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### RESEARCH ARTICLE

#### MAIN ENGINEERING PROPERTIES OF STABILISED EARTH BLOCK BRICKS FORMULATED WITH SOILS FROM N'DJAMENA-CHAD

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#### Abstract

The most used bricks in house building in N'Djamena, city of Chad which is situated in semi dry arid area with 600 millimeters of pluviometry per year and 50 °C as highest temperature, are raw clay bricks, terracotta bricks or bricks in cement block. The raw clay bricks have strong sensibility in water and weak resistance to compression. The terracotta and cement block bricks have high thermal conductivity contrary to the adobe and their manufacturing contribute to destroy the environment. The aim of this paper is to search Stabilised Earth Block (SEB) bricks which are made with clay, sand and few percent of cement and respond to climatic, environmental and economic constraints. Therefore, some bricks are built in mixing different percentages of sand and clay (M1 : 40% sand and 60% clay, M2 : 50% sand and 50% clay, M3 : 60% sand and 40% clay, M4 : 70% sand and 30% clay, M5 : 30% sand, 30% slime and 40% clay, and M6 : 40 % sand, 20% slime and 40% clay) for obtaining physical stabilization and adding 8%, 10% or 15% of cement in each type of brick for the chemical stabilization. The use of moulding press machine grants already the mechanical stabilization to these bricks. Proctor test has allowed to retain M1, M3 and M4 for searching the best values of the rate absorption of water by capillarity, the resistance in compression and the thermal conductivity of these bricks. The results of tests show bricks M3 with 10% of cement have the good values; 21,23 g.cm<sup>-2</sup>.min<sup>-1/2</sup> of rate absorption, 3,82 MPa of resistance in compression and 0,5W.m<sup>-1</sup>.°K<sup>-1</sup> as thermal conductivity.

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#### Introduction:-

The aim of this work is twofold, namely the promotion of local materials and the protection of the environment. Indeed, promoting local materials for habitat construction allows for a drastic reduction in the quantity of imported cement materials, since (Pacheco T et al, 2011) estimated that 50% of the world's cement consumption goes to under development countries. Moreover, developing Stabilised Earth Block (SEB) bricks for the construction of low energy consumption buildings will contribute to reduce greenhouse gas emissions since the manufacture of concrete requires between 400 and 800 kWh whereas only 5 to 10 kWh are needed for the same volume of natural materials

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(Houben H, 1997). Indeed, (Taylor et al, 2006) estimate the share of cement production in global CO<sub>2</sub> emissions to be around 10%, an assertion confirmed by the work of (Emmanuel Ouedraogo, 2015).

The potential of raw earth in building construction (Bahobail M A, 2012) is well established and (Houben H, 2006) have described all the qualities of raw earth that can be improved by incorporating a small amount of mineral binders (Danso H et al, 2015).

To this purpose, it is a question of making the best Stabilised Earth Block (SEB) bricks as they are already known to be resistant, not very absorbent and with low thermal conductivity (Bassa B et al, 2015), starting with their formulation, which consists of mixing different soils (clay, sand and silty sand), respecting the proportions of each of them in order to obtain a reworked soil with the desired characteristics. The different formulations of the selected reworked soils will then be stabilised with cement and finally the blocks of cement-stabilised soil will be manufactured.

Mechanical and thermal characteristics such as the rate of water absorption by capillarity, compressive strength and thermal conductivity depend on the nature of the constituents of the earth concrete and make it possible to classify the SEB bricks as bricks which are competitive with conventional building materials.

## Materials, Equipments And Methods:-

### Materials:-

The elaboration of the Stabilised Earth Block (SEB) brick, with 30x10x9 cm<sup>3</sup> as dimensions, is a shaping process that is accompanied by three types of stabilisation; physical, mechanical and chemical.

Physical stabilisation, the aim of which is to improve the characteristics of the soil by correcting the granularity, generally consists of adding sand to clay or lateritic soils, or sometimes materials of plant origin. Depending on the case, the mixture obtained either reduces the plasticity index of the base material or gives it a certain cohesion. Mechanical stabilisation consists of compacting the reworked soil to reduce the porosity of the material by tightening the particles in order to increase the natural density of the clay. The benefits of high density are the reducing of permeability and compressibility, the reducing of water absorption capacity and swelling. And the chemical stability allows the material to be less sensitive to water. In order to reduce sensitivity to water, the addition of hydraulic binders such as cement is often used to make the treated soils less hydrophilic.

