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Effect of Argan Nut Shell Powder on Thermal and Mechanical Behavior of Compressed Earth Blocks

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Abstract

Improving the behavior of earthen construction materials is one of the subjects of concern to many researchers. Stabilization by organic elements is a solution to consider. This work consists at studying effect of adding organic load based on the powder of argan nut shell (PANS) on mechanical and thermal behavior of compressed earth blocks (CEB). Three load contents are tested; 2, 4 and 6% with a chemical stabilization by adding 5% of cement. Measurements include conductivity and thermal resistance, water absorption, tensile and compressive strength. The results show a considerable improvement in the physical and thermal properties of the loaded CEB and an increase of mechanical strengths in the presence of cement.

Keywords: Compressed Earth blocks; Powder of argan Nut Shells; Thermal properties, Mechanical strengths.

Abbreviations list:

CEB : Compressed Earth blocks
ANS : Argan Nut Shells
PANS : Powder of Argan Nut Shells
CEBW : Compressed Earth Blocks Without Cement
CEBC : Compressed Earth Blocks With Cement
Cb : Water Absorption Coefficient
Cs : Compressive strength
Ts : Tensile strength

INTRODUCTION

Throughout history, earth is one of the main used building materials [1] , Archaeological sites found around the world prove this fact [2] .Today, more than a third of the world's population still lives in earthen houses [3]. The various advantages of this raw material, namely availability, ease of execution and implementation, recycling, allow it to continuously play an important role as a building material.

In Morocco, earthen housing does not cease to exist. It inherited a vernacular tradition, and several techniques of construction are used, such as: rammed earth and adobe [4] .

In order to improve the behavior of this material and handle its weaknesses, mainly water sensitivity, resistance to cracks due to shrinkage..[5], our ancestors use stabilization techniques, notably mechanical stabilization by manual compaction, as in rammed earth, and physical stabilization by adding organic loads or fibers, such as straw in adobes. This latter solution has also some thermal advantages [6] .

Morocco has many organic elements coming from natural wastes of some agricultural products that should be explored. These organic wastes will have environmental benefits in case they are reused. They can also provide earth construction with technical solutions.

Argan nut shell (ANS) is an example to consider. This substance is released while extracting argan oil. The annual quantity of discards in Morocco is approximately 60 thousands of tons [7].

The objective of this work is to improve use of this natural discard in earth construction.

The works carried out up to date do not deal with this type of upgrading; the use of ANS is studied in other apects.

Ben Smail et al. and Bahraoui et al. [8] ,[9] used , for example, ANS as a reinforcement in polymer matrices to obtain bio-composites. Derouiche [7] used it for making composite wood.

The upgrading study conducted in this work is based on the technique of CEB. This is an evolution of the adobe technique. This mode of earth construction has emerged since the 50s of the last century [10], and it is brought to Morocco by French architects in the 80s [4].

The CEB technique makes it possible to obtain blocks by compressing the earth with a press [11], and consequently have high mechanical performances following the elimination of the voids by tightening the particles and increasing the density [5] .

Several blocks are made, and three milled PANS contents were tested: 2, 4 and 6% with chemical stabilization by adding CPJ 45 cement at a rate of 5% in relation to the mass of the block.

The studies carried out concern the measurement of thermal, physical and mechanical magnitudes, namely: conductivity and thermal resistance, capillary absorption, tensile and dry compressive strength.

MATERIALS AND METHODS:

a) Used materials :

i) Soil :

The soil used in the present study comes from the region of Agadir. It has been sieved to remove elements with a diameter greater than 20mm [12] . The granular composition of the soil (Figure 1) was determined through grain size analysis of fractions greater than 80 µm and by sedimentometry tests for smaller diameters . It can be noted that the grain size curve of the soil is well within the granular zone recommended by the XP-P 13-901 standard for compressed earth blocks.

