limits (NF P94-051)

Atterberg limits are water contents by weight corresponding to specific soil conditions. They are determined on the fraction of soil passing through the 400 μm sieve and are expressed as a percentage. The test is carried out in two distinct phases in accordance with French standard NF P 94-051

Determination of the water content at which a groove of standardized size in the soil placed in a Casagrande cup closes under the action of 25 shocks applied in a standardized manner;

Investigation of the water content at which a hand-made soil roller 3 mm in diameter and 10 to 15 cm in length cracks when lifted.

- **The liquidity limit**

Elle corresponds to the value of the water content required to close 1 cm of a groove after approximately twenty-five (25) shocks (Casagrande apparatus).

The clay material was previously removed by quarrying, washed and preserved with washing water in a tank for 24 hours. After settling, the clear water in the tank was siphoned

off without entraining any solid particles. The material is then spread on a plasterboard to dry. After homogenization on a marble slab, the paste is placed in the Casagrande cup with a spatula, where a groove is cut perpendicular to the surface of the cup. The crank is turned at a speed of two strokes per second until the groove closes to 1 cm. Note the number N of strokes as the lips of the groove close. Slightly dry the paste and carry out further tests. Nevertheless, the number of impacts should be between 15 and 35 for the five or so tests to be carried out. The results obtained enable the liquidity limit to be accurately determined using the following formula:

$$\omega_L = \omega(N/25)^{0,121} \qquad (4)$$

With: ω_L: liquidity limit;
N: number of shocks;
ω: water content.

- **Plasticity limit (ω_P)**

For this test, the same dough is used as for the determination of the liquid limit. The plasticity limit is the water content of a cylindrical roller that cracks when its diameter reaches 3mm.

The paste used for the liquidity test is first lightly dried on the plaster, before being spread out on the marble slab (clean and dry). A ball approximately 15 mm in diameter was formed, and a cylindrical roller, 3 mm in diameter and 10 to 15 cm in length, was then produced on a smooth marble slab. The plasticity limit is reached when the cylindrical roller is slightly lifted from the middle and cracks or breaks.

- **Plasticity index (I_P)**

The plasticity index specifies the range within which the clay material can be easily deformed (shaped). It is obtained by the numerical difference between the liquid limit (ωL) and the plastic limit (ωP).

$$I_P = \omega_L - \omega_P \qquad (5)$$

2.2.2 Physico-chemical characterization of basic raw materials

2.2.2.1 Laser granulometry

An initial analysis measures the particle size distribution of the powdered materials studied. This information is essential to get an idea of particle size, and therefore of the powders' ability to react with other materials. The laser granulometer is a machine that uses the diffraction and scattering of a laser beam by fine powders. Particle sizes down to the micrometer can thus be obtained. The machine used is a Mastersizer 2000, available from the Analytical Chemistry Laboratory.

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Photo 1 : Mastersizer 2000

2.2.2.2 Fourier transform infrared spectroscopy (IRTF)

Fourier transform infrared spectroscopy is used to characterize the main chemical functions present in a base material. This technique is based on the absorption by materials of electromagnetic waves (in the infrared range) which excite the vibrational movements of chemical bonds. Each bond is characterized by the absorption of specific wavelengths, linked to the nature of the bond and its environment.

2.2.2.3 Water content

The water content of a material is the ratio of the weight of water contained in a sample of the material compared to the weight of the same dry material. Water content is measured as follows: Take a soil sample and weigh it to determine its wet mass M1. Place the sample in an oven at 105°C for 24 hours, then weigh it again to determine its M2 mass after drying.

$$TE = \frac{(M_1 - M_2)}{M_1} \times 100 \qquad (6)$$

2.2.2.4 Density determination

The density determination will be done according to NF P18-554.

- **Apparent density**

Apparent density is a quantity used mainly with substances in granular form, in the food industry, in soil science for soil description, or in public works buildings for example, to account for the mass of material contained in a given volume, including the volume of interstitial air. The procedure is as follows:

Container volume (V)

Note the weight of the empty container (M1)

Pour dry aggregates in successive layers, without settling.

Flatten with a metal ruler.

