Effect of Ecological Insulating Fiber on the Thermal and Mechanical Properties of Plaster.

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Abstract

This paper is an investigation of the thermal and mechanical properties of new insulating materials plaster-fiber alpha so as to use it in the ceiling on building construction. For this reason, many samples were produced for different percentage of fiber alpha so as to define the best percentage of fiber alpha which assures adequate thermal and mechanical properties. Also, the thermal and mechanical characterization was done using the asymmetrical hot plate, flash, and three flexure points' methods. Moreover, experimental results of thermal conductivity were confronted to different theoretical models to know the nature of fiber alpha distribution inside the matrix plaster. Furthermore, thickness of heat flow diffusion was studied so as to see the effect of the developed samples on the thermal inertia of a ceiling.

Keywords: Plaster-fiber alpha; Hot plate method; Thermal conductivity; Mechanical properties; Theoretical model.

INTRODUCTION

Morocco possesses3.186.000 ha of fiber alpha which presents a big capital of ecological insulating material. For the purpose of energy efficiency, using natural resources and reducing the consumption of electricity. A lot of researchers were done, about the development of the cheap local material with low density, thermal conductivity and with good mechanical properties using ecological insulating material fiber alpha.

The objective of this work is to improve thermal and flexure properties of plaster by combining it by fiber alpha which is known by its good mechanical and thermal properties. The study was done for different percentage of the additive fiber alpha so as to compare its effect on the composites developed.

 The first step consists of thermal characterization using hot plate in permanent regime [1][2] and flash methods[3][4][5] in order to determine thermal conductivity, thermal diffusivity of the developed composites. The second step consists of comparing the experimental results with analytic models of equivalent thermal conductivity and study the thickness of heat flow diffusion. The third step in this study is the mechanical properties using three flexure points so as to determine the flexure strength.

Literature study was done on insulating building material as the work of [6]which studied the interaction between abaca fibers and gypsum matrix in order to produce fiber reinforced plaster-boards with enhanced toughness performances and the fibers were subjected of different chemical treatment in order to improve the surface characteristics to improve the adhesion of matrix. The work of [7] in which they studied the thermal properties of the composite plaster-cork for different sizes of cork using the asymmetrical hot plate, flash and calorimetric methods. The work of [8] which concerns the workability, setting and strength characteristics of polymer plaster composites in which the introduction of latexes onto plaster increases the setting time and decreases the value of flexural and compressive strength. The work of [9]that work on the effect of the variation of volume fraction of wool on the thermal conductivity, thermal effusivity, thermal diffusivity its effect on the damping factor, delay of temperature and heat flow density. The work of [10]concerning the identification of the thermal properties of clay bonded with cork using the hot plate and flash methods.

DESCRIPTION OF USED MATERIALS

Plaster

The plaster is a construction material used in ceiling and in walls. This is a material composed from sulfate of calcium which begun hardness and solidify when it is blended with water. He sends heat when it's combined with water in the opposite of mortar cement which is obtained by calcinations of natural gypsum (sulfate of calcium dehydrated, $CaSO_4$ $2H_2O$) in the temperature of 120-150°C in order to obtain the semi-hydrated with certain quantity of anhydride gypsum .

The chemical reaction in the solidification and hydration of sulfate of calcium hemi hydrated is defined by the equation (1):[7][8].

$$2CaSO_4 \cdot \tfrac{1}{2}H_2O + 3H_2O \rightarrow 2CaSO_4 \cdot 2H_2O \qquad (1)$$
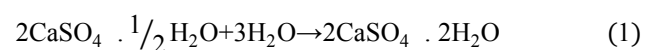
In this work the plaster used is the gypsum hemi hydrated extracted from the city of Safi in Morocco. The water per binder used is 1.33.This gypsum possesses as characteristics: a density of 865.5(kg.m^{-3}) in state hardens, a thermal conductivity of 0,32 (W.m^{-1}.K^{-1}) determined experimentally by the hot plate method in steady state regime.

The table (1) shows the characteristics of the plaster used.

Table 1: Characteristics of plaster.

Characteristics	Value
Fluidity (FLS ring)	22 cm
setting time (knife) 7 min	7 min
End of setting	18 min
Particle size sieve:	
Refusal to 100 u	<13,5%
Refusal to 400 u	<1%
Water / plaster	1,33

Fiber alpha

Alpha (stipatenacissima L) is a Mediterranean perennial grass which belonged ecological-floral sub-region Ibero-from the Maghreb, which is an integral part of the region of Mediterranean-stepic, extending the average valley of the Ebro until that of the Indus. The alpha presented by bundles in good condition and large-sized which can attend a height of 1.2m with a high average of density[11].

The chemical composition of fiber alpha is given in the table 2.

Table 2: Chemical composition of fiber alpha.

Chemical Composition	Value (%)
Cellulose	45
Hemicelluloses	24
Lignine	24
Pectine	5
Cire	2

The apparent density of used fiber alpha is 60 Kg.m^{-3}, thermal conductivity is 0.040-0.043W.m^{-1}.K^{-1}.

DESCRIPTION OF EXPERIMENTAL APPROCH

Formulation Of Samples

The formulation of materials is based essentially on three parameters water/binder W/B; fiber/ binder B/fiber and density.

