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Thermal and Mechanical Study of the Adobe Stabilized with Straws and /or Cement at different Dosage Rates

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Abstract; - In order to better know a material, it is essential to characterize it, that is to say, to identify some of its thermal and mechanical properties. Our study has enabled us to determine the thermal conductivity and the mechanical resistivity in dry compression of the adobe stabilized with straws (1%, 2%, 3% of the mass of the straws) and / or with cement at 4% with the view to facilitate its use as local building materials. We have shown that thermal conductivity decreases when the dosage rate of the straws in the mixture increases. This is 1.4251 $W/m.K$ ***for soil, 1.303*** $W/m.K$ ***for TP1, 1.118*** $W/m.K$ ***for TP2, 0.805*** $W/m.K$ ***for TP3. Conductivity increases when the quantity of cement increases. In our measurements, this conductivity is given a maximum value if the adobe is stabilized with cement only. By adding 4% of the mass of cement, this reaches 1.874*** $W/m.K$***. Lastly, we have also calculated the inside temperature of the facility taking the various types of adobes used in its construction into account. We realized that this internal temperature is an increasing function of the thermal conductivity of materials.***

Keywords: **Building materials, thermal conductivity, mechanical resistivity, adobe, straw, cement, thermo-physical properties.**

Nomenclature

λ : Thermal conductibility ($W/m.K$)
m : mass
e : wall thickness (m)
h : Coefficient of convective heat exchange ($W/m^2.^\circ C$)
S : Surface (m^2)
T_∞ : Infinite temperature (°C)
T_{in} : Inside temperature (°C)
T_{ex} : Outside temperature (° C)
T_p : Temperature of the wall (°C)
R_{th} : Thermal resistance (m^2K/W)
T : Soil
R_C : Compressive resistivity (MPa)
F_C :Compressive force (N)
K_m : Wall transmission coefficient ($W/m^2.^\circ C$)
Φ_{tr} : Transmitted flux (W)
Φ_{SR_m} : Flux received by solar radiation (W)
S_m : Surface of the wall (m^2)
S_P : Surface of the door (m^2)
K_P :Door transmission coefficient ($W/m^2.^\circ C$)
S_{pl} : Surface of the ceiling (m^2)
K_{pl} : Ceiling transmission coefficient ($W/m^2.°C$)
S_{plc} : Surface of the floor (m^2)
K_{plc} : Floor transmission coefficient ($W/m^2.°C$)
T_{sol} : Temperature of the floor (°C)
K_f : Window retransmission coefficient ($W/m^2.^\circ C$)
S_f : Surface of the window (m^2)

I. INTRODUCTION

Housing deficit will not be addressed by using modern building materials only as their production capacities are limited and their costs are mostly high [1]. Therefore, research is conducted on local materials to improve their thermal suitability, their resistance and reliability in order to use them in housing construction. Ezbakhe H. et al [2] in a thermal study of soil stabilized with cement have shown that moisture significantly changes the thermo-physical properties of the soil and cement stabilization increases the resistivity of the material to moisture variations. The impact of density on thermal conductivity has also been shown. P.Meukan et al [3] have showed that laterite blocks mixed with sawdust are better thermal insulators than simple laterite blocks. Hung Thanh Pham et al [9] presented experimental measurements of thermal conductivity carried out on lime-hemp composites using hemp shive volume concentrations at 0 and 30%. Results show that the thermal conductivity decreases when the concentration of shive volume increases. The study of bricks made of clay and those made of stabilized soil with 4-8-12% of cement [4] has shown that the thermal diffusivity of clay bricks is lower than that of bricks made with stabilized soil whatsoever the stabilization rate and thermal conductivity increases according to the dosage of cement. In this paper, we explain the study of the thermo-physical properties of stabilized adobe straws at different dosage rates. We particularly study the influence of straw content on the thermal conductivity and the compressive resistivity of stabilized materials. Adobe is raw soil made in wooden, iron molds or any other material with the same qualities. It provides a thermal mass that is a stock of heat or cool, because of its high density and quality of humidity controller [5].

II. METHODS AND TECHNIQUES USED TO PRODUCE THE MATERIALS.

Bricks marked TS are obtained after preparing the soil dough without any stabilizer. Bricks marked TP1 are bricks made of soil which contains 1% of the mass of the straws used to prepare the soil dough. Bricks marked TP2 are soil bricks which contain 2% of the mass of the straw used in the preparation of soil dough. Bricks marked TP3 are soil bricks which contain 3% of the mass of the straw used in the preparation of soil dough. Bricks marked TC are soil bricks which contain 4% of the mass of cement used in the preparation of soil dough. In addition to the above mixture we added straws at 1% of the mass to make bricks marked TCP1. Bricks marked TCP2 are soil bricks which contain 4% of the mass of cement and 2% of the mass of straws. Bricks marked TCP3 are soil bricks which contain 4% of the mass of cement and 3% of the mass of straws.