Weight the filled container (M2)

The apparent density of the material is then given by the relationship:

$$\rho_{app} = \frac{m_2 - m_1}{V} \qquad (7)$$

Absolute density

The absolute density of laterite and wood ash was determined to get an idea of the mass occupied by a unit volume of these different materials, excluding voids due to the material itself and those existing between the grains of the material. The measurement consists of:

Take a test tube and fill it with water to half its volume V1

For in a dry aggregate sample of mass M

Note the new water V2, which is the volume displaced

The absolute density is then given by the relationship:

$$\rho_{ab} = \frac{M}{V_2 - V_1} \qquad (8)$$

2.2.2.5 Determination of apparent porosity

The porosity of the base materials was determined using the NF P94-410-3 method, in order to get an idea of all the voids existing in them. The determination of porosity, like that of the various densities, will enable us to understand the densification mechanisms of the materials studied. A quantity M (g) of material is weighed and hydrated with a volume of water, then the wet material of mass M1 is immersed for 24 hours and oven-dried at 105°C to constant weight (M2). The apparent porosity (ε) of the material, expressed as a percentage, is given by the relationship:

$$\varepsilon = \frac{M_1 - M_2}{M_1} \qquad (9)$$

2.2.2.6 Determination of specific surface area by methylene blue testing at (NF P94-068)

The methylene blue test measures the specific surface area of clay soil particles. The so-called "spot test".

Test principle

The principle of this method is to control the adsorption of methylene blue injected into an aqueous bath containing the test sample, by observing the behavior of a drop of suspension deposited on a sheet of filter paper.

The spot formed consists of a central deposit of the material, colored a deep blue, surrounded by a colorless wet zone. Excess methylene blue results in the formation of a persistent light-blue halo around the central deposit.

Calculating the methylene blue value:

$$VBS = \frac{B}{M} \times 100 \qquad (10)$$

With:

VBS: blue ground value, M: sample mass in grams, B: mass of methylene blue introduced

The total specific surface area of clay is:

$$SST = 20,93 \times VBS \qquad (11)$$

Table 1: Soil classification [10]

Methylene blue value	Soil classification
VB<0,2	sandy soils
0,2<VB<2,5	silty soils
2,5<VB<6	clayey silty soils
6<VB<8	clayey soils
VB>8	very clayey soils

2.2.3 Production of compressed and stabilized bricks

BTCS was produced using the following process. After sampling, the laterite is sun-dried, then crushed and sieved using a 5mm diameter sieve. The wood ash is sieved to remove coals and unwanted particles. It is then washed. After washing, it is dried in the sun; to the different masses of laterite is added a mass of wood ash deduced from the experimental design. The mixture is then homogenized in the dry state to ensure contact between the particles and homogeneous distribution of the constituents. A quantity of water is then added to the previous mixture to moisten the materials. This step ensures homogeneous redistribution in the mixture and facilitates particle cohesion. The moist sample is then placed in a greased mold. The mold is placed on the press platen and the entire assembly is pressed at 10 MPa. The material is compressed vertically at the top by means of a parallelepiped piston. This compression reduces the porosity of the mixture and makes it denser. Once the required pressure has been reached, the block is immediately removed from the mold and placed in wet cure for 7 days, during which time the bricks are covered with plastic. This is followed by a 21-day dry cure, during which the bricks are exposed to the sun. At

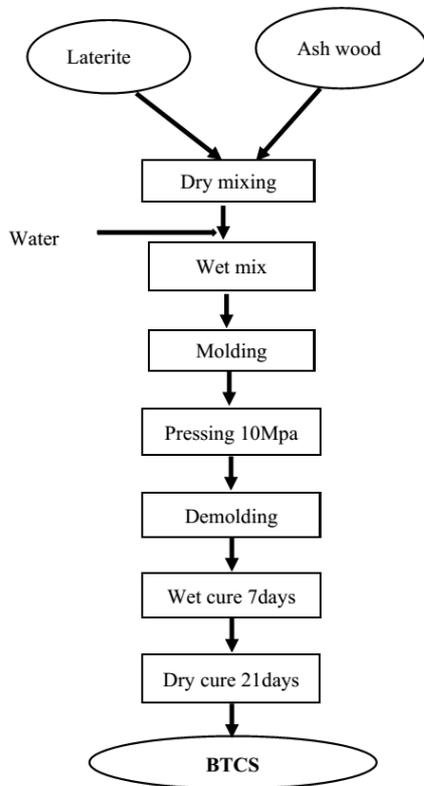the end of this dry cure, the compressed and stabilized earth blocks undergo the following treatment.

Figure 3: The production layout of BTCS

2.2.4 Optimizing the production of compressed and stabilized clay bricks

The development of a mixing plan for the production of BTCS began with the choice of factors based on the literature and preliminary tests.