The first step consists of determining the mass of the insulating material (fiber alpha which completes the full volume of the two molds. Then, we note the percentage which corresponds to 80%, 60% and 40% of the mold's volume.

We prepare samples of plaster alone in order to compare the thermal and mechanical properties of the composites developed.

The table 3 concludes the different dosage of each component of the composite plaster-fiber alpha for different percentage of the insulating material fiber alpha.

Table 3: Percentage of different component of the composites developed.

Samples	100%	80%	60%	40%	0%
Plaster	150	160	170	180	200
Water	200	213	226	239,4	260
Fiber alpha	13	10	7,8	5,2	0
W/B	1,33	1,33	1,33	1,33	1,33
B/Fiber	11,54	16,00	21,79	34,62	-

For the goal of studying the influence of the variation of insulating material percentage on the physical properties, we proceed to the fixation of the W/G to 1.33.

For the purpose of the mechanical and thermal characterization of the composites plaster-fiber alpha, we have prepared three samples of each percentage of additives. Concerning the mechanical samples of 4x4x16cm, they were produced in order to determine the strength of flexure. However, for thermal characterization samples of 10x10x2cm were produced.

Deshumidification Of Samples

In order to study the influence of the variation of insulating material on the physical properties, we have tried to remove all moisture existing in samples to avoid the variation of samples densities.

The samples produced were done in the oven in a regular temperature of 60°C. The mass of samples was weighted each 24h until its weight become constant in a time of 94h.

The thermal samples were confronted to the thermal characterization to avoid their humidification while mechanical characterization was putted in temperature of the room until 23°C (±2°C) and 65% of moisture. The period of test is 7, 14 and 21days.

The figure 1 shows the mechanical samples of dimensions 4x4x16 cm and thermal samples of 10x10x2cm of composites plaster-fiber alpha.
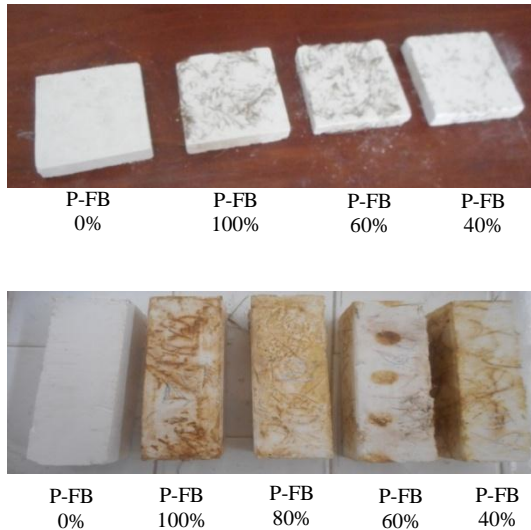

| P-FB 0% | P-FB 100% | P-FB 60% | P-FB 40% |

| P-FB 0% | P-FB 100% | P-FB 80% | P-FB 60% | P-FB 40% |

Figure 1: Thermal and Mechanical Samples of plaster fiber alpha in different percentage.

THERMAL CHARACTERIZATION METHODS DESCRIPTION

Hot Plate In Steady State Regime [1][2]

The Hot Plate method in steady state regime characterizes thermal conductivity (λ) of samples. When the system reaches the steady state regime, we write:

$$\emptyset = \emptyset_1 + \emptyset_2; \quad \emptyset_1 = \frac{\lambda_1}{e_1}(T_0\text{-}T_1); \quad \emptyset_2 = \frac{\lambda_2}{e_2}(T_0\text{-}T_2) \quad (2)$$

$$\lambda_1 = \frac{e_1}{T_0 - T_1}\left[\emptyset - \frac{\lambda_2}{e_2}(T_0 - T_2)\right] \quad (3)$$

Thermal conductivity of sample that we look for, e_1 the thickness of the sample; $\lambda_2 = 0.04 \, w.m^{-1}.K^{-1}$ and $e_2 = 10 \, mm$: parameter of the insulating foam.

Experimental Approach Of The Flash Method [3][4][5]

This method gives the thermal diffusivity of solid. A strong luminary flow is sent on the sample's parallel faces in a short period. A thermocouple in touch with the bottom face registers the rise of temperature in the moment when the face receives the flash. A modeling of heat transfer in the sample estimates thermal diffusivity from the experimental thermogram. Using Laplacetransform and quadruples methods we write:

$$\begin{pmatrix} \theta_{1(p)} \\ \Phi_{1(p)} \end{pmatrix} = \begin{bmatrix} \cosh(qe) & \frac{1}{\lambda qS}\sinh(qe) \\ \frac{1}{\lambda qS}\sinh(qe) & \cosh(qe) \end{bmatrix} \begin{pmatrix} \theta_{2(p)} \\ \Phi_{2(p)} \end{pmatrix} \quad (4)$$

$$\begin{pmatrix} \theta_{1\,(p)} \\ \Phi_{1\,(p)} \end{pmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{pmatrix} \theta_{2(p)} \\ \Phi_{2(p)} \end{pmatrix} \quad (5)$$

According to the Laplace transformation:

$$\Phi_1(p) = L\big(\varphi_0(t) - h.\theta_1(p)\big) \quad (6)$$

We combine this relation we have

$$\theta_2(p) = \frac{\varphi_0}{p}\frac{1-e^{(-pt_0)}}{C+2Ah+Bh^2} \quad (7)$$

Theoretical Model To Check The Experimental Value Of Thermal Conductivity

Authors compare experimental results with theoretical models for the equivalent thermal conductivity of materials concerning the two components: continuous phase (plaster) and dispersed phase (alpha). Different theoretical models were used to confirm the experimental value of thermal conductivity for instance :Series [12](Wiener O),Parallel [12][12](WienerO),Hamilton[12],Geometric[13] and beck's models.