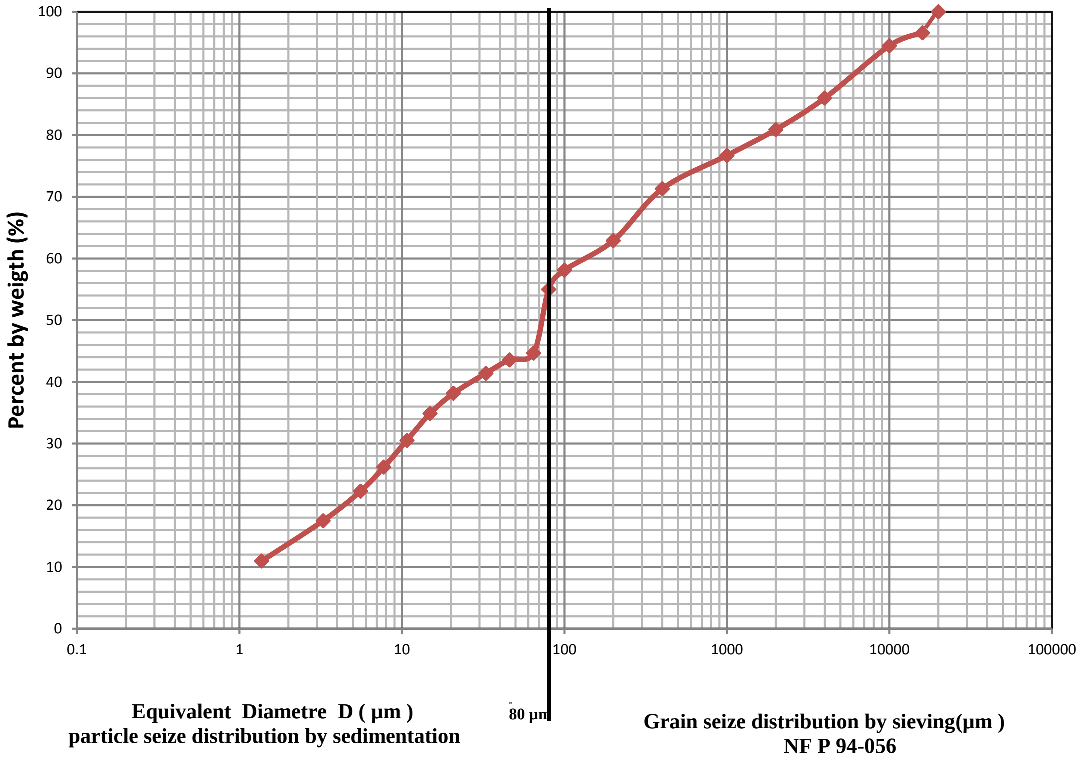

Figure 1: Grain size distribution of the tested soil.

The chemical composition of the soil produced by X-ray fluorescence (Table 1) shows that the soil contains only a few traces of sulphates which are harmful in case of cement stabilization [13] , whereas the amount of iron oxide is very important (35.34%) , as it can give a very favorable effect on stabilization even with small amounts of cement [1] .

The measured organic content is 0.320%, this rate does not exceed 2%, which represents the limit recommended by Doat and Venuat [1],[14] .

The physicochemical properties of the soil (Table 2) make it possible to conclude that the soil studied is very suitable for the construction of the CEB [12] .

Table 1 : Soil chemical composition (%).

Chemical components	%
MgO	0.39
Al2O3	12.68
SiO2	22.82
P2O5	0.98
K2O	7.97
CaO	17.28
TiO2	2.08
Fe2O3	34.35
ZrO2	0.36
Ag2O	1.10

Table 2: Soil physical and chemical characteristics

Apparent density (kg/m3)	1432
Specific density (kg/m3)	2410
Liquid Limit (LL)	32
Plastic Limit (PL)	19
Plasticity Index (PI)	13
Methylene Blue value	1.79
Classification of soil	A2

ii) Cement :

The chemical stabilization by adding cement enhance the mechanical properties of the CEB [15].

Indeed, according to Mesbah et al. [16], the hydraulic binder dosage used in CEB shall vary between 4 and 10% of the mass of the dry soil. Fetra et al. [17] stresses that for a cement dosage of more than 10% the CEB are no longer economic. Rigassi [18] confirms that it takes at least 5% cement to have satisfactory results.