Water, expressed in ml will be noted X1,

Wood ash, expressed in g will be noted X2.

Laterite, expressed in g will be noted X3.

The response studied is compressive strength, which is a very important parameter for the use of a material in construction. It is expressed in mega Pascal (MPa) for compressive strength and will be denoted Y.

Table 2: Levels, factors and factor codes

factors	variable Codes	level
Water	X_1	5 – 10
Wood ash	X_2	7 – 15
Laterite	X_3	80 – 88

The matrix generated by Stat graphic software is as follows:

Table 3 : Test matrix generated by Stat graphics software

Test	X_1(g)	X_2(g)	X_3(g)	Y(Mpa)
1	5	15	80	
2	5	7	88	
3	10	10	80	
4	10	7	83	
5	6,25	12,375	81,375	
6	6,25	8,375	85,375	
7	8,75	9,875	81,375	
8	8,75	8,375	82,875	
9	5	11	84	
10	7,5	12,5	80	
11	7,5	7	85,5	
12	10	8,5	81,5	
13	7,5	9,75	82,75	
14	5	15	80	
15	5	7	88	
16	10	10	80	

2.2.5 Characterization of compressed and stabilized earth bricks

2.2.5.1 Compressive strength

Compressive strength has been evaluated using the XP X30-437 method to determine the pressure required to cause a block to break. It gives an idea of the load-bearing capacity of blocks crushed flat, in the same position they occupy during construction of a building. It is measured by crushing the block using a type 769YP-24B hydraulic press. The test consists in placing the block on the working surface of the hydraulic press and subjecting it to a continuous and progressive load until it is crushed. The value of the block's breaking pressure (expressed in MPa) is read directly from the hydraulic press pressure gauge.

2.2.6 Modeling the BTCS production process

2.2.6.1 Mathematical model

Modelling will enable compressive strength to be translated into a mathematical model. It is carried out in order to get an idea of the contribution of each factor and the influence of the interaction between the different factors on the desired compressive strength. The model used is a special cubic model. The model equation is:

$$Y= a_1X_1+a_2X_2+a_3X_3+a_{12}X_1X_2+a_{13}X_1X_3+a_{23}X_2X_3+a_{123}X_1X_2X_3$$

(12)

With: **Y**: Response to compressive strength, **a₁a₂a₃**: linear coefficients, **a₁₂a₁₃a₂₃**: double interaction coefficients, **a₁₂₃**: the triple interaction coefficient

2.2.6.2 Model validation

Validation of the mathematical model will enable us to assess whether the model chosen is suitable for understanding the phenomenon of compressive strength of materials. The model was validated by evaluating the coefficient of determination (R2), the absolute analysis of maximum deviation (AADM), the bias factor (Bf) and the accuracy factors (A_{f1} and A_{f2}), whose equations are given in Table 4.

Table 4: Indices and validation conditions for the mathematical model

Validation index	Determination equation	Constant expressions	Validation conditions
Coefficient of determination	$R^2 = \sum_{i=1}^{n} \left(\dfrac{Y_{théo}}{Y_{exp}} \right)$		$R^2 \geq 0,90$
Adjusted coefficient	R^2 Adjusted		R^2 Adjusted $\geq 0,80$
Absolute analysis at maximum deviation	$AADM = \dfrac{\sum_{i=1}^{n} \left(\dfrac{\lvert Y_{iexp} - Y_{ithéo} \rvert}{Y_{iexp}} \right)}{n}$		$0 < AADM < 0,2$
Bias factor	$B = \dfrac{1}{n} \sum_{i=1}^{n} \log \left(\dfrac{Y_{ithéo}}{Y_{iexp}} \right)$	$B_f = 10^B$	$0,75 < Bf < 1$
Accuracy factor	$A = \dfrac{1}{n} \sum_{i=1}^{n} \log \left\lvert \dfrac{Y_{ithéo}}{Y_{iexp}} \right\rvert$	$A_f = 10^A$	$0,75 < Af < 1$

With: **Yi_exp**: Experimental response, **Yi_theo**: Theoretical response obtained from model, **i**: trial number, **n**: Total experience.

2.2.7 Study of hydration behavior

2.2.7.1 Total immersion absorption

This is used to assess the resistance of BTCS to extreme hydration conditions (rainwater and/or flooding) in accordance with ASTM C 20-74. It is determined by immersing a material in water to constant mass and measuring the increase in mass. Water absorption by immersion (Abs) is expressed as a percentage (%) of dry mass and is calculated by the following relationship:

$$\text{Abs} = \frac{m_{wet} - m_{dry}}{m_{dry}} \times 100 \qquad (13)$$

With:

m wet: the constant wet mass of the specimen after immersion,
m dry the constant dry mass of the specimen after oven drying.