Series model

$$\lambda_{\perp\perp} = \frac{1}{\frac{1-y}{\lambda_{cont}} + \frac{y}{\lambda_{disp}}} \quad (8)$$

Parallel model

$$\lambda_{\parallel\!/} = (1\text{-}y).\lambda_{cont} + y.\lambda_{disp} \quad (9)$$

Hamilton model

$$\lambda_{eq} = \lambda_{cont}\left[\frac{\lambda_{disp} + (n\text{-}1)\lambda_{cont} - (n\text{-}1)y(\lambda_{cont} - \lambda_{disp})}{(n\text{-}1)\lambda_{cont} + \lambda_{disp} + y(\lambda_{cont} - \lambda_{disp})}\right] \quad (10)$$

With (n=3/ξ)

Geometric model

$$\lambda_{eq} = \lambda_{disp}{}^{y} * \lambda_{cont}{}^{(1\text{-}y)} \quad (11)$$

Beck's model

$$\lambda_{eq}= \sqrt{\lambda_{\parallel}*\lambda_{\perp\perp}} \qquad (12)$$

Description Of The Approach To Measure Depth Heat Flow Diffusion

According to the thesis of [14], an analysis was conducted to see the variation of thickness of composites according to time of diffusion of heat flow using the relation (12).

The relation between the thickness and the time of heat flow diffusion inside a homogeneous component inside building is defined as the product of heat capacity and thermal resistance of the same component.

$$t=R.Q= \left(\frac{e}{\lambda}\right)*(e.\rho c) \qquad (13)$$

We conclude that

$$t=\frac{e^2}{a} \qquad (14)$$

MECHANICAL CARACTERISATION METHODS DESCRIPTION

Flexure Three Points

The flexure strength was measured on three specimens of each time 7, 14 and 21 days. The mechanical tests were carried out using a hydraulic press with a capacity load of 10KN.

According to the relation of flexure and knowing the load P obtained in rupture, we can calculate the flexure strength σ as indicated in relation (15). Where b is the width, d is the

thickness and L length of the specimen.

$$\sigma = \frac{3P.L}{2.b.d^2} \qquad (15)$$

RESULTS

Density

Using the volume and the mass of each sample, we have determined thermal and mechanical densities of each sample; we have opted for the average density between both mechanical and thermal samples.

Knowing the density of plaster, fiber alpha, we can easily find the volume fraction of composites for different percentage of these additives using this formula (16).

$$y = \frac{\rho_{p-ad} - \rho_p}{\rho_{ad} - \rho_p} \qquad (16)$$

According to the figure 2 which presents the density in function of volume fraction of fiber alpha, authors conclude that:

The density of samples produced are between the maximum value concerning the plaster attending 897 (kg.m-3) and the minimum value for the composite plaster-fiber-alpha (y=0.29) and this is due to the creation of porosity by fiber alpha inside the matrix plaster.

Authors observe that there is a linear correlation between densities and volume fraction of insulting materials (figure 2).

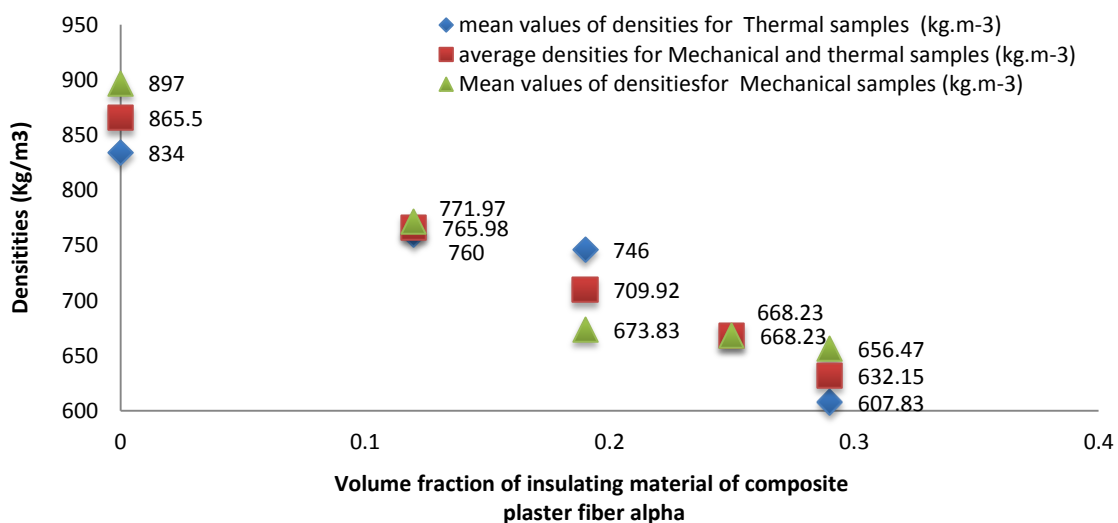We note that the measures of error are of the order between 0.1% and 1.4%.