For our study, we opted for a minimum cement dosage recommended for CEB, i.e. 5%.

The cement used is CPJ 45 from the Imi Mkour cement plant in the Agadir region. Determination of the chemical, physical and mechanical properties of the cement (Table 3 and Table 4) shows that it complies with the NM 10.1.004 standard.

Table 3: Cement chemical composition

paf	12.61
MgO	1.13
SO3	2.76
Na2O	0.11
K2O	1.27
Cl^-	0.01
Insoluble résidue in HCl	2.59

Table 4: Cement physical and mechanical characteristics

Density (g/cm^3)	3.04
Setting time(min)	135
blaine specific surface (cm^2/g)	4450
Expansion of heat (mm)	1.0
Rc2 (mpa)	20
Rc7 (mpa)	29
Rc28 (mpa)	38

iii) Powder of Argan Nut Shells (PANS):

The powder of the argan nut shell (PANS) is obtained by crushing the shells of argan (Figure 2). This operation is carried out by using a knife mill type RETSCH SM 100. The powder has undergone a sieving operation to get particles with a controlled particle size (Figure 3). The physical characteristics of the powder are recorded in Table 5.

Figure 2: Crushing and sieving of PANS

Table 5: Physical characteristics of PFANS

Item	Value
Natural water content (%)	5.43
Absolute density (g/cm 3)	1.04
Apparent density (g/cm^3)	0.74
Absorption after 24h under water (%)	26.3