The addition of cement, in a minimum proportion of 4% by weight in relation to the dry weight of the earth (Pierre Meukam, 2004), allows the grains of sand to be bonded while stabilising the clay and improves, in addition to the stability with regard to water, the mechanical characteristics of the processed material. In order to produce the specimens that will be used to determine the mechanical and thermal characteristics of the SEB bricks, geotechnical tests are carried out on six mixtures (M1, M2, M3, M4, M5 and M6) with different proportions of clay, sand and sometimes silty sand. The clay, with 39,4 as plasticity index and 2,49 g.cm<sup>-3</sup> as density, is extracted from the Siguété quarry located about fifteen kilometres at east of N'Djaména city. The Chari sand, with 2,61 g.cm<sup>-3</sup> as density and a tight grain size with a high proportion (76,2%) of medium elements, is used to correct the texture of the clay. Silty sand and SONACIM cement of class PC 32.5 are added to the sand and clay to make the SEB bricks.

Mixture M1 (40% sand and 60% clay), mixture M2 (50% sand and 50% clay), mixture M3 (60% sand and 40% clay), mixture M4 (70% sand and 30% clay), mixture M5 (30% sand, 30% silt and 40% clay) and mixture M6 (40% sand, 20% silt and 40% clay) underwent the Proctor test to define the optimum formulation in terms of compressive strength. It is noted that the mixing water used for each of the mixes during compaction varies from 8% to 14% of the total dry weight of the mix. The realized Proctor test made it possible to retain three mixes to make the samples useful for the tests, namely mixture M1 (60% clay and 40% sand), mixture M3 (40% clay and 60% sand) and mixture M4 (30% clay and 70% sand) whose densities and water contents after compaction are given in Table 1 below.

**Table 1:-** Densities of sand-clay mixtures.

Compacting characteristics	Proportion of sand and clay mixtures		
	M1	M3	M4
Moisture content of the modified Optimum	12,5	12,0	11,0

Proctor (%).			
Maximum dry density ( $\text{g.cm}^{-3}$ )	1,87	1,91	1,96

The compaction water content of the cement-stabilised earth block bricks will be set equal to or slightly higher than the water content of the modified Proctor optimum given in Table 1.

To the three different proportions retained (M1, M3 and M4) for the preparation of the geoconcrete will be added 8%, 10% or 15% of cement for the formulation of the earth concrete and the manufacture of 9 classes of BTS in order to ensure repeatability and to cover the different tests. Thus, twelve (12) bricks were made per class using the manual brick press (see Fig. 2.a). These one hundred and eight (108) SEB bricks were put to dry in the shade, covered with plastic (see Fig.1) for 28 days in order to avoid shrinkage and cracking and to maximize cement crystallization.



**Figure 1:-** Conservation and curing of Stabilized Earth Block (SEB)bricks.

### Equipments

The manufacture of bricks in Stabilised Earth Block (SEB) requires a manual press (see Fig.2), its accessories (a shovel, a doser and a scraper) and a plastic to cover the bricks.

The other equipments that follow are necessary to carry out the mechanical and thermal characterisation work:

- A digital balance (Fig.3) for weighing the test samples;
- An oven (Fig.4.a) to dry the test specimen by setting a temperature on  $105^{\circ}\text{C} \pm 5^{\circ}\text{C}$ .
- A tank with dimensions 35cmx50cmx15cm (Fig.4.b) for the water absorption test by immersion ;
- A CONTROLAB press for the brick crushing test (Fig.5).
- A device for determining the thermal conduction coefficient, equipped with a heating plate, two calibrated thermometers and isolation (Fig.6).



a) Manual press



b) Moulded and ejected brick

**Figure 2:-** Manual press for making SEB bricks.



Figure 3:- Digital scale for weighing SEB bricks.



a) Oven for drying



b) Immersion tank

Figure 4:- Capillary water absorption test devices.



Figure 5:- Controlab press for the crushing test.



Figure 6:- Device for determining thermal conductivity.