Figure 2: View of Densities according to different volume fraction fiber alpha.

The table 4 indicates the average densities taken between the thermal and mechanical samples, the volume fraction of fiber alpha.

Table 4: Densities of samples

Samples	Identification		$\rho_{composite}$ for Thermal samples (kg.m^{-3})	$\rho_{composite}$ for Mechanical samples (kg.m^{-3})	$\rho_{composite}$ average (kg.m^{-3})	Error (%)	$y_{additif}$	Gain on lightness (%)
PF1	Plaster(y=0.12) Fiber alpha (W/B=1,33)	1	758,00	760,50	759,25	0,9	0,13	11
		2	760,00	780,00	770,00	0,5	0,12	
		3	762,00	775,40	768,70	0,4	0,12	
		Mean value	760,00	771,97	765,98	-	0,12	
PF2	Plaster(y=0.19) Fiber alpha (W/B=1,33)	1	746,00	672,00	709,00	0,1	0,20	18
		2	747,00	675,00	711,00	0,2	0,19	
		3	745,00	674,50	709,75	0,0	0,19	
		Mean value	746,00	673,83	709,92	-	0,19	
PF3	Plaster(y=0.25) Fiber alpha (W/B=1,33)	1	-	668,00	668,00	0,0	0,25	23
		2		669,00	669,00	0,1	0,25	
		3		667,70	667,70	0,1	0,25	
		Mean value		668,23	668,23	-	0,25	
PF4	Plaster(y=0.29) Fiber alpha (W/B=1,33)	1	607,00	656,00	631,50	0,1	0,29	27
		2	609,00	657,00	633,00	0,1	0,29	
		3	607,50	656,40	631,95	0,0	0,29	
		Mean value	607,83	656,47	632,15	-	0,29	
P	Plaster	1	830,00	901,00	865,50	0,0		
		2	835,00	920,00	877,50	1,4		
		3	837,00	870,00	853,50	1,4		
		Mean value	834,00	897,00	865,50	-		

After analyzing the results, we deduce that:

The volume fraction of fiber alpha inside matrix plaster presents just 1/3 of the global volume of the composites

We obtain a gain of 27%, on lightness concerning the composite plaster-fiber alpha for the highest volume fraction of additives.

Thermal Properties

The table 5 indicates that:

Thermal conductivity is decreasing from 0.32 to 0.14 (W.m^{-1}.K^{-1}) by adding the fraction(y=0.29) of fiber alpha on the plaster. The fiber alpha permits a significant decrease of thermal conductivity.
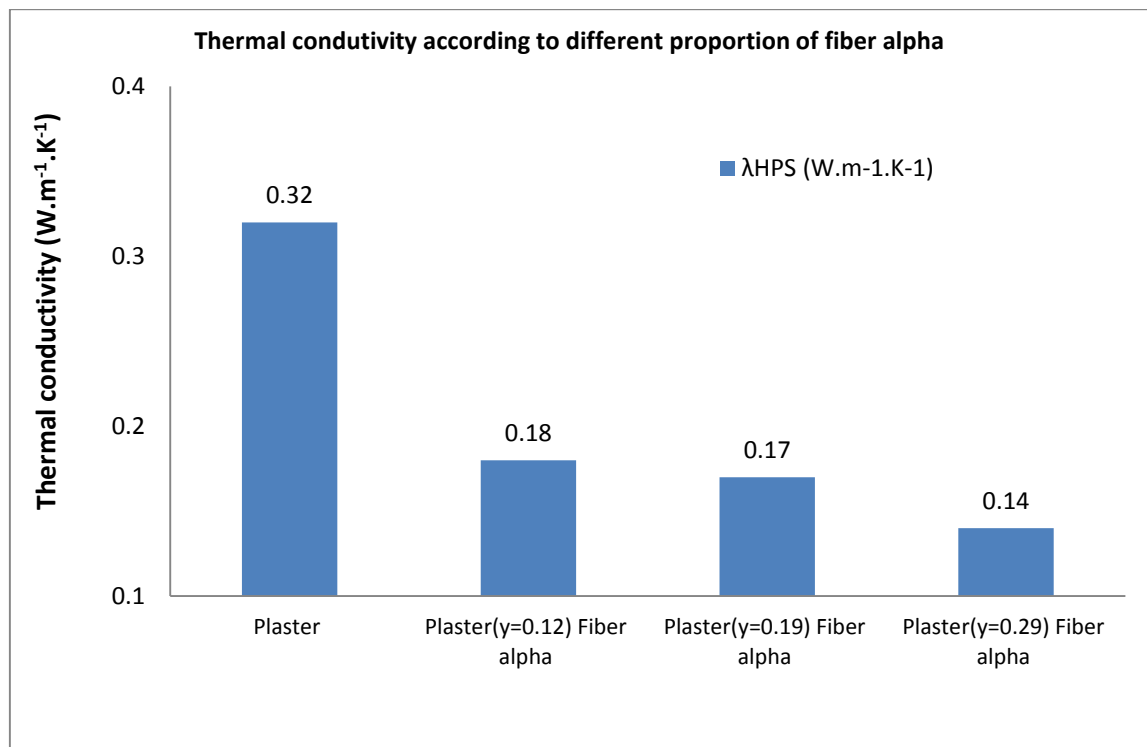
Thermal diffusivity is decreasing from 2.4 to 1.7 .10^{-7}(m^2.s^{-1}) by adding fiber alpha to the plaster for the highest volume fraction of additives(y=0.29). Adding the insulate material to plaster permits to reduce the thermal diffusivity so the transfer of heat flow takes more time to cross the composite if we compare it with plaster alone.