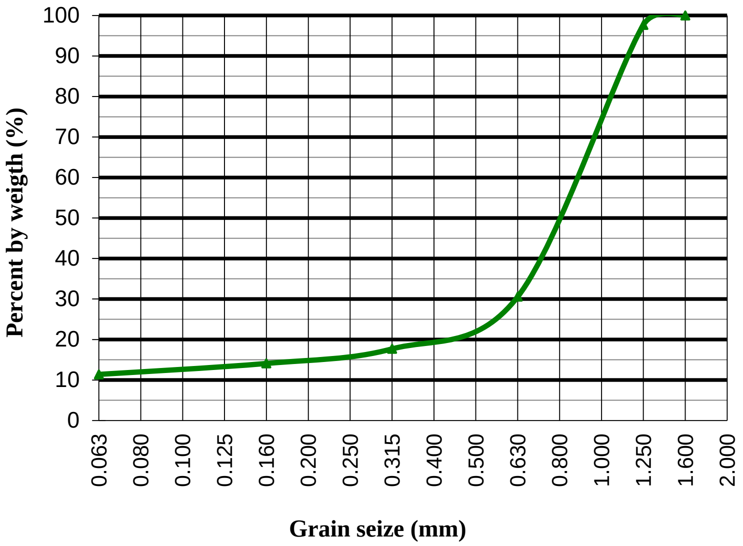

Figure 3: Grain size distribution of the Powder from the Argan Nut shells

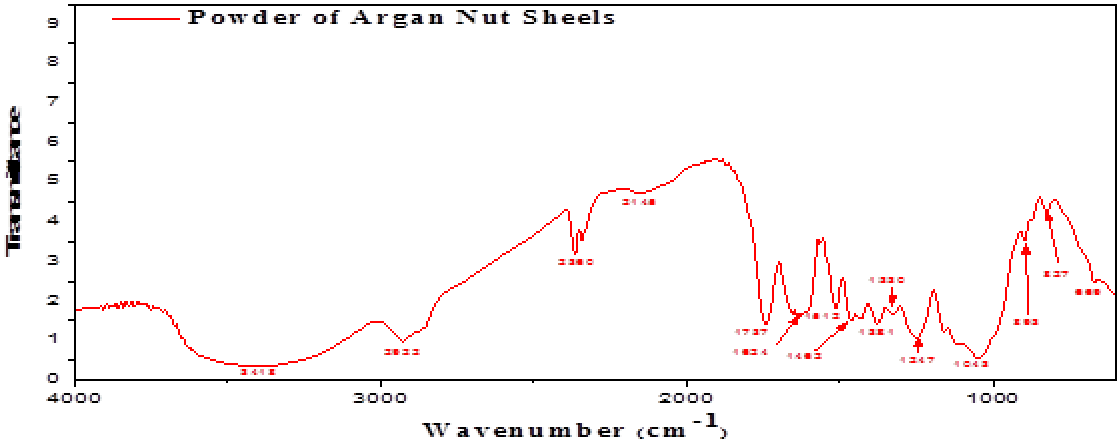

Figure 4: FTIR Spectra of PFANS

The main chemical components of PANS are determined by infrared spectroscopy (Figure 4). We note that the spectrum of the particles has absorption bands of grouping lignocellulosic characteristics composed of: cellulose, hemicellulose and the main bands concerned are 1732, 1512, 1422, 1371, 1273, 1028, 804 and 667cm-1. This composition was also confirmed by Essabir [19] who mentioned that the argan shell is composed of 25% Cellulose, 34.3% Hemicelluloses and 34.5% Lignin.

b) Manufacturing of CEB :

To study the impact of adding organic load and the cement on the thermal and mechanical behavior of the CEB, several mixtures were made (Table 6).

Table 6: Compositions of manufactured CEB

Ref	Number of samples	PFANS (%)	Cement (%)	Drying time (days)
R1	9	0	0	14
R2	6	2	0	14
R3	6	4	0	14
R4	6	6	0	14
R5	9	0	5	28
R6	9	2	5	28
R7	9	4	5	28
R8	9	6	5	28

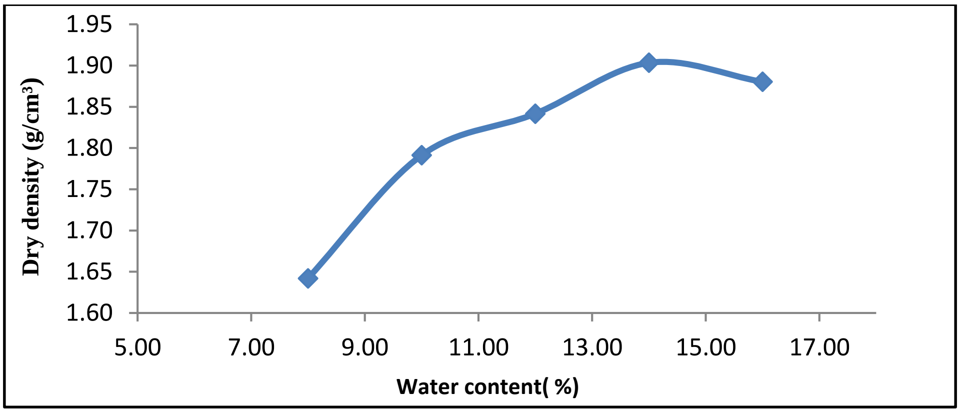

Figure 5: Optimum water content for the reference mixture

The optimum water content of the reference mixture (R1) is determined by drawing the dry density versus moisture content curve (Figure 5). The value obtained is equal to 14%.

For the other mixtures, readjusting water content is carried out according to the case studied.

Mixing is carried out manually. The static compaction is applied by hand press (Figure 6). This consists of a mold dimension: lxLxe = 14mmx29.5mm xe mm (= variable).It generates a compacting force of 2 MPA order [20] , [21] . The blocks, once made, are kept in the laboratory at a temperature of 20 ± 2 ° C during the cure period (Table 6). To prevent quick drying out, the blocks stabilized with cement are covered with a plastic waterproof film for the first 14 days. Before testing the blocks, they are put in oven at 40± 5°C until a constant mass to eliminate excess moisture.

Figure 6: Press for CEB fabrication

c) Tests conducted :

i) Thermal tests :

(1) Thermal conductivity measurement:

Thermal conductivity of the studied blocks is measured using "FP2C" apparatus (Figure 7). It is an electronic acquisition device for measuring the thermo-physical properties of materials.