2.2.7.2 Capillarity

The capillary absorption test is used to assess the behavior of BTCS in a humid environment, and the rate of absorption over a given period. It consists in placing a section (s) of the block in contact with water and following the increase in its mass. Water absorption by capillary action is then measured by weighing as a function of time. The absorption coefficient is determined by the relationship:

$$C_{ac} = \frac{m_{h.t} - m_i}{S} \qquad (14)$$

With: C_{ac}: capillary absorption coefficient (g /mm^{-2}),
$m_{h.t}$: wet block mass at a given moment t (g),
m_i: initial block weight (g),
S: block section in contact with water (mm^2).

III. RESULTS AND DISCUSSION

3.1 Geotechnical characteristics

3.1.1 Nature of the earth

The jar test revealed that after 24 h the different proportions of soil particle classes are: sand 50%, silt 16.66 and clay 33.33. These proportions obtained are placed in the texture triangle and the following figure X shows the result obtained.

It can be seen from this figure that the introduction of these data into the texture triangle has made it possible to determine the texture of the laterite, which is a sandy clay loam soil. Indeed, the presence of these particles could probably promote good particle cohesion during compressed brick production. In addition, the methylene blue test gave a blue value of 2.66, which is a value within 2.5<VB<6 characteristic of clayey silty soils [10]. This result confirms that laterite can be used for the production of compressed earth bricks.
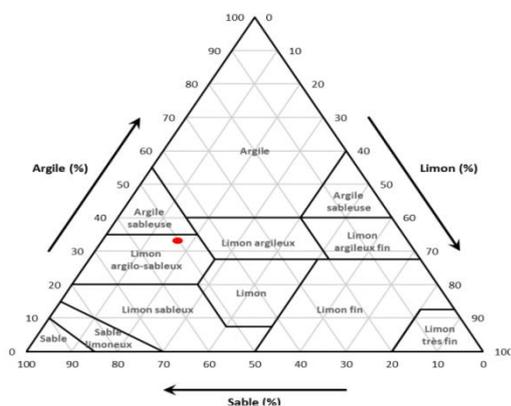

Figure 4: Texture triangle

3.1.2 Particle-size analysis

The granulometric analysis of the laterite was carried out and the results obtained are shown in figure 5.
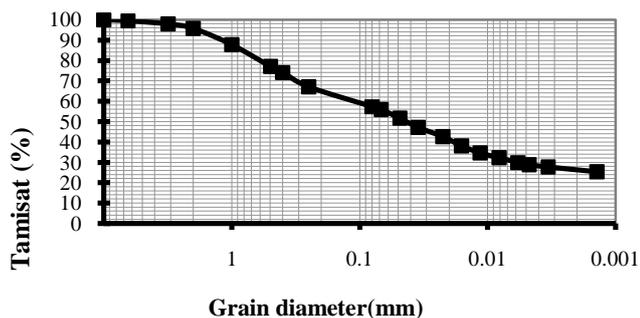

Figure 5: Laterite grading curve

Figure 13 shows the particle size distribution curve for laterite, plotting sieves (%) against grain diameter (mm). It can be seen that the curve decreases, meaning that the % of sieve decreases with grain diameter. According to the data in the particle size distribution table:

Table 5: Particle size distribution

Constituents	Gravel	Sand	Silt	Clay
Diameter Φ (mm)	Φ >2	2>Φ>0.02	0.02>Φ>0.002	Φ<0.002 mm
Proportion (%)	4,3	53,1	15,0	27,6
Like CRATerre	0 à 40	25 à 80	10 à 25	8 à 30

The particle size analysis shows that the curve lies within the limit recommended by the CRATerre standard for compressed earth blocks [11]. Laterite has several granulometric proportions of its constituents: 42.6% of fine particles, including 15% silt and 27.6% clay. Coarse particles, on the other hand, represent the highest proportion, with 53.1% and 4.3% respectively for sands and gravels. This high proportion of coarse particles could help improve the mechanical properties of compressed and stabilized earth blocks.

3.1.3 Atteberg limits

The results of the limit tests are shown in Table 6.