A. *Thermal Conductivity Measurement Principle*

Thermo-physical properties of materials are magnitudes that characterize the performance of materials. They represent the power of heat to spread in a body or to be there stored. Thermo-physical properties such as thermal conductivity, thermal diffusivity and the volumetric specific heat were measured using KD2-pro, a dual needle probe developed by Decagon Corporation [7]. This device uses CRASLAW and JAEGER [8] model to solve the equation of heat transfer by the method of propagation of linear heat source in transitory regime in a semi-infinite medium, an equation published in IEEI standards [9, 10]. The main advantages of this type of method include the simplicity of the equipment, the easy measurements and the possibility to work in situ in any hygrothermal condition.

B. *Result of Measurements*

Results of the thermal conductivity measurements are shown in Table1 below. Values obtained in Table1 allowed us to draw the curve of the thermal conductivity according to the stabilizer level (Figure 1)

Table 1: Value of the Thermal Conductivities of Materials.

Materials	Thermal conductivity (λ) en $(W/m^2.°C)$	Measurement error
TS	1.452	0.01495
TP1	1.303	0.0150
TP2	1.118	0.0132
TP3	0.805	0.0450
TC	1.874	0.0131
TCP1	1.725	0.006
TCP2	1.622	0.00945
TCP3	1.568	0.0074

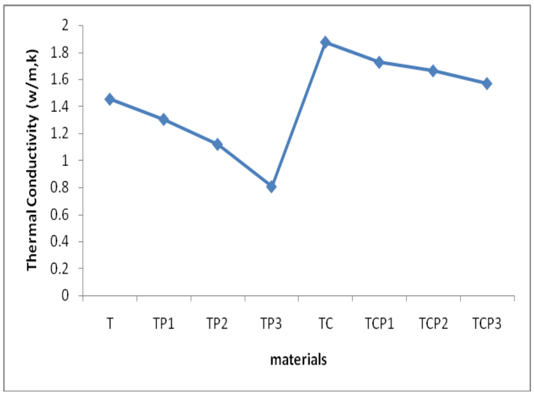

Fig 1: Variation of the Thermal Conductivity according to the stabilizer rate in materials

1) *Analysis and Interpretation of Results*

The value of the thermal conductivity (Figure1) of the simple soil without stabilizer gives an average value of 1.452W / mk. This value decreases as we add straw as stabilizer. It reaches 1.303W / m.K at 1% of the mass of straws; 1.118W / m.K at 2% of the mass of straws and 0.805W / m.K at 3% of the mass of the straws. By adding 4% cement as stabilizer to soil, we get a conductivity of 1.874W / m.K. By adding 1% of straws to the above mixture, the thermal conductivity is1.725W / m.K, accounting for 7.9% decrease. By adding 2% of straws, this gives a thermal conductivity of 1.622W / m.K; this value decreases by 13.44%. If the rate of straws added is 3%, the thermal conductivity decreases to 16.32%. The thermal conductivity decreases when the rate of straws increases [3]. Indeed, cement not only stabilizes the soil, but also closes the pores. It provides the initial material with many fine particles that close the pores created by the proximity of large particles. The material obtained after mixing is less porous than the original material. Heat goes through the material and the greater the stabilization, the easier heat goes through the material because of the reduction of the vacuum due to the cement. The pores contain air, and air is an insulator. The presence of straw fibers during the mixing also leads to the increase in the volume of the air brought in our soil blocks [12]. Straws increase the pores in the material that is why the conductivity decreases when the rate of straws increases. When the cement reduces the pores, it decreases the air contained in these pores, yet the conductivity of the air is very low. The conductivity increases with cement dosage rate [4].

C. Study of the Compressive Resistivity's of Materials according to Straw Dosage Rate.

Tests to assess the dry compressive resistivity have been performed. A test of the dry compressive resistivity consists in submitting to a sample (a dry adobe), a simple compressive load, by using crushing press until it completely breaks and calculating the value of the load that broke the sample (read on the screen of the crushing press). The dry compressive resistivity of bricks is calculated using the following formula:

$$R_C = \frac{F}{S}$$

(01)

In which

- F is the maximal load supported by the brick in Newton (N) ;
- S is the surface under load in mm^2

1) Measurements of compressive resistivity's of soil blocks stabilized with straws and with cement.

