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RESEARCH ARTICLE

HYGROSCOPIC CHARACTERIZATION OF EARTH BRICKS MADE FROM LATERITE AND CLAY OF SENEGAL

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Abstract

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Earth is the main raw material most used in building construction in Africa and particularly in Senegal. It is a particularly malleable material, easy to handle, from which hard bricks (unfired or fired) can be made. Thus for a good prediction of the mechanical and thermal behavior of a material, it is important to determine its hygroscopic properties. This is why our study focuses on the hygroscopic characterization of earth materials based on laterite and clay. We are mainly interested in the study of adsorption and desorption isotherms by water vapor. The adsorption and desorption isotherm curves of the samples were determined by a volumetric method using the "Belsorp Aqua3" apparatus. The measurement results showed that the earth materials are hygroscopic materials. Furthermore, unfired earth materials adsorb more moisture than fired earth materials.

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Introduction:-

The building is an object of concern in terms of health, energy consumption and environmental impacts.

With more than 40 % of the world's energy consumption and high CO_2 emissions, the building industry is one of the most energy-intensive sectors. In fact, since the beginning of the 1990, the building sector has been one of the biggest emitters of greenhouse gases, leading to major economic and environmental challenges in the world [1].

The impact of buildings on the environment is so great that construction techniques have been evolving significantly for several years.

Several solutions have been implemented to reduce the impact of buildings on energy consumption and, more generally, on the environment. They include the use of materials that have little impact on the environment and are more efficient from a thermal point of view.

Used for a long time as a natural building material next to wood, earth is a material that seems to meet all the above requirements due to its low environmental impact and its interesting hygroscopic properties [2].

In advanced economies, earthen construction was abandoned in favor of concrete for several decades after the Second World War [2]. Concrete, the most widely used material in Senegal today, is unsuitable for the climatic

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conditions of Sahelian countries. In addition, cement production consumes a lot of energy and is a source of greenhouse gas emissions.

This is why today the earth has become attractive again. The advantages of this material with respect to the new requirements described above are clear: the resource is available in large quantities, the energy required to extract, transform and produce earth materials is low and it is a completely recyclable material (in the case of earth bricks that are not chemically stabilized). In addition to these advantages, the main interest of this material lies in the high thermal inertia that can be obtained, which could improve the comfort of the occupants [3].

Although there are many studies on the mechanical properties of earth materials, there are few scientific studies on the hygroscopic properties of these materials.

Researchers have studied the thermal and hygroscopic properties of unfired earth materials based on laterite. Among them is the work of Meukam et al. [4] on the characterization of local materials used in the thermal insulation of buildings. They showed that laterite bricks incorporating natural pozzolan or sawdust have better thermal insulation than simple laterite bricks. Bal et al. [5] studied the valorization of local building materials in Senegal with a view to improving their performance in terms of thermal insulation. They used a mixture of laterite and millet pods. The results showed that the gradual addition of millet pods to laterite significantly decreased the thermal conductivity of the final composite material.

Sindanne et al. [6] studied laterite blocks stabilized with cement, sawdust and lime. The evolution of the thermal properties of the earth blocks as a function of the stabilizer rates and their nature was discussed. The results indicate that the thermal conductivity increases when the percentage of cement and lime increases. However, it decreases when the percentage of sawdust increases. Houngan et al. [7] conducted a study on laterite bricks stabilized with cement. These laterite bricks are stabilized with 20 % cement. The sorption isotherms of the samples were determined. The samples used are of dimensions 20 x 20 x 5 mm^3. The samples are introduced into a chamber with controlled climatic conditions (temperature, relative humidity) using an electronic balance with magnetic suspension of 80 g capacity, with a resolution of 10^{-5} g and can work up to 250 °C. The relative humidity of the chamber is varied from 0 % to 90 % at two temperature levels of 30 °C and 50 °C. The results and interpretations of the sorption isotherms revealed a sorption hysteresis whose loop decreases with increasing temperature. Abhilash et al. [8] worked on laterite bricks. The hydric properties of these bricks were determined. For sorption isotherm measurement, the samples are dried in an oven at 105 °C and then placed successively in the relative humidity levels of 23 %, 43 %, 59 %, 75 %, 85 % and 97 % at a temperature of 20 °C. For desorption, the samples are humidified at 97 % relative humidity and are placed at different humidity levels. The buffer humidity is measured by placing the sample for 8 h at 75% relative humidity and then for 16 h at 33% relative humidity at a temperature of 23 °C. The results show that laterite bricks have strong hygroscopic characteristics with a buffer humidity of 2.8 g/ (m^2.%RH).

Touré[9] studied the mechanical, thermal and hygroscopic characterization of laterite brick compressed and stabilized with cement at the material scale. The bricks used in this study were obtained from eight different brickyards. The results showed that the compressive strength of the sampled bricks taken vary from 1.7 MPa to 3.3 MPa. Thermal characterization shows that these bricks have a thermal conductivity ranging from 0.66 $W.m^{-1}.K^{-1}$ to 0.85 $W.m^{-1}.K^{-1}$. The thermal effusivity varies from 1159 $W.s^{1/2}.m^{-2}.K^{-1}$ to 1354 $W.s^{1/2}.m^{-2}.K^{-1}$. From the hygroscopic point of view, earth bricks have a low resistance to water vapour and a good capacity of regulation of indoor humidity.