Table 6: Parameters derived from Atteberg limits

Limits	Liquidity limit (wl)	Plasticity limit (wp)	Plasticity index (Ip)
Laterite	47,0	33,8	13,2
NC 102-114, 2002-2006	25-50	20-35	2-30

Table 6 shows the parameters taken from Atteberg's limits. The plasticity index of the laterite studied is equal to 13.1%. According to the Cameroonian standard for BTC (NC 102-114, 2002-2006), this value falls within the recommended range, as do the values of the other limits, so the laterite studied can be used for BTC production.

3.2 Physico-chemical characteristics

3.2.1 Physico-chemical characteristics of raw materials

The physico-chemical characteristics of the raw materials were carried out and the results obtained are reported in table 7.

Table 7 : Physico-chemical characteristics

Raw materials	Laterite	Wood ash
Water content (%)	23,2	4,08
Apparent density (g/cm^3)	0,94	0,66
Absolute density (g/cm^3)	1,76	2,57

Apparent porosity (%)	5	7,5
Specific surface area (m^2/g)	55,67	62,79

This table presents the physico-chemical characteristics of laterite and wood ash.

Analysis of water content shows that the materials analyzed have different water contents. Laterite has the highest water content, at 23.2%, while wood ash has a value of 4.08%. This high-water content in laterite can be explained by the absorption of moisture from the air during storage. These results show that compressed and stabilized soil blocks (BTCS) will take time to stabilize their weight during drying in order to obtain a constant mass

It can be seen that the absolute density of laterite (1.76g/cm^3) is almost twice as high as its apparent density (0.94g/cm^3); similarly, the absolute density of wood ash (2.57g/cm^3) is almost four times higher than its absolute density (0.66g/cm^3). This result could be explained by the fact that absolute densities, as opposed to apparent densities, do not take into account voids due to the material and those existing between the grains of the material. Compressed and stabilized earth blocks will be less porous and therefore less absorbent and denser.

Specific surface analysis shows that laterite has a small specific surface (55.67 m^2/g) compared with wood ash (62.79 m^2/g). As specific surface is linked to particle fineness, the smaller size of a material, the greater its specific surface. In effect, this creates a cohesion between laterite and wood ash particles in the presence of water, resulting in the creation of strong chemical bonds during the production of compressed and stabilized earth blocks.

3.2.2 Wood ash particle size distribution

It enables us to measure the particle size distribution of the powder materials under study. This information is essential to get an idea of particle size, and therefore of the ability of powders to react with other materials. Laser particle size analysis of wood ash is shown in figure 6.
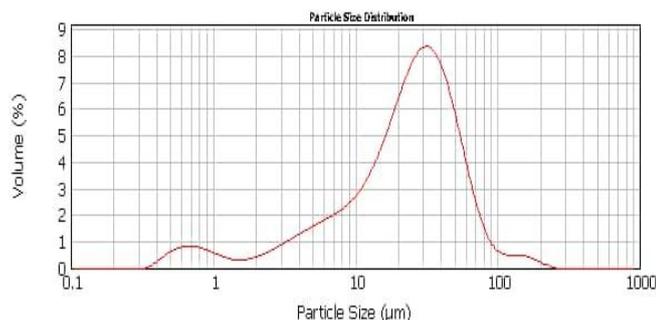

Figure 6: Laser particle size distribution of wood ash

Figure 6 shows the laser particle size analysis of wood ash. The graph shows the particle size distribution.

Two peaks can be seen, the first for particles smaller than 1 μm and the second for particles smaller than 100 μm. According to Table 8.

Table 8: Wood ash particle size distribution

| Diameter	d(0,5)	d(0,5)	d(0,9)
Distribution	4,227 μm	24,844 μm	57,360 μm

The table shows that the majority of particles are smaller than 24.844 μm, with a circumference of 0.5. In view of these results, we can say that particle size generally influences the reactivity of aluminosilicate raw materials during BTC production. If we look at particle size alone, the smaller the particle size, the greater its specific surface area, meaning that wood ash is likely to react with clay particles to reinforce the structure of clay bricks.