Results of the measurement of the compressive resistivity are detailed in Table 2

Table2: Compressive Resistivity

Compressive resistivity			
	Fc (KN)	Rc(MPa)	Average (MPa)
SOIL	10.53	0.501	0.517
	11.43	0.544	
	10.68	0.508	
SOIL+STRAW1	12.10	0.576	0.554
	11.33	0.567	
	10.39	0.520	
SOIL+STRAW2	13.24	0.662	0.630
	12.93	0.647	
	11.63	0.582	
SOIL+STRAW3	14.11	0.706	0.740
	15.69	0.785	
	14.56	0.728	
SOIL+CEMENT	21.77	1.088	1.126
	22.34	1.117	
	23.49	1.174	
SOIL+CEMENT+ STRAW1	21.83	1.091	1.066
	20.98	1.049	
	21.18	1.059	
SOIL+CEMENT+ STRAW2	20.51	1.025	1.002
	19.43	0.972	
	20.17	1.01	
SOIL+CEMENT+ STRAW3	19.89	0.995	0.974
	18.83	0.942	
	19.72	0.986	

The various values of the compressive resistivity's detailed in this table allow us to draw the variation curve of the compressive resistivity according to the stabilizer rate in materials (figure2).

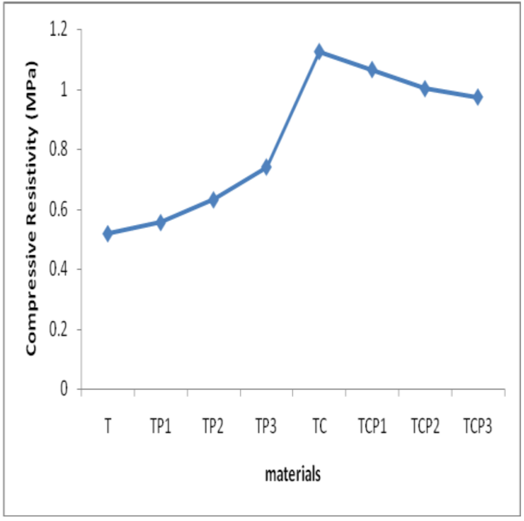

Fig 2: Compressive Resistivity according to the Stabilizer Rate in Materials

2) Analysis and Interpretation of Results

These results (Figure2) show that the compressive resistivity increases according to the rate of straw used to make soil paste. This compressive resistivity reaches its highest level, i.e. 1.126 MPa, when we add 4% of cement to soil.

The compressive resistivity is due to the molecular cohesion. The greater the cohesion, the higher the compressive resistivity. Straw is an organic material which provides good adherence to soil particles and the higher the rate of straws in the material, the stronger the adherence. The compressive resistivity of soil reinforced with date palm is better than that reinforced with straw fiber. This is due to the good adherence between pastes. The resistance is an increasing function of straw dosage rate. Stabilization improves the compressive resistivity and enables angles to contain abrasion and impacts [3]. The compressive resistivity develops contrary to dosing rate of straw in the Soil + cement after 28 days. This resistance decreases as we increase the rate of straws in this mixture. This is explained by the fact that since straw is an organic material, this has likely delayed the action of cement. Tests were performed one month after the preparation of the samples; this means that the cement had not yet completed its action in bricks that contain straws. This delay is due to the presence of free sugars from the straw (plant products) V. F. Fisher et al [13, 14].

III. ENERGY BALANCE CALCULATION OF THE INTERNAL TEMPERATURE OF THE VARIOUS FACILITIES BUILT WITH OUR MATERIALS

A. Heat intake by solar radiation through walls

Energy intakes corresponding to heat productions within the room are ensured either from outside, i.e. the solar radiation or from equipments set in the room. The equation below summarizes the energy received by the walls of the room.

$$Q_{SRm} = \alpha F.S.R_m$$ **(02)** [9]

Where F is the solar radiation factor which gives quantity of heat absorbed by the surface and transmitted through the wall of the room.

R_m is solar radiation absorbed on the surface of the wall in W / m^2.

S: is the surface of the wall in m^2.

α is the wall absorption coefficient under radiation. In our study, we use $\alpha = 0.7$ [9].

The value of " R_m " on the walls depends on:

- The position of the room,
- The position of the wall,
- The time for which the calculation is performed

B. Heat Intake sent within through the Coating of the House.

Heat sent within the house may be calculated using the following formula:

$$Q = K.S.\Delta\theta$$ (03) [9]

Where K is the thermal transfer coefficient of the wall or of the window pane put in $W / m^2.C$)

S : surface of the wall or of the window used.

$\Delta\theta$: Temperature gap between both sides of the wall in °C.

C. Heat Intake by Air Renewal.

$$Q_{S_R} = q_v(T_{ex} - T_{in}) * 0.33$$ (w) (04) [9]

Where q_v is the outflow of the external renewal air (m^3 / h).