Other researchers have been interested in the mechanical, thermal and hygroscopic properties of unfired earth materials clay-based.

Champiré et al. [10] studied three different clay soils named STR, CRA and ALX. The clay content is equal to 15 % for STR, 16 % for CRA and 8 % for ALX. The bricks (cylindrical) are manufactured with different water contents (7 %, 9 %, 11 %, 13 % and 15 %) at different material quantities (from 8.6 kg to 9.2 kg with an increase in steps of 2kg). They are compacted using a manual press. The impact of relative humidity on the mechanical behavior of the compressed earth bricks was studied. The samples were dried at 50 °C before being placed in a chamber with a temperature of 24 °C and conditioned at three different relative humidities 25 %, 75 % and 95 %. The results obtained show that the compressive strength decreases with relative humidity whatever the earth (STR, ALX or CRA).

Mounir et al. [11] studied a clay-cork composite material. They tried to improve the thermal properties of clay by combining it with cork. The authors showed that the thermal conductivity of clay decreases with the addition of cork. Abdessalam[12] studied the mechanical and thermal properties of earth bricks (clay). In his study, he mixed clay, dune sand and date palm fibers. He varied the percentage of sand from 0 % to 40 % and the percentage of fiber from 0% to 3 % by mass. The results showed that the increase in % of sand or fiber is beneficial for improving thermal properties with acceptable mechanical strengths.

Sutcu[13] studied the influence of expanded vermiculite on the physical, mechanical and thermal properties of clay bricks. The author found that the use of 10 % by weight of expanded vermiculite reduces the density of the samples from 1.76 g / cm^3 to 1.34 g / cm^3. It was observed that the porosity rate is improved with the increase of vermiculite, while the compressive strength decreased. The thermal conductivity of porous samples with 10 % vermiculite decreased from 0.96 W/m.K to 0.65 W/m.K. The author showed that the brick samples produced by addition of vermiculite can be used as insulating material in construction.

Maillard et al. [14] studied the effect of anisotropy on the hygrothermal properties of extruded earth (clay) brick. They were interested in the thermal conductivity and water vapour permeability by placing the brick in the direction parallel and perpendicular in relation to the extrusion direction. The authors showed that the extrusion process has a major influence on the orientation of the clay layers and has an impact on the hygrothermal properties.

Cagnon et al. [2] studied the hygrothermal properties of five extruded earth bricks produced in five brickyards in the vicinity of Toulouse, France. The hygrothermal properties studied were vapour sorption isotherms, water vapour permeability, heat capacity, moisture-dependent thermal conductivity and effusivity. Mineralogical characterization of the five mud bricks showed differences in the nature of the clay: the clay minerals contained in bricks 1-4 were montmorillonite, chlorite, and illite while the only clay mineral contained in brick 5 was kaolinite. Despite this difference, the hygrothermal characteristics measured were very similar in the five bricks and often close to the few data existing in the literature on earth materials.

The measurement results showed that the hygrothermal properties of the five earth bricks confirmed their ability to regulate the relative humidity of the indoor air.

However, several researchers have been interested in studying the physical, mechanical and thermal properties of fired earth materials based clay.

Boumhaout et al. [15] carried out an experimental study to determine the thermal conductivity of fired earth (clay) brick using two different measurement methods: the box method and the hot wire method. The thermal conductivity of the fired clay brick obtained by the box method is about 0.60 W/m.K while that given by the hot wire method is 0.52 W/m.K.

Russ et al. [16] studied the effect of incorporating spent grain into fired clay bricks. The clay used in the production of factory brick was mixed with the spent grain. The aim of their work was to test the physical and mechanical properties of earth bricks produced with the addition of spent grain. Clay bricks produced with spent grain have superior strength, high porosity and reduced density compared to those of unfired clay brick. The results of the experiment show the relevance of using spent grain to increase the porosity of bricks. This results in better thermal insulation properties of the bricks.

Demir[17] studied the effect of the addition of organic residues on the thermal properties of fired earth bricks. He mixed clay with sawdust, tobacco and grass residues. He reports that the addition of 5% organic residues improves the thermal insulation properties in buildings.

Sutcu et al. [18] studied the physical, thermal and mechanical properties of fired clay bricks with the addition of marble waste powder as building materials. The authors showed that marble powder can be used at certain ratios to lighten and make porous the body in the production of fired clay bricks. Therefore, these bricks produced with addition of marble waste can be used as building material for thermal insulation.

Bodian et al. [19] determined the physical, mechanical, and thermal properties of unfired earth and fired earth bricks made from a mixture of clay and laterite. Experiments were conducted with five clay bricks compositions prepared by adding laterite (between 10 % and 50 % by weight). Test results showed that the clay brick containing 30 % laterite had the best compressive strength and thermal conductivity compared to the other bricks.

The works presented above show that some authors have focused on laterite while others have worked on clay. Few authors, however, have been interested in the hygroscopic properties of the clay-laterite mixture.

This is why in this paper we are mainly interested in the study of water vapour adsorption and desorption isotherms but also in the water vapour permeability of earthen materials made from a mixture of clay and laterite.

Experimental method:-

Methods of hygroscopic characterization of building materials:-

The fixing of relative humidity affects the mechanical and thermal properties of the material. In this paper, an experimental campaign is undertaken with the aim to identify and determine the hydric properties of the materials studied.