The histogram 1 shows the decrease of thermal conductivity according to the proportion of the fiber alpha from 0.32 (W.m^{-1}.K^{-1}) to 0.14 for the highest proportion of fiber (y=0.29).

The histogram 2 shows the gain obtained in term of thermal conductivity which attends 56% so the creation of porosity inside the matrix plaster decreases thermal conductivity because it creates the air inside the composites which possesses a low value of thermal conductivity.

Table 5: Gain obtained in thermal properties

| Mixture	Identification	SamplesSeries	λ_{HPS}(W.m^{-1}.K^{-1})	Error (%)	Gain (%)	$a_{composite}10^{-7}$ ($m^2.s^{-1}$)	Error (%)	Gain (%)
		1	0,18	0,9	44	1,97	3,4	
PF1	Plaster(y=0.12) Fiber alpha (W/B=1,33)	2	0,175	1,9		2,05	0,5	
		3	0,18	0,9		2,1	2,9	
		Mean value	0,18	-		2,0	-	15
		1	0,17	0,2	47	1,95	0,0	
PF2	Plaster(y=0.19) Fiber alpha (W/B=1,33)	2	0,168	1,4		2,05	5,1	
		3	0,173	1,6		1,85	5,1	
		Mean value	0,17	-		1,95	-	19
		1	0,145	1,9	56	1,78	4,7	
PF4	Plaster(y=0.29) Fiber alpha (W/B=1,33)	2	0,14	1,6		1,7	0,0	
		3	0,142	0,2		1,62	4,7	
		Mean value	0,14	-		1,70	-	29
		1	0,325	2,1		2,45	2,1	
		2	0,32	0,5		2,35	2,1	
		3	0,31	2,6		2,4	0,0	
P	Plaster	Mean value	0,32	-		2,40	-	

Histogram 1: Thermal conductivity according to the volume fraction of additives.
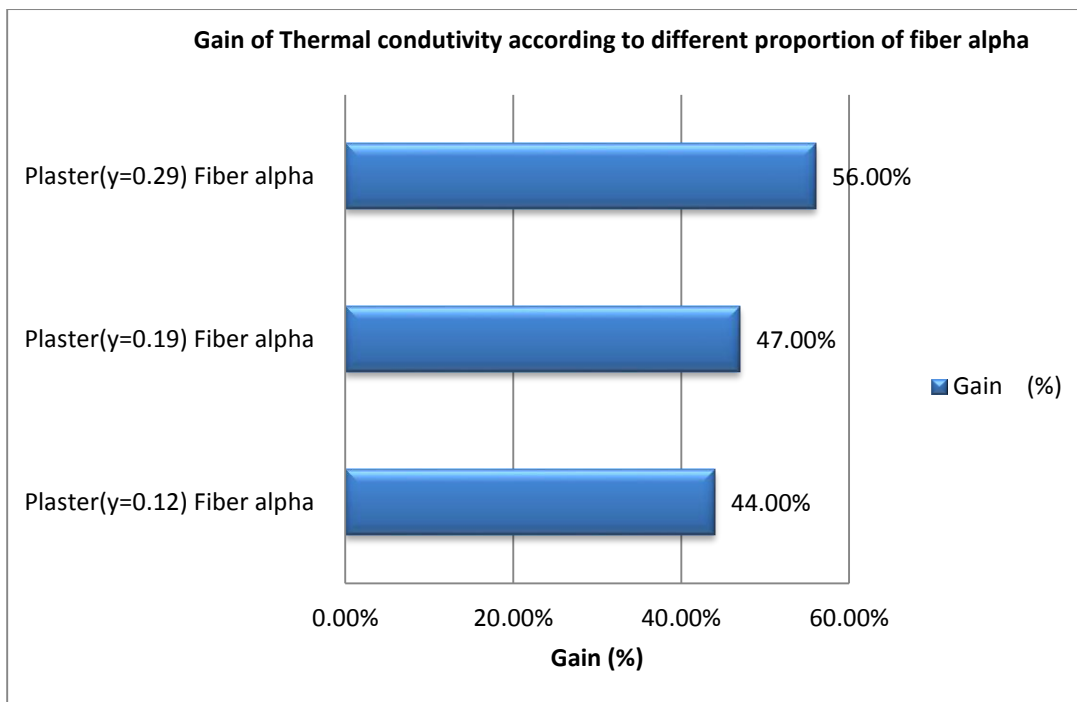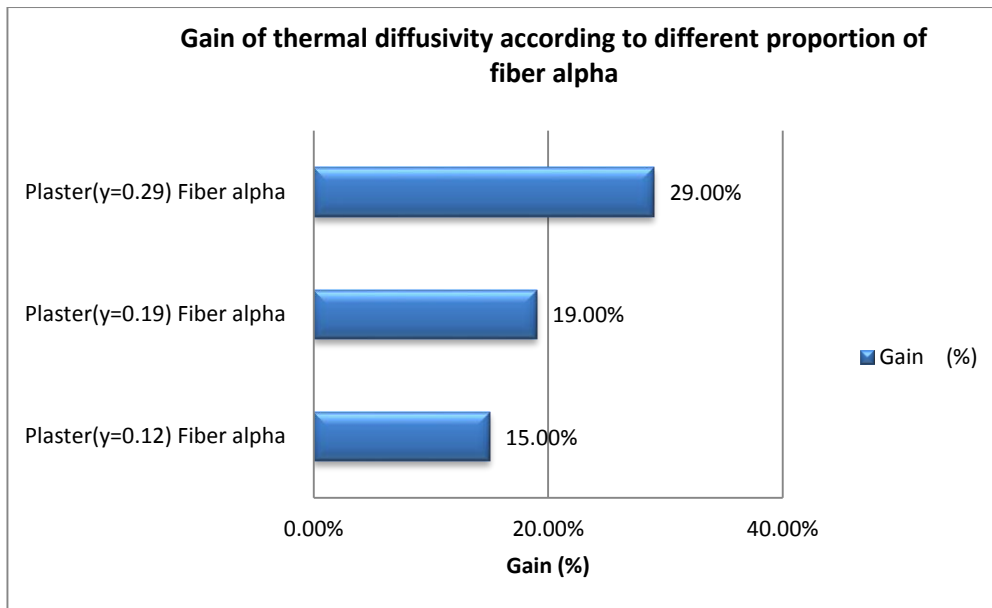
Histogram 2: Gain on the thermal conductivity according to the proportion of fiber alpha.