In case of natural ventilation, we can consider that air renewal equals the volume of the room per hour (1vol / h).

In order to calculate the overall coefficient of heat transfer through the walls (k), the following formula is used:

$$K = \frac{1}{\frac{1}{h_e} + \sum_{k=1}^{n} \frac{e_k}{\lambda_k} + \frac{1}{h_i}} \quad (W / m^2 °C)$$ (05) [9]

Where h_e and h_i are overall convection coefficients on the walls and λk the thermal conductivity coefficient of the wall used. We will use $h_e = 16.7 W / m^2.°C$ and $h_i = 9 W / m^2.°C$ [9].

The values of K (overall transmission coefficient) of various walls are detailed in the table below. These values are obtained from formula (05).

Nature of the wall	T	TP1	TP2	TP3	TC	TCP1	TCP2	TCP3
K ($W / m^2.°c$	3.23	3.08	2.85	2.38	3.6	3.46	3.39	3.34

Table3: Thermal Transfer Coefficients according to the dosage

We have chosen the baseline external temperature, namely the hottest month of the year, i.e. April.

T_{ex} = 40°C [9] and the unknown temperature T_{in} must be calculated.

By using the conservation of the flux, we have :

$$\Phi_{SR_m} = \Phi_{tr}$$ (absorbed Flux = Flux transmitted in the house)

$$\Phi_{SR_m} = (S_{mur}K_{mur} + S_pK_p + S_{pl}K_{pl} + S_fK_f + 9.18q_v)(T_{ex} - T_{in}) + S_{plc}K_{plc}(T_{sol} - T_{in})$$

(06)

Or

$$T_{in} = \frac{\left(S_{mur}K_{mur} + S_pK_p + S_{pl}K_{pl} + S_fK_f + 9.18q_v\right)T_{ex} + S_{plc}K_{plc}T_{sol} - \Phi_{SR_m}}{\left(S_{mur}K_{mur} + S_pK_p + S_{pl}K_{pl} + S_fK_f + 9.18q_v\right) + S_{plc}K_{plc}}$$

(07)

This formula (07) allows calculating the temperature inside the room.

Materials	T	TP1	TP2	TP3	TC	TCP1	TCP2	TCP3
T_{in} (°C)	29,55	29,20	28,26	27,23	30,31	30,04	29,89	29,79

Table 4: Internal Temperature of the House according to the dosage of the Adobe

The various temperature values obtained in the table above allow us to draw the internal temperature variation curve of the houses depending on the nature of local materials used.

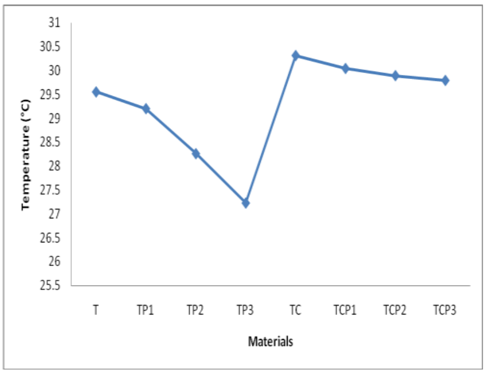

Fig 3: Variation of the Internal Temperature of the House according to the Dosage of the Adobe

1 Analysis and Interpretation of Results

The temperature (Figure3) within the house decreases if it is built using soil stabilized with straw. It decreases as the quantity of the straws increases. The inside temperature is maximum when the room is built with Soil + cement. The temperature in the house depends on the thermal conductivity of materials used. It is an increasing function of the thermal conductivity of materials used. Temperature values range from 27.23 ° C to 30.31 ° C depending on the type of bricks used. The temperature recommended to ensure comfort is 26 °C; the internal atmosphere of the house built in TP3 alone is closer to the thermal comfort. Yet, bricks that contain cement are less sensitive to water and humidity, which are very harmful factors. The improvement of the stability to water will increase the sustainability of these materials.

IV. CONCLUSION

This research has allowed us to calculate the thermal conductivity and the dry compressive resistivity of the adobe stabilized with straws and cement at different dosage rates. We have also through the method of heat balance simulation, calculated the indoor temperature of the various facilities built using materials based on the rate of stabilizer contained in the adobe. We find that indoor temperature decreases according to the rate of straws used to produce these materials. The study of thermo-physical properties of building materials is important in the context of research on energy saving in housing and on its thermal comfort. The thermal conductivity and compressive resistivity change according to the nature and the level of the stabilizer. Indoor temperature depends on the thermal conductivity of the building materials used. Mechanical and thermal performances of formulated materials have been described. It emerges from this study that the adobe stabilized with straws constitutes a credible and durable alternative as building materials.

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