Measurement of sorption-desorption isotherms

The water activity in a product depends mainly on its water content and its temperature. The curve, representing for a given temperature, the variation of the water content in function of the relative humidity of the medium at equilibrium is called:

- Adsorption isotherm if the material is placed in increasing humidities. In this case, the water content of this material increases;
- Desorption isotherm if the surrounding relative humidity decreases and the water content of the material also decreases.

The water vapour adsorption and desorption isotherm curve constitutes a hydric identity card of the material [20].

The contact of a porous material with the ambient air generates an exchange of humidity between the two media. Indeed, an increase in the relative humidity of the air at the surface of the material causes an increase in its apparent mass. This increase in mass is due to the phenomenon of physical adsorption. Reciprocally, a decrease in the relative humidity of the surrounding air causes a loss of apparent mass, due to the phenomenon of desorption.

These two phenomena of adsorption and desorption of water are represented by the associated curves which translate the evolution of the water content of a material according to the value of the relative humidity of the air in equilibrium at a constant temperature.

The adsorption isotherm is determined experimentally. According to the shape of the adsorption isotherm curve, a classification has been proposed by the International Union of Pure and Applied Chemistry (IUPAC) according to the type of porosity and the nature of the interaction [1].

The interpretation of an experimental isotherm is done by breaking it down into several portions as a function of typical isotherms.

There are several techniques and devices for measuring water vapour adsorption and desorption isotherms. These devices can be classified according to the technique of determination of the water content, in two categories: gravimetric and volumetric methods.

Dynamic and gravimetric methods

Gravimetric methods are the most widely used for characterization with respect to storage and hygroscopic transfers in porous building materials.They are based on the monitoring of the mass versus time for different humidity states of the sample to be characterized.

Method using saturated salt solutions

This is the determination of the water content of the sample as a function of the relative humidity of the ambient air. The method consists of placing samples in hermetically sealed containers containing saturated salt solutions.

For each relative humidity level, the mass of the sample is monitored over time by regular weighing until hydric equilibrium is reached, defined by the constancy of the mass. A point of the adsorption isotherm is thus obtained. The complete sorption-desorption isotherm curve is obtained by repeating the same experiment for different humidity levels ranging from 0 % to 100 % for sorption and from 100 % to 0 % for desorption. The equilibrium time can vary, depending on the materials tested, from one month to more than 2 years. The role of the saturated salt solution is to regulate naturally and with great precision the relative humidity of the air inside the tanks.

Faced with the slowness of the traditional gravimetric method based on the use of salt solutions [ISO -12571, 2000] [21], several devices for the measurement of sorption-desorption isotherms make it possible to reduce the test time. Among these, we can mention the DVS (Dynamic Vapour Sorption) and the VSA (Vapour Sorption Analyzer).

Dynamic Vapour Sorption method (DVS)

The DVS (Figure 1) consists primarily of a calibrated pod that carries the sample of a few grams. The pod is connected to a precision balance at 0.1 μg. The relative humidity inside the incubator is generated by enriching dry air with water vapour until the set relative humidity is reached.

This device allows to make measurements on low mass samples. The adsorbed mass is then even lower and the time necessary to reach the equilibrium is shorter. The protocol adopted consists in grinding samples and conditioning them in an oven at 45 °C for a minimum of 15 days. The grinding allows to take samples of masses of the order of the milligram. Also, drying allows to accelerate even more the test by positioning itself as close as possible to the dry state. For each humidity level, an automatic acquisition of the mass of the samples is carried out until the equilibrium is reached, which is adopted by the criterion $dm / m_{sèche} \leq 5 x 10^{-6} (\%)$. Where, the dm is the mass difference corresponding to a time difference between two successive measurements [22].

Figure 1:- Device for measuring sorption isotherms by DVS (Dynamic Vapour Sorption) [22].

Vapour Sorption Analyzer method (VSA)

The VSA (Figure 2) is a device for measuring sorption-desorption isotherms similar to the DVS. It uses globally the same principle as the DVS with the specificity of a larger sample size (cylinder of 40 mm diameter and 6 mm thickness). Nevertheless, its balance isless sensitive (± 0.1 mg).

Figure 2:- Device for measuring isotherms according to the VSA (Vapour Sorption Analyzer) (DECAGON-Aqualab-USA) [1].

Volumetric method (BELSORP -aqua3)

Like dynamic methods, volumetric methods also make it possible to considerably reduce the measurement time of the sorption-desorption isotherms of materials, while working with very small samples combined with dynamic vapour flow. BELSORP-aqua3 (Figure 3) is one of the equipments that use the volumetric theory for the measurement of sorption-desorption isotherms. The adsorption rate relative to pressure can be obtained experimentally.

The measurement process consists in defining a quantity of gas adsorbed by the sample by using the mole number of the gas. The initial volume is filled with an initial mole number given by the law of perfect gases. After the expansion of the gas in the cell containing the sample, the latter starts to adsorb a part of the gas up to a given equilibrium point. The number of moles remaining in the gas phase is then calculated knowing the low pressure in the system [23].

It is important to note that the use of the BELSORP-aqua3 device allows a significant reduction in the total duration of the test (one to two weeks on average) compared to the classical gravimetric method using saturated salt solutions, which lasts on average 2 years for a 5 mm thick concrete material [22][23]. On the other hand, the size of the samples presents a disadvantage. Indeed, the quantity of the tested sample is of the order of one mg which is not always representative, particularly for heterogeneous materials like concrete.