The measurement of the thermal conductivity is performed by connecting this device to a hot wire probe.

The hot wire method [22] allows to estimate the thermal conductivity of a material from evolution of measured temperature by a thermocouple placed in the vicinity of a resistive wire.

The wire is considered infinitely long. It produces conductive radial heat transfer at the center of the sample. The sample is of infinite dimensions and its thermo-physical properties are considered constant.

Figure 7: Experimental device F2PC

(2) Thermal resistance calculation :

Thermal resistance is used to quantify the insulating properties of materials for a given thickness.

For the blocks studied, this quantity was determined from the following relation:

$$R_{th} = \frac{e}{\lambda} \qquad (5)$$

where :

e : Thickness of the material, expressed in m.

λ :Thermal conductivity of the material, expressed in W/m.K.

(3) Thermal conductivity measurement of PANS and soil :

The measurements of the intrinsic thermal conductivities of PCA and soil are carried out using a device type Hot disk TPS 2500 S. This apparatus is composed of an acquisition unit connected to a Kapton probe. The measurement technique of this device is widely described in [23].

Before testing, both materials were dried in an oven at 105 °C. To measure the thermal conductivity, each sample was put into a metal container, wherein the probe was introduced (Figure 8). For each test, the measurement was repeated three times and the average value was calculated (Table 7).

Figure 8: Measurement of thermal conductivity of PANS and soil

	Thermal conductivity of PANS (W/m.K)	Thermal conductivity of soil (W/m.K)
measurement n°1	0.1565	0.3053
measurement n°2	0.1570	0.3011
measurement n°3	0.1545	0.3002
average values	0.156	0.3022

ii) Physical and mechanical tests :

(1) Dry compressive strength :

This test is carried out according to the standard of compressed clay blocks [12]. It consists of subjecting the two half-blocks of the studied sample bonded by a mortar to a simple compression test (Figure 9).

The value of the compressive strength is given by the following formula:

$$R_c = \frac{10 * F}{S} \qquad (6)$$

Or :

R_c : Compressive strength (MPA).

F : Maximum charge supported by both half-blocks (KN).

S : Average surface area of test faces (cm^2)

Figure 9: Compressive strength test

(2) Tensile test :

This test is derived from the splitting tensile test (Brazilian test) [24]. It consists of compressing the block along two rods put on either side of a block. This results in a tensile stress following a vertical facet between these two rods (Figure 10).

The splitting tensile strength of the blocks is given by the following formula[24]:

$$R_t = 0.9 * 10 * \frac{2 * F}{\pi * l * h} \qquad (7)$$

Or :

Rt: Tensile strength (MPA).

F : Maximum charge supported by both half-blocks (KN).

l : Block width (cm).

h: Block thickness (cm).

Figure 10 : Splitting tensile test

(3) Capillary absorption:

The CEB concerned by this test are those stabilized by cement.

The objective of this test is to measure the ability of blocks to absorb water by capillarity. It is made according to the standard XP 13-901 [12]. The idea is to immerse the facing surface in a thin layer of water (5 mm) for 10 min and observe the mass uptake of block during this test .

The water absorption coefficient of each block is expressed by:

$$Cb = \frac{100M}{S\sqrt{t}} = \frac{100(P_1 - P_0)}{S\sqrt{10}} \qquad (8)$$

M : Mass of water absorbed per block during the test (g)

S : Surface of the immersed face (cm²)

t : Immersion time of the block (min)

Figure 11 : Capillary absorption test

2) RESULTS AND DISCUSSION:

a) Thermal conductivity:

This property reflects the ability of the material to transfer heat. The lower the conductivity of the material, the more insulating it gets.

The Figure 12 shows that for CEBW the thermal conductivity is 0.865 W / m.K at 0% of loads and it reaches 0.745 W / m.K for 6% of loads; a decrease of the order by 13.8%.

For the CEBC, these values go from 0.635 W / m.K to 0.481 W / m.K between 0% and 6% of loads; i.e. a decrease of approximately 24.2%.