3.2.3 Functional groups of base materials

The results of infrared spectroscopic chemical analyses of laterite and wood ash are shown in figures 7.
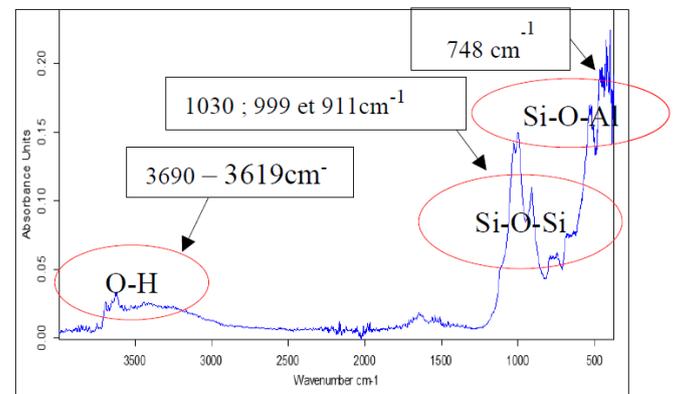
a) Laterite
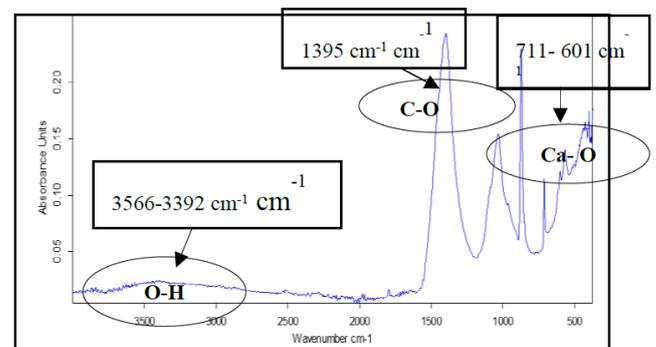
b) Wood ash

Figure7: Fourier transform infrared spectroscopy of base materials

Figure7 shows the IRFT spectrum of the base materials (laterite and wood ash). The spectrum is a plot of Absorbance versus wave number (cm^{-1}).

From the spectrum, we observe:

In the first region, the bands at 3690 and 3392 cm-1 are attributable to the elongation vibration of the O-H. Bonds of the hydroxyl groups of laterite kaolinite and wood ash or originating from moisture.

The second domain of laterite comprises three absorption bands. The peaks at 1030, 999 and 911 cm-1 are respectively attributable to the symmetrical and asymmetrical elongation vibrations of the Si-O-Si bond characteristic of clay minerals and silicates [12].

In the third domain, laterite, the band at 748 cm-1corresponds to the different vibrational modes of the Si-O-Al bond characteristic of aluminosilicates.

The peak at 1395 cm-1 in wood ash: may correspond to deformation vibrations of the C-O.

The peaks at 711 and 601 cm-1 correspond to the vibrations of the chemical bonds present in the calcium oxide CaO structure [14].

The Si-O-Si, Si-O-Al and Ca-O groups for laterite and wood ash respectively are those that will interact under the action of water to form stable chemical bonds during the production of compressed bricks. It is these bonds that give bricks their good mechanical properties.

3.3 Optimization of compressed and stabilized soil block production

3.3.1 Modeling BTCS production

3.3.1.1 Experimental production matrix and model validation

In order to understand the phenomenon involved in the production of compressed and stabilized mud bricks, the matrix and the values of the various compressive strengths are presented in the following table:

Table 9: Experimental matrix and BTCS production response

N° testing	X1	X2	X3	RC exp	RC théo
B1	5	15	80	6	6,11
B2	5	7	88	4	4,12
B3	10	10	80	2	1,77
B4	10	7	83	1	1,32
B5	6,25	12,375	81,375	4,5	4,49
B6	6,25	8,375	85,375	4	3,59
B7	8,75	9,875	81,375	3	2,67
B8	8,75	8,375	82,875	2	2,41
B9	5	11	84	4,5	4,32
B10	7,5	12,5	80	4	3,87
B11	7,5	7	85,5	3	2,77
B12	10	8,5	81,5	2	1,66
B13	7,5	9,75	82,75	3,5	3,34
B14	5	15	80	6,5	6,11
B15	5	7	88	4	4,12
B16	10	10	80	1,5	1,77