To check the reproducibility of the results, the instrument is equipped with three sample holders.

Figure 3:- Belsorp-aqua3 [1].

Water vapour permeability

Water vapour permeability is an essential property in the hydric characterization of building materials. It provides informations about the diffusion of water vapour in a material.

In terms of analyzing hydric behavior, water vapour permeability is the most measured property for building wall materials. The water vapour permeability coefficient of a material allows to characterize its "sealing/leakage" properties. It represents the quantity of vapour transmitted through a surface per unit of time, pressure and thickness. This property depends on the nature of the material and its hydric state.

The water vapour permeability coefficient is determined by the cup method using the standard [NF EN ISO 12572] [24]. It consists in creating a vapour pressure gradient between the two compartments upstream and downstream of the sample (Figure 4), this gradient is ensured by the application of two different hygrometries (93 % inside the cup, 50 % outside) for a uniform temperature of 23 ° C.

The principle of the method consists in imposing, at a constant temperature, a fixed gradient of water vapour pressure between two faces of a sample. In order to ensure a good analysis of the results obtained, the one-dimensional character of the physical phenomenon is privileged by the choice of cylindrical and axisymmetric specimens. The specimen is placed in a cup, the sealing, between the walls of the cup and the material, is ensured with a silicone gel. The interior atmosphere of the cup is regulated with a salt solution. The whole is placed in a climatic chamber controlled in terms of temperature and humidity. Afterwards, the mass is monitored until the equilibrium state is reached, characterized by the constancy of the mass.

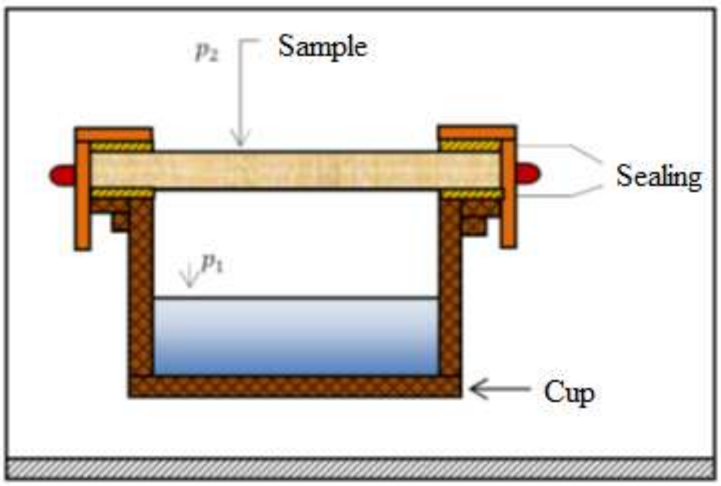

Figure 4:- Representative diagram of a cup.

In the present work, the GINTRONIC GraviTest device (Figure 5) is used for the determination of water vapour permeability based on the cup principle. The advantage of this device is the automation of the test, especially for mass monitoring. The device, with a capacity of six cups, allows to test several samples at the same time. In order to check the accuracy of the balance during the test, it is preferable to limit the number of samples to five and keep a control cup. All the cups are placed in a climate chamber regulated in temperature and hygrometry by means of a humidity generator. The size of the cylindrical samples tested is 6 cm in diameter with a thickness of 1 cm.

The duration of a permeability test is approximately 20 days, depending on the nature of the material. The equilibrium is determined by the stability of the sample mass over a period of 48 h according to the following equilibrium criterion:

$$\frac{m(t) - m(t+48h)}{m(t+48h)} \leq 0{,}1\% \qquad (1)$$

Before the test, the specimens are stored in an environment with a uniform temperature of (23±5) °C and (50 ±5) % relative humidity for a sufficiently long period of time (duration depending on the nature of the material, these dimensions, etc.) according to the standard so that their masses stabilize.

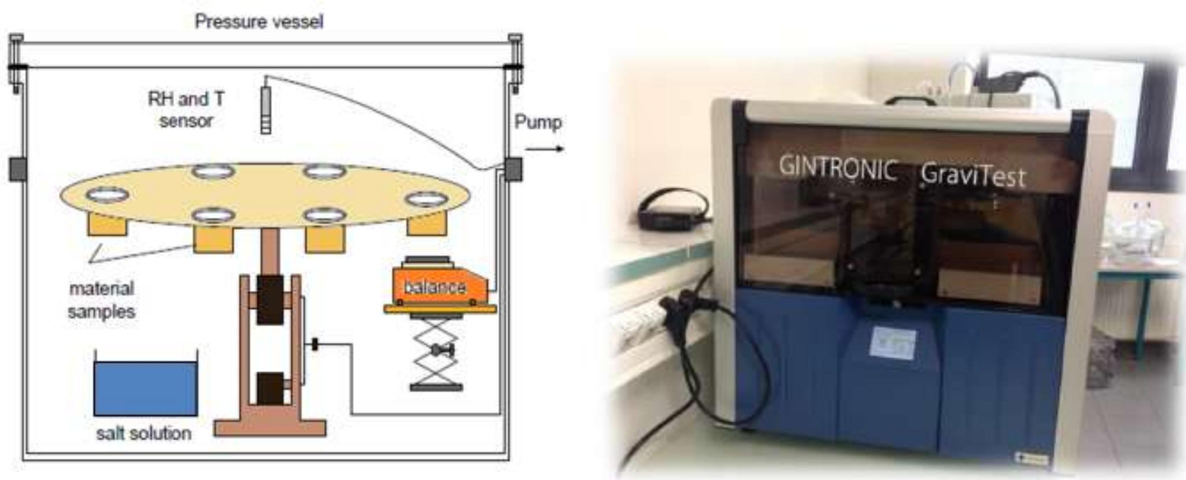

Figure 5:- Experimental device for measuring water vapour permeability by the GintronicGravitest cup method [1].