For both types of blocks, a decrease in the thermal conductivity according to the content loads is observed . This can be explained by the low thermal conductivity of the PANS compared to that of the clay matrix (Table 7).

The presence of cement in the BTCAC causes a decrease in their thermal conductivities. This may be due to a drop in the mixture maneuverability found when making blocks. This prevents a good distribution of the earth in the mold , therefore a good compaction to reduce the pores.

Increasing the porosity means more air inside the samples leading to a decrease in thermal conductivity [25].

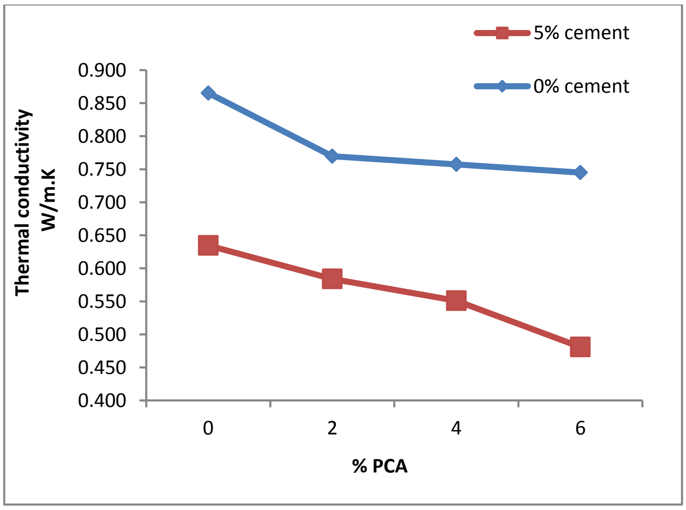

Figure 12 : Evolution of the thermal conductivity according to the PANS content

We can also establish a relationship between the densities of the CEB and their thermal conductivities. Figures 13 and 14 show thermal conductivity decreases as density for the two types of blocks studied goes down.

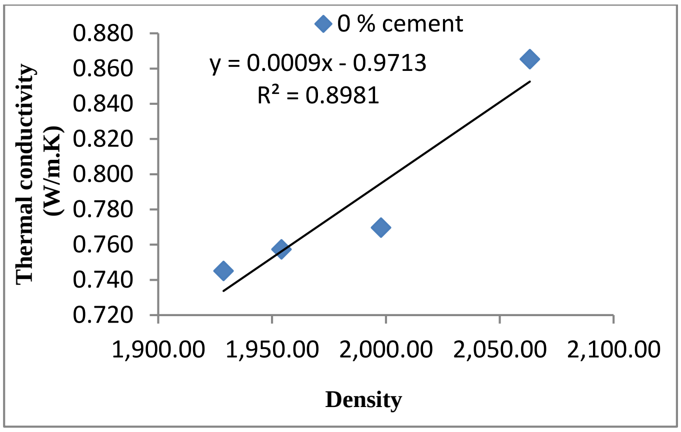

Figure 13 : Evolution of thermal conductivity according to CEBW density

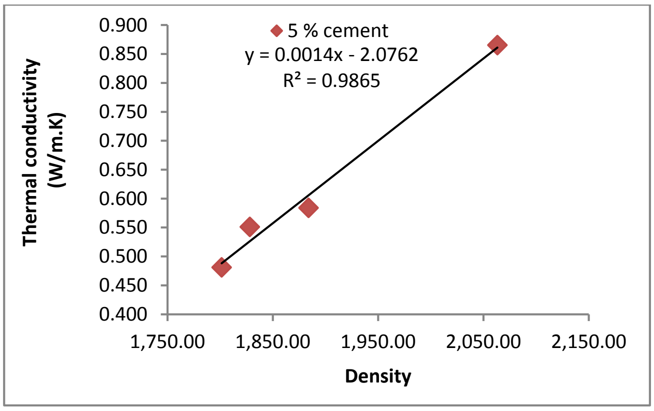

Figure 14 : Evolution of thermal conductivity according to CEBC density

These results comply with those of Taallah and Binici [15], [26] . They find out that thermal conductivity of the CEB decreases by fiber addition, and that a strong correlation can be found between their densities and thermal conductivities.

b) Thermal resistance :

Thermal resistance is used to quantify the insulating performance of materials. A wall is the more insulating as its thermal resistance is high.