### Methods:-

#### Water absorption by capillary action

The principle of testing, based on standard NBN-B-24-206(1997), consists of drying a test specimen in an oven at a temperature of  $105^{\circ}\text{C} \pm 5^{\circ}\text{C}$  until a constant mass  $m_1$  is obtained. The specimen is then immersed for 24 hours. Placed, in a container filled with water, on a horizontal plane such a way that the immersed side of the specimen is 5 mm below the water level. Let  $m_2$  be the mass of the specimen after immersion. The suction power of the water expressed in  $\text{g}/\text{cm}^2 \cdot \text{min}^{1/2}$  is characterised by the absorption coefficient  $C_b$  given by the following formula :

$$C_b = \frac{(m_2 - m_1) \cdot 100}{S\sqrt{10}} \quad (\text{I.1})$$

With  $C_b$ : coefficient of resistance to capillary rise ( $\text{g} \cdot \text{cm}^{-2} \cdot \text{min}^{-1/2}$ )

$m_2$  : mass of the specimen after immersion (g)

$m_1$ : mass of the specimen before immersion (g)

S: surface area of the immersed specimen ( $\text{cm}^2$ )

Thus, the bricks made of the mixtures M1, M3 and M4 with the three rates (8%, 10% and 15%) of cement were immersed for 24 hours after complete drying in the Oven.

#### 1) 2.3.2 Compression strength

The compressive strength test is carried out on three bricks of each mixture using a CONTROLAB hydraulic press (Fig.5) in accordance with standard NF P18-455(2003). This press, not being intended for crushing parallelepipedal bricks, has been provided with specific devices to adapt the machine to the test. These are two rectangular steel plates, occupying the entire surface to be crushed, which have been screwed, one on the mobile jaw in order to establish complete contact with the top of the brick to be tested and the other on the fixed jaw to support the entire base of the brick.

The compressive breaking load  $R_c(N)$  read on the dial of the CONTROLAB press and the area of application of the load  $S_c(\text{mm}^2)$  are used in the following formula (I.2) to calculate the compressive strength :

$$\sigma_c(\text{MPa}) = \frac{R_c}{S_c} \quad (\text{I.2})$$

#### Thermal conductivity

The method used for the determination of this property consists of measuring the temperatures on both sides of the brick submitted, one at the temperature imposed by a hot plate and the other in contact with the ambient temperature of the laboratory. The temperature of the heating plate and that of the free upper face of the brick are measured respectively with the calibrated thermometers of  $100^{\circ}\text{C}$  and  $250^{\circ}\text{C}$ . The  $250^{\circ}\text{C}$  thermometer is placed on the heating

plate and the other thermometer is in contact with the free upper side of the brick. The temperature of the side in contact with the heating plate is taken equal to the temperature of the heating plate.

The brick is surrounded by a wooden box to create isolation in order to limit heat loss through the sides of the brick and to guarantee the unidirectionality of the flow through the thickness of the brick. The test takes about 3 hours to reach steady state and temperature statements are taken every 30 minutes by reading the dials of the two thermometers. The difference between temperatures  $\Delta T$  ( $^{\circ}\text{K}$  or  $^{\circ}\text{C}$ ) in steady state will allow the determination of the thermal conductivity  $\lambda$  ( $\text{W}\cdot\text{m}^{-1}\cdot^{\circ}\text{K}^{-1}$ ) of the brick knowing its thickness  $e$  (m) and the electrical power of the heating plate (150 W) to be identified with the thermal power  $\Phi$  ( $\text{W}\cdot\text{m}^2$ ) while taking into account the area  $S$  ( $\text{m}^2$ ) of the brick in contact with the heating plate. For this purpose, it is sufficient to use the classic thermal formula :

$$\Phi = \lambda/e \cdot \Delta T \cdot S \quad (1.3)$$

Twelve test bricks are taken from the three mixtures (M1, M3 and M4), each containing 0%, 8%, 10% and 15% cement.

## Results and Discussions:-

### Mechanical characteristics of SEB bricks

Water absorption by capillary action

The results of the capillary water absorption tests, obtained by formula (I.1), are summarised in Table 2 below:

**Table 2:-** Variation of the water absorption coefficient by capillarity of SEB bricks according to the cement content.

Mixture	Coefficient of water absorption by capillarity ( $\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1/2}$ )		
	8% of cement	10% of cement	15% of cement
<b>M1</b>	51,53	32,37	16,89
<b>M3</b>	25,91	23,21	22,15
<b>M4</b>	32,16	25,79	24,17

It can be seen from table 2 that the rate of water absorption by capillarity decreases, for each type of SEB bricks, when the proportion of cement increases. The addition to the clay of the cement, made up of finer particles, reduces the pores in the bricks.

For M1 bricks containing more sand, the decrease is considerable - from  $51,53\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1/2}$  to  $16,89\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1/2}$  - due to the fact that these mixtures contained more pores in the unstabilized state. Their low plasticity gives better compaction results.