Results And Discussion:-

Mineralogical composition of the samples

The mineralogical composition of the samples was determined by Bodian et al. [19].

Figure 6 shows the diffractograms of the two raw materials studied.

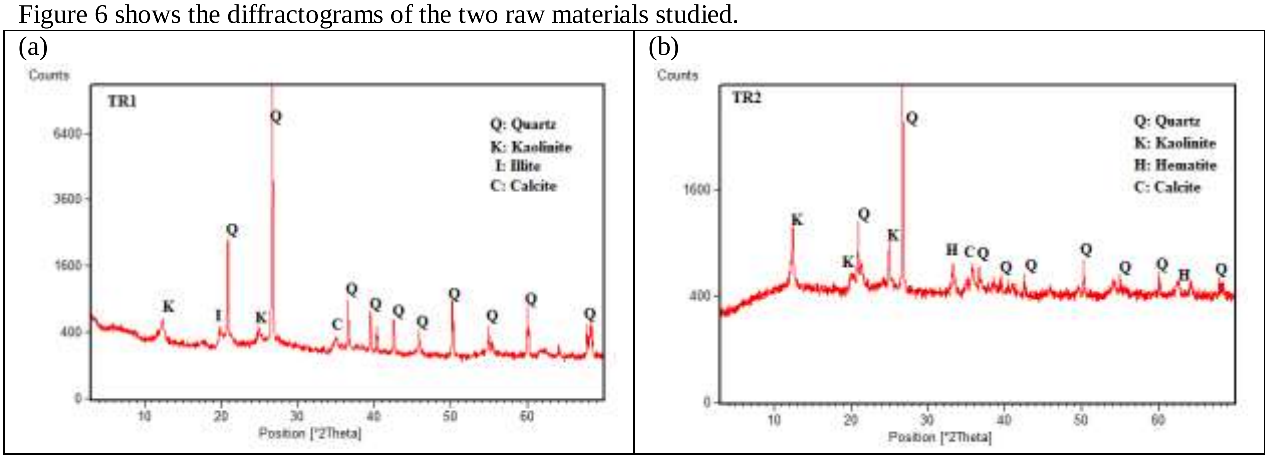

Figure 6:- X-ray diffractograms of clay (a) and laterite (b) powders

The XRD results show that our clay consists mainly of quartz (Q), kaolinite (K), illite (I) and calcite (C) while laterite consists of quartz (Q), kaolinite (K), hematite (H) and calcite (C).

Chemical analysis of raw materials

The chemical composition of the samples was determined by Bodian et al. [19].

The results of the chemical composition of the samples are presented in Table 1.

Table 1:- Chemical composition of raw materials (wt %).

Samples	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5
Laterite	23,00	22,77	33,67	< L.D.	0,13	0,16	0,03	0,11	1,32	1,63
Clay	74,04	12,16	4,12	< L.D.	0,69	0,19	0,16	1,24	1,04	0,10

The results show that the most abundant oxides in both samples are: SiO_2, Al_2O_3 and Fe_2O_3 while K_2O, CaO, MgO, Na_2O, TiO_2 and P_2O_5 are present only in small amounts. The relatively high SiO_2/Al_2O_3 ratio of the clay sample (6.09) is an indication of the large amount of kaolinite in the material.

The relatively high amount of SiO_2 in the clay indicates a greater presence of quartz in the clay than in the laterite.

Another important aspect in relation to the chemical composition is the low amount of K_2O in the clay. This indicates a low illite content in the clay.

Preparation and composition of Specimens

For specimens preparation, we mixed a certain mass of clay with several doses of laterite by weighing. The proportions of laterite incorporated in the clay are shown in Table 2.

Table 2:- Constitution of the specimens.

Designation of specimens	B10	B20	B30	B40	B50
Proportion of Laterite (% wt.)	10	20	30	40	50

Our study focuses on unfired and fired clay bricks.

For firing the bricks, an electric furnace was used. The dried samples were fired for 1 h30 at 900 °C.

Compressive strength of unfired and fired earth bricks

To realize the mechanical tests we tested specimens built with a mold of dimension 16 cm x 4 cm x 4 cm (Figure 7) on a compression- bending (or splitting) test machine of 50 kN of class 1.

(a) (b)

Figure 7:- Constructed mechanical specimens (a): unfired and (b): fired.

Figure 8a and Figure 8b show respectively the variation of the compressive strength of unfired and fired clay bricks with the percentage of laterite. The results show that the addition of laterite up to 30 % improved the compressive strength of the bricks. Beyond this percentage, a progressive decrease of this resistance is observed. The clay brick with 30 % laterite has the highest compressive strength in both cases. These strength values are 4.98 MPa and 22.93 MPa respectively for the unfired and fired clay bricks.