According to Diatta et al. [27] a material is considered as insulating if its thermal resistance is at least

5 m².K / W.

Figure 15 shows that adding PANS improves the thermal insulation of blocks studied. The thermal resistance of the CEBW increased from 11.79 m².K / W to 13.02 m².K / W for a content of loads ranging between 0 and 6%; an improvement of 10.4%.

For the same load values, this resistance goes from 15.6 m².K / W to 20.17 m².K / W for the BTCAC; a thermal improvement of 29%.

The increase of the thermal resistance of the blocks is explained by the decrease of their thermal conductivities (Figure 12), because those two parameters are inversely proportional.

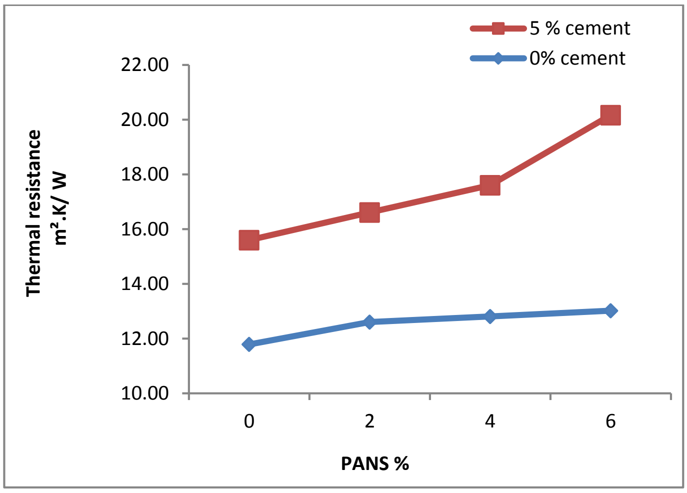

Figure 15 : Evolution of thermal resistance according to density

c) Tensile strength :

The tensile strengths of CEBW slightly decrease according to content load (Figure 16). These resistances go from 0.75 MPA to 0.65 MPA for load contents ranging from 0% to 6%.

For the CEBC, the tensile strengths have improved. They range from 0.9 MPA to 0.68 MPA with the same load levels.

This can be explained by low adhesion between the matrix of CEB and the particles of the argan nut shell as their diameters, greater than 0.063mm, represent more than 90% and the ease with which cracks can propagate under tensile strength [28] .

The slight increase in resistance of CEBC comes from the creation of some rigid links connecting the soil particles that are formed in the presence of cement.[29].

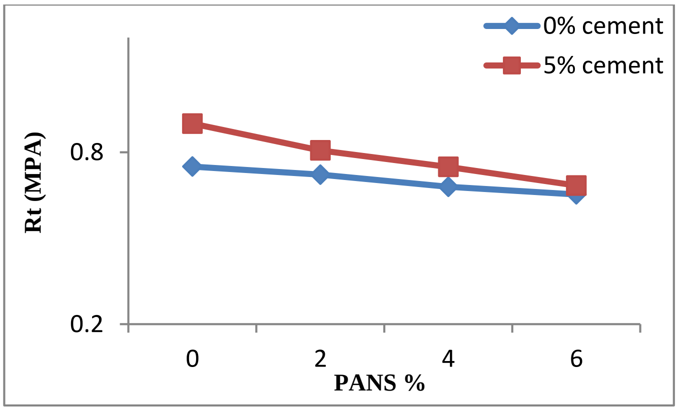

Figure 16 :Tensile strength of CEB according to PANS

d) Dry compressive strength :

Dry compressive strength of non-stabilized cement blocks decrease according to the load content (Figure 17) while remaining above the required minimum compressive strength of 1 Mpa as stated by Mansour et al. [30]. It goes from 2.21 MPA to 1.89 MPA.

This is due to a decrease in binding forces between the granular network, formed by the PANS, and the clay binder.