The histogram 3 shows the decrease of thermal diffusivity according to the proportion of the fiber alpha from $2.4 \cdot 10^{-7}$ to $0.14 \cdot 10^{-7}(m^2.s^{-1})$ for the highest proportion of fiber alpha (y=0.29).

The histogram 4 shows the gain obtained in term of thermal diffusivity which attends 29% so the fiber alpha retards the acceleration of heat flow inside the composite developed.
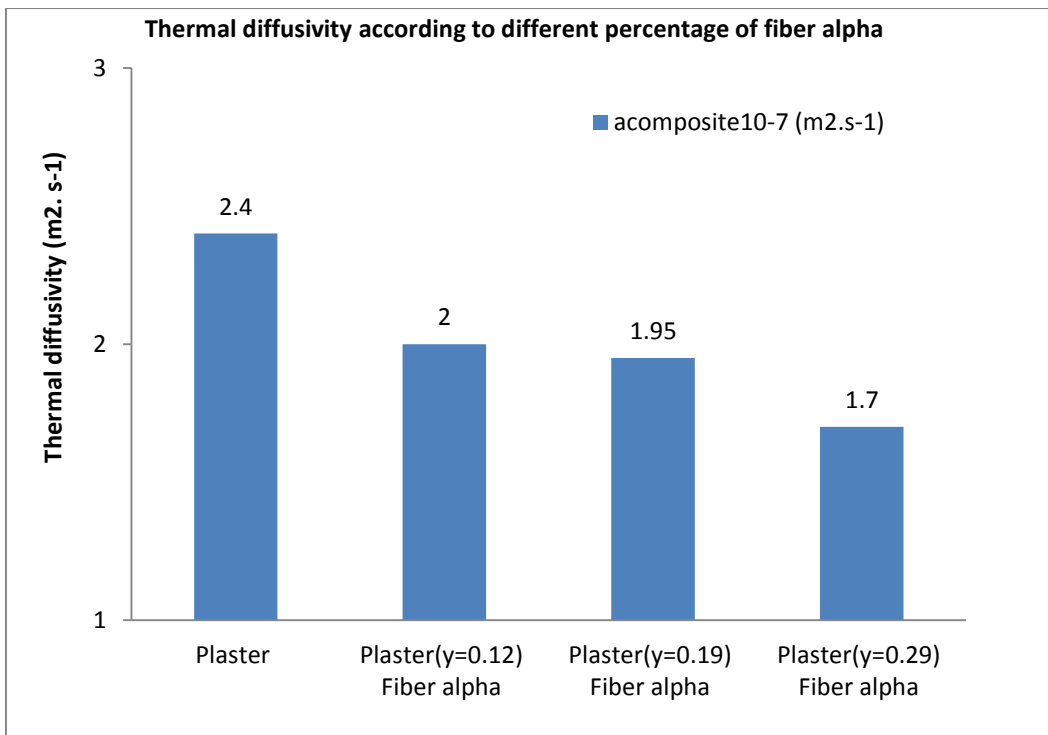
Histogram 3: Thermal diffusivity according to the proportion of fiber alpha.

Histogram 4: Gain on the thermal diffusivity according to the proportion of fiber alpha.

Comparison Of The Experimental Results WithAnalytical Models Of Equivalent Conductivity

Authors compare the experimental results with theoretical models which calculate the equivalent thermal conductivity of materials of two components: a continuous phase (plaster in our case) and a dispersed phase (fiber alpha).