Thus firing increased the compressive strength by a factor of about 4.

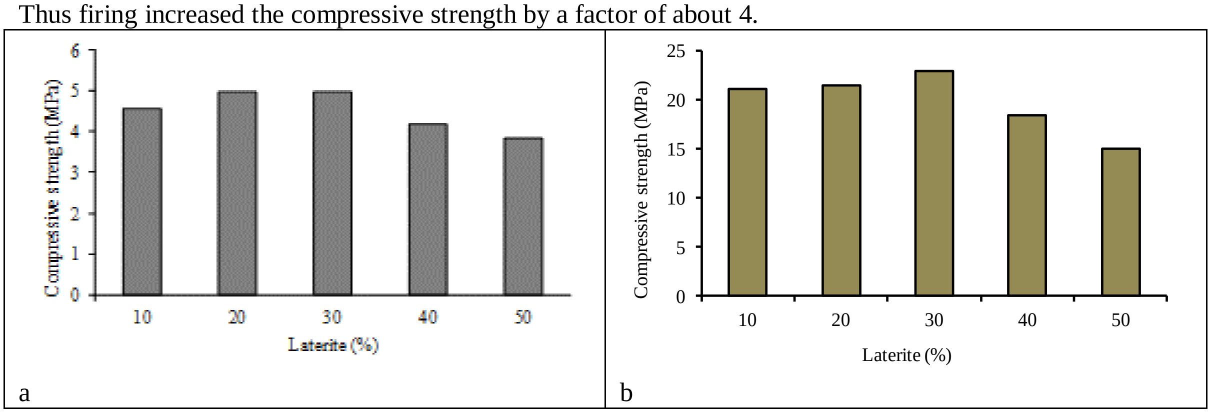

Figure 8:- Variation of compressive strengths of unfired clay bricks (a) and fired clay bricks (b) as a function of laterite percentage.

Thermal conductivity of unfired and fired earth bricks

The thermal conductivity of the brick samples was determined by the asymmetric hot plane method.

The experimental device (Figure 9) for this method consists of a 10 cm x 10 cm surface probe powered by a direct current (DC) generator. A type K thermocouple, constituted of 0.05 mm diameter wires, placed under the probe allows to measure the temperature at the center of the latter.

The probe with the same section as the sample is placed below the sample. The sample-probe-thermocouple assembly is placed between two blocks of 5.9 cm thick polystyrene foam. The outer surface of each polystyrene foam block is in contact with the surface of a 4 cm thick aluminum block in order to obtain a constant temperature on this surface. The acquisition of the temperature measurements is ensured by the AGILENT BENCHLINK DATA LOGGER 34970A coupled to a computer. A flux step is sent in the heating element and the temperature T(t) in the center is recorded.

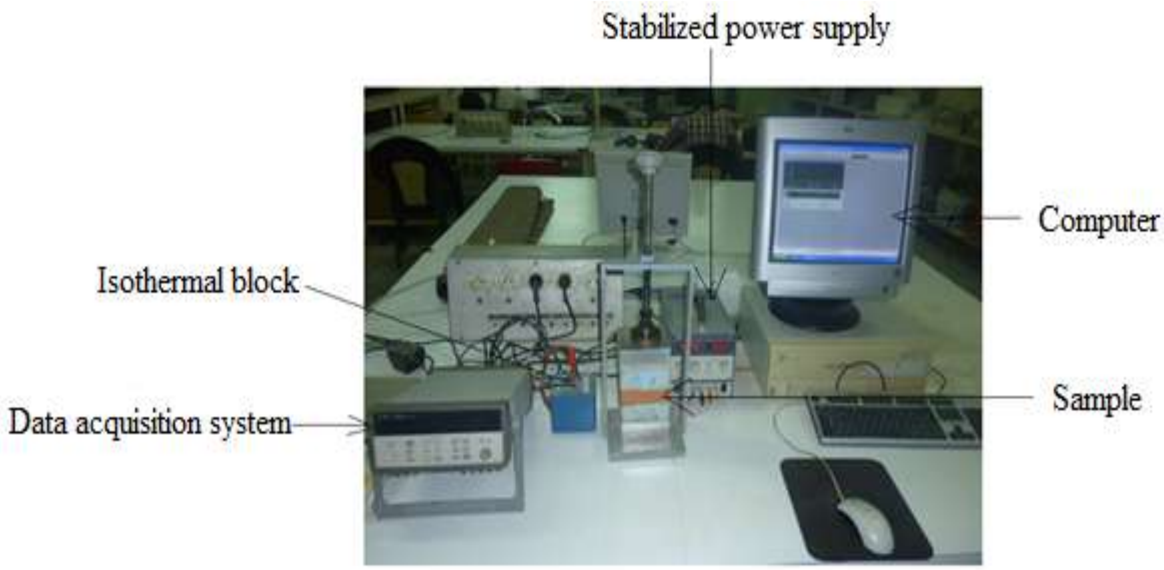

Figure 9:- Experimental device of the asymmetric hot plane.

Thermal tests were carried on the unfired and fired earth bricks composed of 10 %, 20 %, 30%, 40 % and 50 % laterite (Figure 10).

Figure 10:- Earth specimens for thermal tests.