This table shows that the compressive strengths of compressed and stabilized earth bricks, whether experimental or theoretical, vary according to the quantities of water, wood ash and laterite. Brick 14 has the highest compressive strength. This may be explained by the fact that compressive strength increases with the amount of wood ash. This result is similar to those of other researchers [13], who observed that cement-stabilized earth bricks at 8% had an average strength of 6.5 MPa at 28 days curing. Contrary to the results of Kouassi et al, 2022, the compressive strengths are 3.28MPa for 5% cement and 25% ash, and 2.18MPa for 5% cement and 5% ash at 14 days of dry curing. On the basis of these analyses, we can say that wood ash can be used to stabilize compressed earth bricks, as it offers better compressive strength at 15% wood ash. Analysis of experimental and theoretical data enabled us to calculate validation indices, the results of which are presented those of other researchers [13], who observed that cement-stabilized earth bricks at 8% had an average strength of 6.5 MPa at 28 days curing. Contrary to the results of Kouassi et al, 2022, the compressive strengths are 3.28MPa for 5% cement and 25% ash, and 2.18MPa for 5% cement and 5% ash at 14 days of dry curing. On the basis of these analyses, we can say that wood ash can be used to stabilize compressed earth bricks, as it offers better compressive strength at 15% wood ash. Analysis of experimental and theoretical data enabled us to calculate validation indices, the results of which are presented in the following table:

Table 10: Model validation parameter values

Index	Value	Validation condition
R^2 (%)	93,99	≥90
R adjusted (%)	89,98	≥80
AADM	0,009	0-0,2
Bias factor	0,84	0,75-1,25
Accuracy factor	1,01	0,75-1,25

This table shows that all these validation indices are in line with the model's validation conditions. The chosen model

is therefore suitable for understanding the phenomenon of compressed and stabilized earth block production. The model is therefore valid, i.e. we can discuss the effects of interactions.

3.3.1.2 Model equation and coefficients

The validated cubic model is described by the following equation:

$$Y = -0,319216*X_1 + 6,02989*X_2 + 4,12085*X_3 - 0,969913*X_1*X_2 - 0,210327*X_1*X_3 - 1,95582*X_2*X_3 + 17,5124*X_1*X_2*X_3 \quad (15)$$

This model shows that, in view of the coefficients of the equation obtained, the various factors studied each make a significant contribution to the production of compressed and stabilized earth blocks. The table below shows the model's various coefficients.

Table 11: Model coefficients

Factors	Coefficients
X_1	0,319216
X_2	6,02989
X_3	4,12085
X_1X_2	0,969913
X_1X_3	0,210327
X_2X_3	1,95582
$X_1X_2X_3$	17,5124

The model used takes into account main effects, double interaction effects and the triple effect. The table shows that factor X_2 (wood ash) is the governing factor in BTCS production, almost 20 times greater than main effect X_1 (water) and almost 1.5 times greater than effect X_3 (laterite).

The double interaction effect X_2X_3 (wood ash* laterite) is 2 times greater than effect X_1X_2 (water *wood ash) and 9 times greater than effect X_1X_3 (water* laterite)

The triple interaction effect $X_1X_2X_3$ (water *wood ash* laterite) is 9, 5 times greater than the X_2X_3 (wood ash*laterite) effect and 83 times greater than the X_1X_3 (water*laterite) effect, as well as 18 times greater than the X_1X_2 (water*wood ash) effect.

Wood ash and laterite are the factors governing the production of compressed and stabilized earth blocks. This observation is explained by the fact that wood ash contains alkaline compounds such as calcium oxide (CaO), which is the majority compound; when mixed with laterite, the CaO contained in wood ash reacts chemically with clay minerals to form alkali silicates. These alkali silicates act as a binder,

reinforcing the structure of earth bricks and improving their strength.

3.3.2 Contour diagram of compressive strength surface and optimum condition
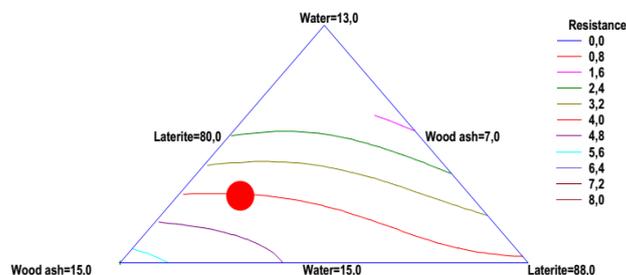

Figure 8: Response surface contour curve

Observation of the response surface contour curve shows that variation is non-linear due to the double interaction effects X2X3 (wood ash* laterite), X1X2 (water*wood ash) X1X3 (water* laterite), and the triple interaction effect X1X2X3 (water*wood ash* laterite). The red point is the optimal point where the best compromise for all properties of the compressed and stabilized earth brick was deduced.

Table 12: Optimum result

Water (ml)	Wood ash (g))	Laterite (g))	Compressive strength (MPa)
5	15	80	6,11

This table shows that the better compressive strength is 6.11MPa, at a combination of 5ml water, 15g wood ash and 80g laterite.