### Compressive strength

The compressive strength is calculated using formula (I.2) and the results obtained are carried forward in the following table.3 :

**Table 3:-** Compressive strength of SEB bricks after 28 days of consolidation.

Cement dosage	Compressive strength (MPa) after 28 days		
	M1	M3	M4
0%	1,57	2,02	2,58
8%	2,58	2,64	3,37
10%	4,61	3,82	3,82
15%	5,00	4,55	5,05

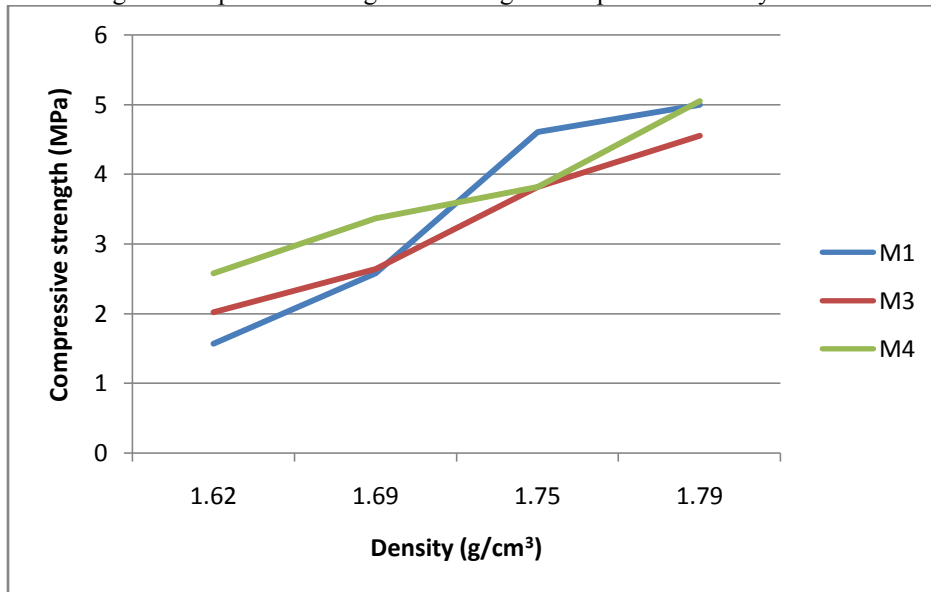
The compressive strengths of the bricks from the three mixtures increases with the cement content (Table 3). In fact, the addition of 8% to 10% of cement rapidly increases the compressive strengths of the brick, a growth that almost stabilises at around 15%. Increasing the proportion of cement increases the compressive strengths of a soil by creating rigid bridges between clay and sand particles (Cedric F, 2014).

By combining Table 3 of the compressive strengths of SEB bricks and Table 4 which groups the densities of these bricks, the graphs showing the variation of compressive strengths according to the density can be drawn (Fig.7) below.

**Table 4:-** Density of the SEB bricks studied.

Mixture M1		Mixture M3		Mixture M4	
Cement content	Density (g/cm <sup>3</sup> )	Cement content	Density (g/cm <sup>3</sup> )	Cement content	Density (g/cm <sup>3</sup> )
0%	1,52	0%	1,54	0%	1,62
8%	1,59	8%	1,59	8%	1,69
10%	1,73	10%	1,74	10%	1,75
15%	1,75	15%	1,76	15%	1,79

Figure 7 Shows the change in compressive strengths according to the specimen density.

**Figure 7:-** Variation of the compressive strength according to the density

As the increase of density indicates a decrease in porosity, therefore the sand and clay particles are tightened and firmly bound. This strong bond improves compressive strengths.

The convergence point (1,73 g.cm<sup>-3</sup> and 3,70 MPa) of the curves (Fig.7) is obtained with a cement dosage between 9% and 10%.