Figure 11 presents the results of the thermal conductivity of unfired bricks and fired clay bricks. The results show that the variation of thermal conductivity with the percentage of laterite has the same shape for the unfired bricks and fired clay bricks on. The values 0.64 W/m.K and 0.34 W/m.K, respectively, for unfired bricks and fired clay bricks show a decrease in the thermal conductivity of the bricks for an addition of laterite up to 30 % then it remains constant. Firing decreases thermal conductivity by a factor of about 2. Firing increases the porosity of clay materials.

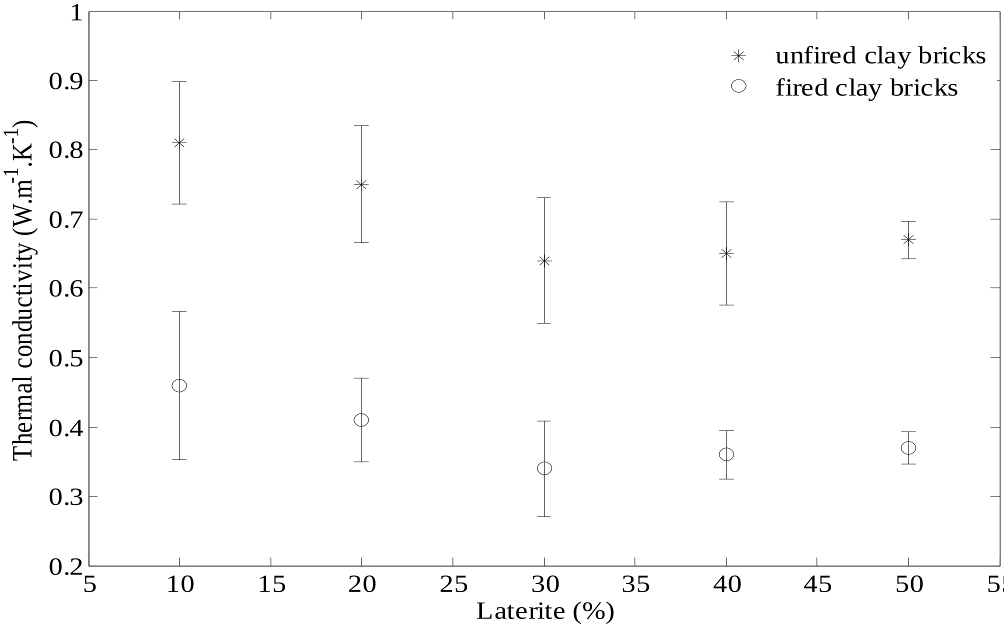

Figure 11:- Variation of the thermal conductivity of unfired and fired clay bricks as a function of laterite percentage.

Measurement of water vapour adsorption and desorption isotherms

In our study, the measurements of adsorption and desorption isotherms are carried out using the "Belsorp Aqua3" device whose protocol is described below.

The choice of this device is justified by the fact that it allows to clearly reduce the total duration of the test (one to two weeks on average) but also it is the device which was available at the Laboratory of Engineering Sciences for the Environment (LaSIE) of the University of La Rochelle.

The BELSORP-aqua 3 is a device for the automatic measurement of the variation of the volume of vapour adsorbed or released by a material using the mole number of the gas.

The samples were first dried in an oven at 40 °C for 24 h and then placed in sample tubes to be degassed under vacuum to finalize their drying. The whole was weighed to determine the dry masses. The device was then immersed in a temperature controlled thermostatic bath.

The method used is manometric, based on the calculation of the quantity of water adsorbed from the acquisition of vapour pressures and the use of the law of perfect gases.

For our study, adsorption and desorption isotherms tests at 23 °C were undertaken on unfired and fired earth materials (Figure 12).

(a) Unfired earth samples (b) Fired earth samples

Figure 12:- Samples used for the determination of adsorption and desorption isotherms at 23°C

Adsorption and desorption isotherms were performed at 23 °C for almost all formulations. Here we present the sorption isotherms for the 30 % laterite formulation which is the optimal formulation from a compressive strength and thermal conductivity point of view.

Figure 13 shows the adsorption and desorption isotherms obtained by the volumetric method for the unfired earth material (a) and fired earth material (b).

(a) (b)