Using the theoretical models of equivalent thermal conductivity in our study, oblige us to know the thermal conductivity of the continuous phase $\lambda_{plaster}$=0.32(W.m^{-1}.K^{-1}) and of dispersed phase: fiber alpha λ_f=0.04 (W.m^{-1}.K^{-1}).

The authors apply these theoretical models to the produced samples and then they represent their evolutions according to

the volume of fiber alpha (figure3).

According to results, we deduce that the experimental results are between the lower limit (series model) and upper limit (Parallel model). Also, the experimental results of thermal conductivity of this material are represented with two models series and beck'swhich is a combination between the series and the parallel model, then come the geometric model. The parallel model is far to represent the experimental results of thermal conductivity. Moreover, it comesthe Hamilton model which is far from representing those results because it considers that the additive added resemble to sphere or cylinder or this is not the case for the fiber alpha.
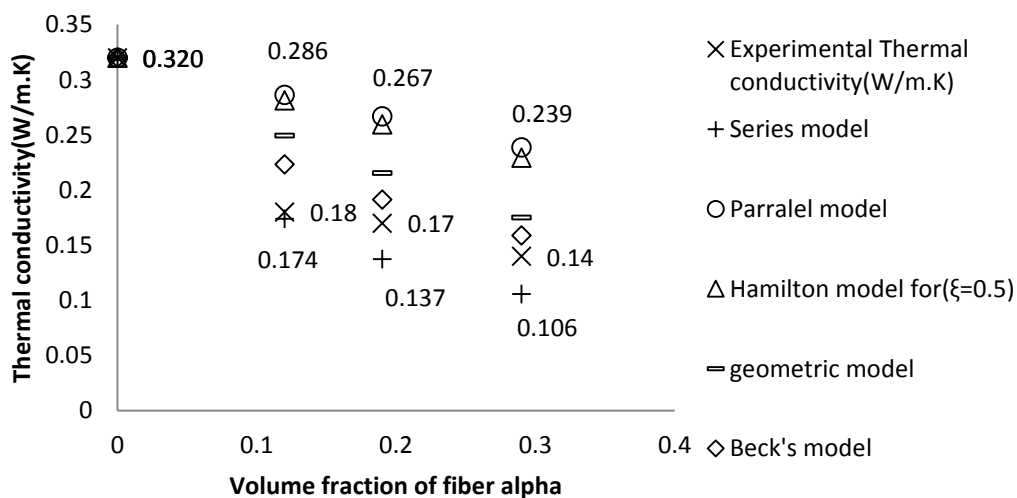
Figure 3: Results of the experimental thermal conductivities confronted to the theoretical model for mixture of plaster-fiber alpha.

Thickness Of Heat Flow Diffusion

An analysis was conducted to see the variation of thickness of the composite clay-expanded perlite according to time of heat flow diffusion using the relation (18).

The relation between the thickness and the time ofheat flow diffusion for a homogenous component inside building is defined as the product of heat capacity and thermal resistance of the same component

$$t = R.Q = \left(\frac{e}{\lambda}\right) * (e.\rho c) \qquad (17)$$

We conclude that

$$t = e^2/a \qquad (18)$$

According to the figure 4, authors observe that the thickness of heat flow diffusion of plaster according to time (3h, 6h,9h and 12h) is:

(5.09, 7.20, 8.81,10.18)(cm).

The gain of depth heat flow diffusion is between the minor values corresponding to the fraction of fiber alpha (y=0.12) (4.28, 6.05, 7.42, 8.56 (cm) and the major values of depth heat flow diffusion (5.09, 7.2, 8.82, 10.18 (cm) for the fraction (y=0.29) of fiber alpha.

The decrease of the depth heat flow diffusion by adding fiber alpha is due to the porosity created inside materials.

According to this, authors conclude that the fiber alpha decreases more and more the thickness of heat flow diffusion and retards the diffusion of heat flow inside houses.
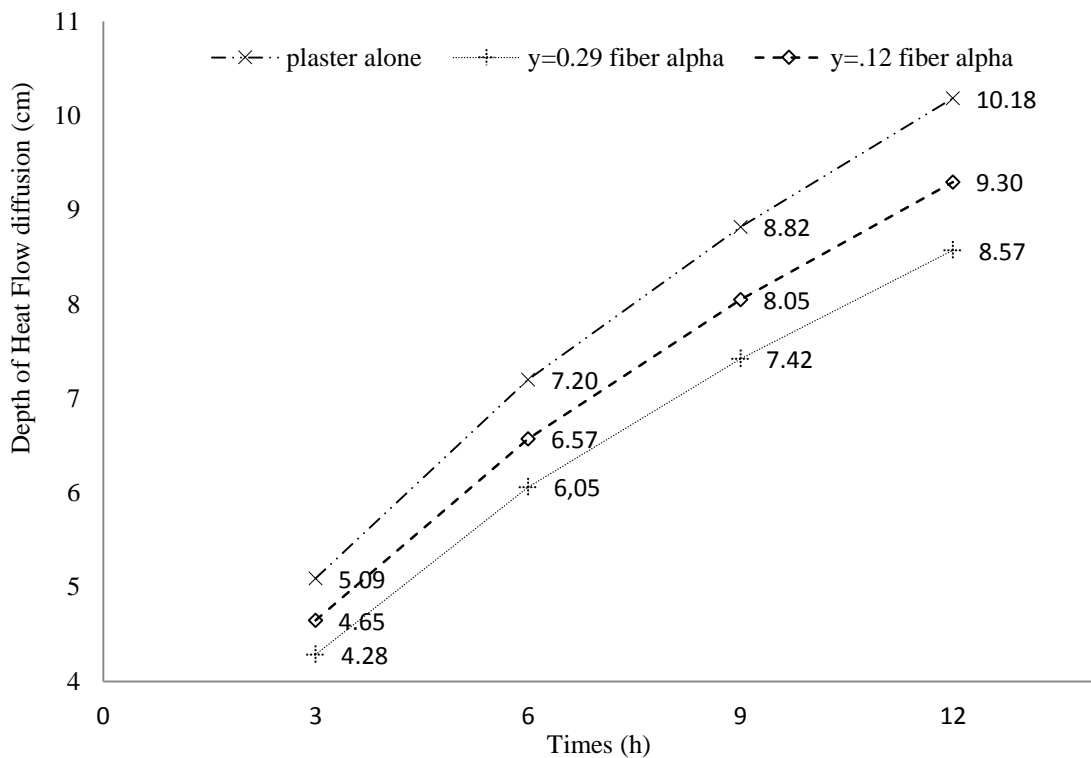