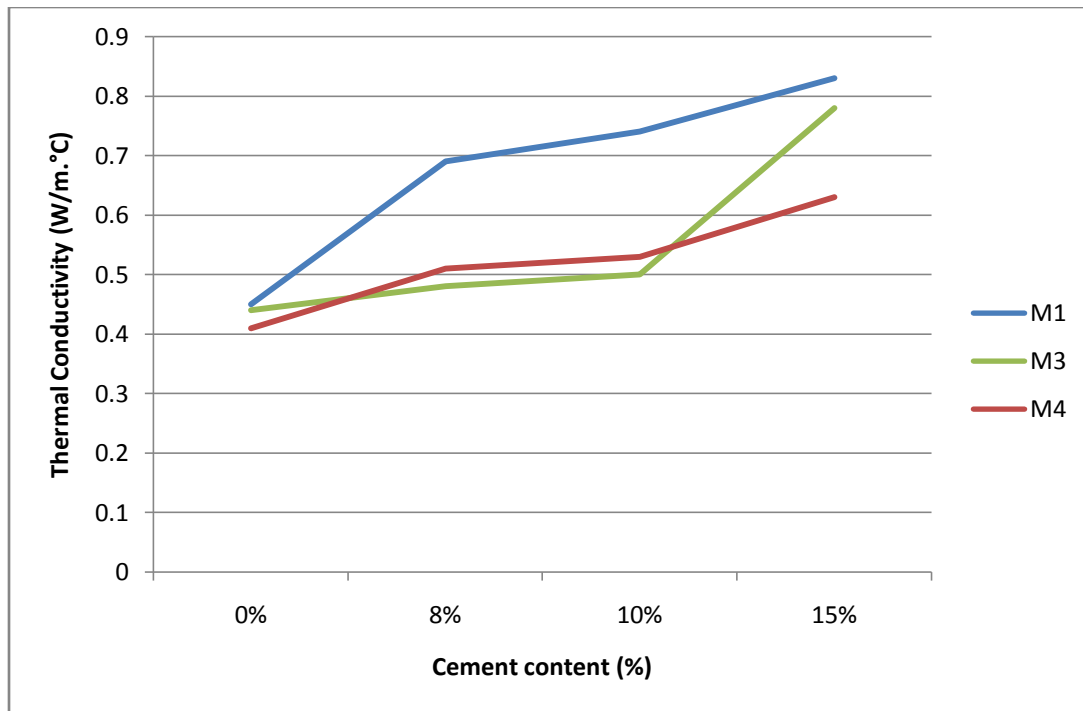
#### Thermal characteristics of BTS

The results of the determination of the thermal conductivity coefficients, obtained using formula (I.3), are summarised in Table 5.

**Table 5:-** Thermal conductivity coefficients of SEB bricks.

Mixture M1		Mixture M3		Mixture M4	
Cement content	Thermal conductivity (W.m <sup>-1</sup> .°K <sup>-1</sup> )	Cement content	Thermal conductivity (W.m <sup>-1</sup> .°K <sup>-1</sup> )	Cement content	Thermal conductivity (W.m <sup>-1</sup> .°K <sup>-1</sup> )
0%	0,45	0%	0,44	0%	0,41
8%	0,69	8%	0,48	8%	0,51
10%	0,74	10%	0,5	10%	0,53
15%	0,83	15%	0,78	15%	0,63

The transcription of this table into graphical form gave rise to Figure 8 below, which shows the evolution of the thermal conductivity coefficients of the SEB bricks according to the cement content.



**Figure 8:-** Variation of thermal conductivity according to cement content.

The reading of the three curves (Fig.8) shows the increase in thermal conductivity with the cement content. In fact, the pores initially occupied by air are now filled by cement grains with a relatively higher thermal conductivity than that of air. The thermal conductivities of bricks made with the M4 mixture are still much higher than those of other bricks. This is due to the fact that the high proportion of clay in the mixture has the ability to retain water for long time, even after 28 days of curing. The water, which is a heat carrier and trapped in the pores of this brick, is the basis of the high values of thermal conductivity, whatever the content of cement incorporated.

For bricks with M1 and M3 mixes with an addition of 10% cement, the thermal conductivity is approximately  $0.5 \text{ W.m}^{-1}.\text{K}^{-1}$ .

### Conclusion:-

The limitation of environmental degradation and the concept of sustainable development require the use of local materials that consume little energy and emit less greenhouse gases. Stabilised Earth Block (SEB) bricks, considered as local materials, have been made by mixing sand, clay in measured proportions (M1, M3 and M4) and adding a small amount of cement (8%, 10% and 15%). The essential thermomechanical characteristics of these bricks, i.e. water absorption capacity, compressive strengths and thermal conductivity were determined. This led to the choice of the brick with the M3 mixture with a cement content of 10%, as this is a reasonable level of an energetic material compared to its interesting characteristics (a density of  $1,7\text{g/cm}^3$ , a capillary water absorption coefficient of  $21,23 \text{ g.cm}^{-2}.\text{min}^{-1/2}$ , a compressive strength of 3,82 MPa and a conductivity of  $0,5\text{W.m}^{-1}.\text{°K}^{-1}$ ). Thus SEB bricks with mixture M3 and 10% cement, dense and with low capillary absorption ( $C_b < 40$ ), can be considered as an ideal compromise between relatively high cost, satisfactory compressive strength and low thermal conductivity for the construction of less energy-intensive eco-buildings.

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