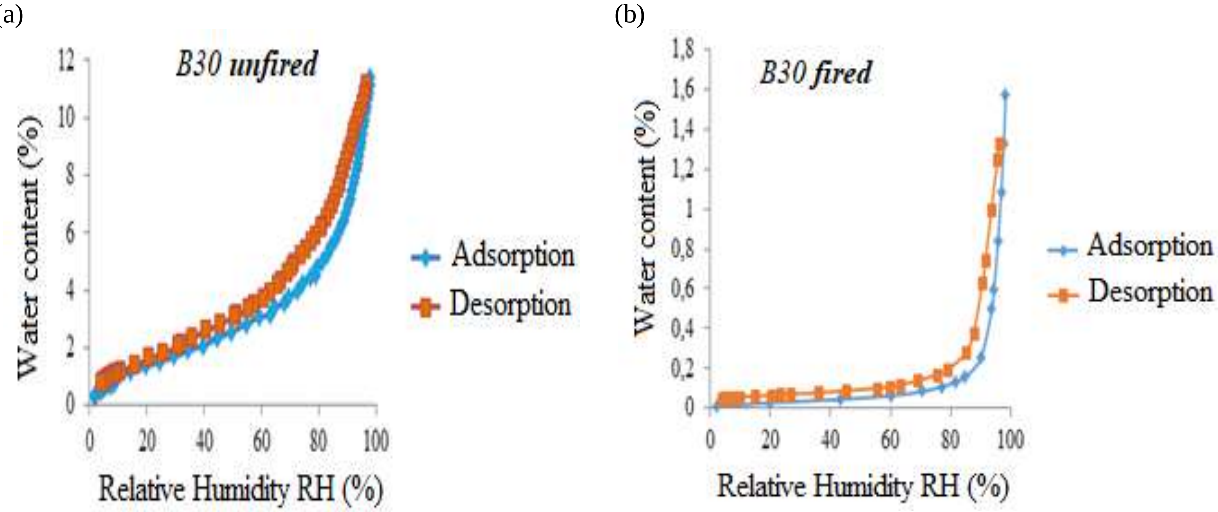

Figure 13:- Adsorption and desorption isotherms of unfired earth material (a) and fired earth material (b) with 30 % laterite at 23 °C.

The shape of the curve in Figure 13(a) indicates that the isotherm of unfired earth material is of type II [1]. Isotherms of this type are characterized by a very gradual increase in the adsorbed layer. This suggests that the unfired earth brick has a macroporous character with multimolecular adsorption.

Figure 13(b) shows that the isotherm of the fired material is of type III characterized by relatively low adsorption. This type of isotherm suggests that the clay brick has a macroporous character with a weak interaction with water vapours.

The results show that the adsorption and desorption curves do not coincide. The shape of the curves is similar but the desorption branch takes higher values of water content than the adsorption branch for the same relative humidity level. It appears thus a phenomenon of hysteresis. This can be explained by the fact that during desorption, less water is released from the material compared to that which was trapped during adsorption.

The adsorption/desorption isotherms of the fired clay material show that this material has a very low adsorption compared to the unfired clay material. For example in the vicinity of 98% relative humidity, the water content of the unfired clay brick is 11 % while that of the fired clay brick is only 1.57 %. The difference in behavior between these two materials may be due to the weaker interaction between the surface of the fired clay and water vapour.

Measurement result of the water vapour permeability

The equipment (Gravitest, GINTRONIC, Switzerland), used for the measurement of water vapour permeability, consists of a temperature and humidity controlled enclosure in which are placed six cups whose weighing is automated. The dimension of the samples is about 6 cm in diameter and 1 cm in thickness. The relative humidity inside the dish is ensured by a saturated salt solution of KNO_3 (93 %).

Figure 14 shows the samples used for the water vapour permeability test.

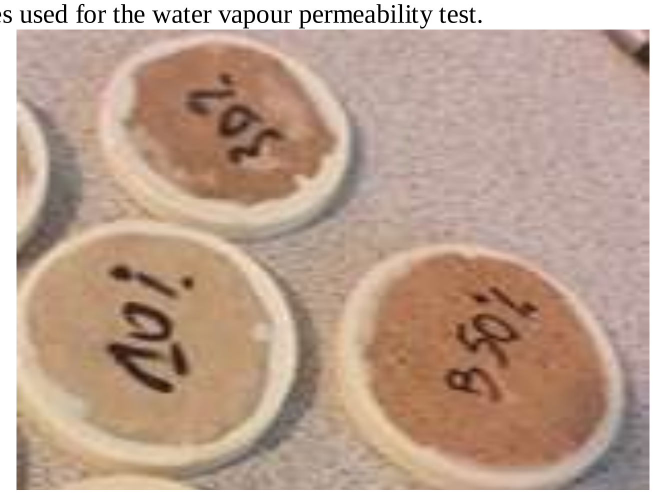

Figure 14:- Samples used for the water vapour permeability test

We performed the characterization of three samples (B10, B30 and B50) in unfired earth to see the variation of water vapour permeability with the addition of laterite.

The water vapour permeability measurement results of these samples determined by the Gravitest method are presented in Table 3.

Table 3:- Water vapour permeability of some unfired earth bricks.

Unfired earth bricks	Water vapour permeability (kg/m.s.Pa)
B10	$3{,}60.10^{-11}$
B30	$3{,}65.\ 10^{-11}$
B50	$4{,}04.\ 10^{-11}$

The results show that the water vapour permeability increases slightly with the addition of laterite. The values are of the same order of magnitude as those found by P. M. Touré[9]. In comparison with the results of M. Y. Ferroukhi[1], the permeability of unfired earth is higher than that of fired earth by a factor of 10.

Conclusion:-

In this paper we have presented the different methods of hygroscopic characterization and the results of hygroscopic tests of earth materials.

An experimental campaign to characterize the hygroscopic properties of unfired and fired earth brick samples has been performed. The main properties characterizing water transfer were measured, including adsorption and desorption isotherms and water vapour permeability. The adsorption and desorption isotherm curves of the samples were determined by a volumetric method using the Belsorp aqua3. The results showed that earth materials are moisture absorbing materials. On the other hand, unfired earth materials adsorb more moisture than fired earth materials. The results of measuring the water vapour permeability of unfired earth bricks obtained by the Gravitest method show that the water vapour permeability increases slightly with the addition of laterite.

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