Figure 4: Comparison of Thickness of heat flow diffusion between samples studied for different volume fraction of fiber alpha according to time.

Resistance Of Flexure

The results of flexure strength are presented on the histogram 5concerning the composites plaster-fiber alpha fordifferent percentage of additives.

Analyses of results permit those observations:

The flexure strength increases according to the increase of time capture of binder.The increase in the value of strength flexure according to time is due to the delayedbinding of the

binder. The causes of this increase are the absorption of water by the fiber andthe interaction between the material plaster and fiber alpha.

The flexure strength increases about 25% comparing the initial value of plaster in a period of 21 days when the volume fraction of fiber-alpha increases.

This gain in flexure strength is due to the fiber-alpha which makes the composite more resistant to flexure according to the

ductile behavior of composite.

The authors observe that during essays of flexion three points the composite plaster-fiber alpha does not break itself suddenly but the crack appears on the lower face of samples gradually.

The composite plaster-fiber alpha is an association between two materials of different rigidity. A rigid binder which gives fragility behavior and a supple insulating material which gives the ductility behavior.
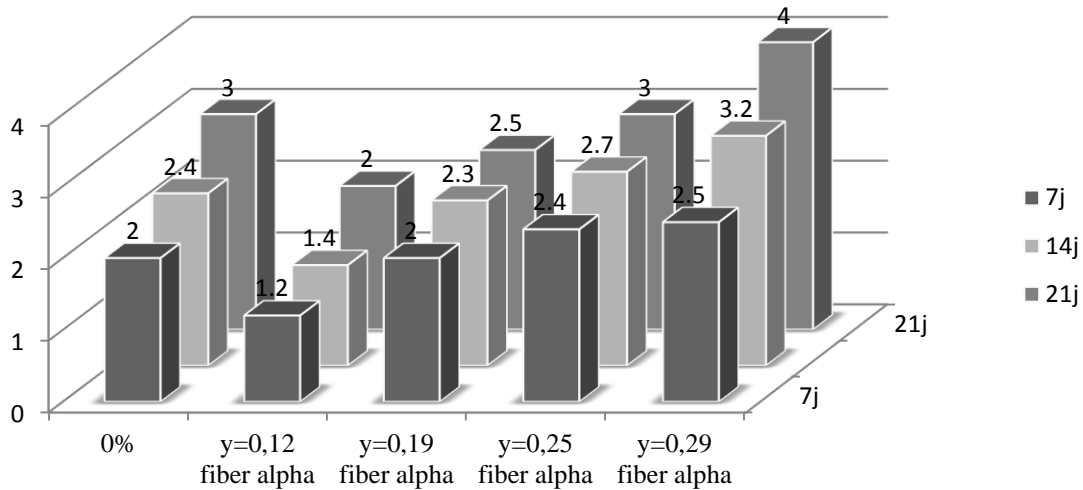
Histogram 5. Flexure strength for samples for different percentage of the additives fiber alpha.

CONCLUSION

This paper is an investigation of thermal and mechanical properties of a developed material plaster-fiber alpha.Many percentages of fiber alpha was studied to see the best proportion of fiber which assures an optimum mechanical and thermal characteristics.

The methods used in thermal characterization are the asymmetrical hot plate and flash methods.However, for the mechanical properties flexure three points method was studied.Also, heat flow diffusion was investigated to see the effect of this developed material on the thermal inertia.

The results obtained indicates that we attend a gain in term of lightness 27% comparing to the plaster alone.

However, for the thermal conductivity we attend a gain of 56% comparing to the conductivity of plaster when for the thermal diffusivity ,this gain attend 29%.

Moreover ,for the thermal inertia especially the heat flow diffusion decreases from 11cm to 9cm which makes our developedmaterial possesses good properties Furthermore, for the mechanical properties the flexure resistance increases more than 25% comparing with plaster alone.

According to this, this developed material possesses a good thermal and mechanical properties which make it useful in construction building, especially in the ceiling.

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