3.3.3 Study of the hydration behavior of compressed and stabilized earth bricks

3.3.3.1 Water absorption by total immersion

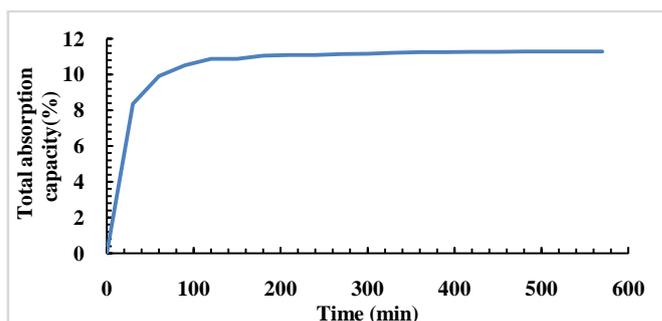Figure 9 shows the total immersion over time of the optimal compressed and stabilized brick.

Figure 9: Total immersion absorption

This figure shows that absorption by total immersion increases rapidly before the first two hours and tends to stabilize after 5h. This is due to the increase in porosity around the aggregates and the hydrophilic nature of wood ash aggregates. Compressive strength drops from 6.5MPa to 4MPa for the optimum brick after stabilization by total immersion. Despite this drop, compressive strength still complies with Cameroonian standard 102-114 (2002-2006), so it can be used in construction.

3.3.3.2 Capillarity

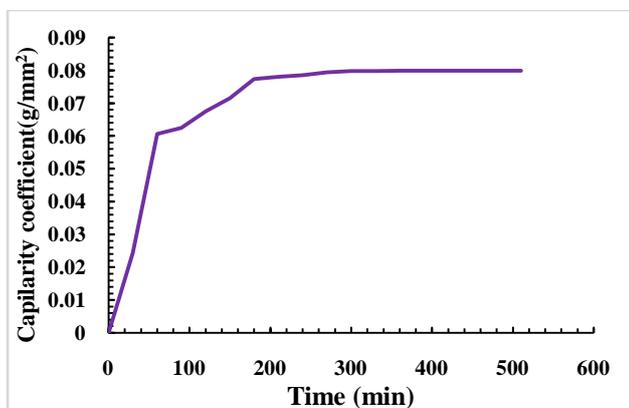Figure 10 shows the capillary absorption coefficient of the optimal compressed and stabilized brick.

Figure 10: absorption by capillarity

The figure shows that the capillary absorption coefficient increases rapidly before the first two hours, tends to be constant between 2h and 8h and is completely stable beyond 8h, meaning that there is more capillary rise. Given that the capillarity coefficient is low (0.08), we can say that the pore network is non-linear, resulting in an increase in surface area. The bonds formed during densification lead to cation exchange between laterite cations and the calcium ion contained in the ash, resulting in optimal brick stabilization.

IV. CONCLUSION

At the end of this project, the general objective of which was to use wood ash to stabilize compressed earth bricks, The geotechnical and physico-chemical characteristics of the base materials (laterite and wood ash) show that the particle size distribution is within the range recommended by CRATerre, and the plasticity index of 13.2% is within the range recommended by NC 102-114 (2002-2006) for materials suitable for the production of compressed earth bricks. Functional groups on the surface of the base materials showed that laterite and wood ash are rich in silicate, aluminate and calcium oxide, which are responsible for the chemical bonds involved in brick densification. These results show that basic materials can be used in the production of earth bricks compressed and stabilized.

Optimization of the production of compressed and stabilized earth bricks using the mixing plan showed that wood ash is the factor governing compressive strength, but this variation depends on the proportions of laterite and wood ash. Determination of the optimum point for the production of compressed and stabilized earth bricks showed that for a water volume of 5ml, masses of 15g wood ash and 80g laterite give a compressive strength of 6.11MPa.

A study of the hydration behavior of soil bricks stabilized by total immersion and capillary action showed that stabilized soil bricks absorb water due to the presence of pores. However, all these absorptions (partial and total) remain low due to their low porosity, and are below the recommendations of 15% and 0.1 g/mm2 respectively for total immersion and capillarity. Determination of the compressive strength of compressed and stabilized mud bricks in the wet state showed a reduction in compressive strength from 6.5MPa to 4MPa, but this still complies with Cameroonian standard NC 102 114, 2002-2006. In short, the production of BTCS with ash enables us to obtain bricks with acceptable performance, sometimes better than others.

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