These results comply with those of khedari et al. [6]. They concluded that the increase in fiber content results in a decrease in the binding force of the specimens, leading to a lower compressive strength.

In the presence of cement, the dry compressive strength increases to an optimum value equal to 3.12 MPA, corresponding to a PANS content of 2%, then it decreases for higher load levels to reach 1.85 MPA at 6% load.

This is due to the fact that 2% is the optimal quantity of loads which allows a good adhesion with the matrix of blocks to a cement content equal to 5%, and that for values of loads higher than this optimum, the content of cement that can bind natural aggregates becomes insufficient.

These results comply with those of Taallah et al. [31]. They find out that for cement quantities of the order of 5%, the decrease in the compressive strength can be attributed to the predominance of the effect of the loads on this content because the quantity of hydration products is low compared to the importance of the voids created in the mixture.

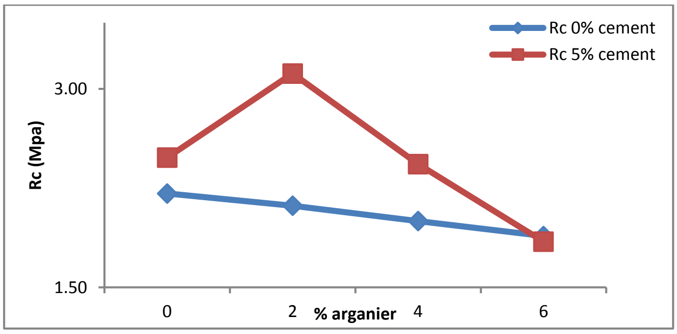

Figure 17 : Dry compressive strength of CEB according to PANS

e) Absorption by capillarity :

The Figure 18 shows that the water absorption coefficient (Cb) of the CEB decreases by adding the PCA. It goes from 16.92% for unloaded blocks to 10.1% for a content of loads equal to 6%.

These values are lower than the minimum threshold fixed by XP 13-901 standard [12] for weakly capillary classified blocks, which is 20%.

The decrease in Cb values is justified by the non-absorbing nature of embedded PANS (Absorption = 26.3%), compared for example with other plant particles mentioned in [32] and whose absorption exceeds 50%.

Being aware of the coefficient Cb gives possibly an idea of the mechanical performances of the CEB, because according to Kerali [33], the less the water absorption of a block, the better is its mechanical performances becomes.

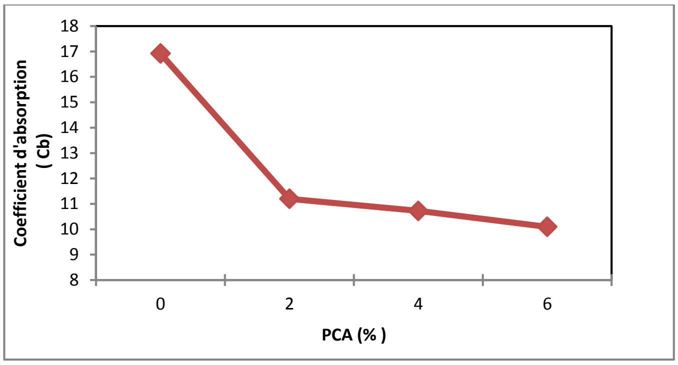

Figure 18 : Variation of Cb according to PCA content

CONCLUSION:

In this article, we have studied the impact of organic load based on argan null shells powder and cement on thermal and mechanical behavior of the CEB. The results allow us to conclude that:

- Adding load helps to considerably improve thermal insulation of the blocks; the more they are loaded, the more their thermal conductivities decrease and their thermal resistances improve;
- A strong correlation can be made between the density of blocks and their thermal conductivities; the less dense blocks are the most thermally insulating they become;
- The tensile strength of CEB decreases slightly according to the loads content due to the low adhesion between argan particles and clay matrix;
- With a cement stabilization of 5%, the optimum load content to achieve the maximum dry compressive strength is 2%;
- PANS embedding may reduce the capillary absorption capacity of the blocks studied.

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