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Thermomechanical and Physical Properties of Plaster Concrete Reinforced with Natural Fibers

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KEYWORDS

Luffa sponge fibers;
Reinforced plaster;
Mechanical characteristics;
Thermo-physical properties.

ABSTRACT

The main objective of this experimental study is to valorize local materials in order to use them as composite Materials (CM) for construction. In this study case, the CM is composed of fibers of Luffa sponge embedded in plaster. Although material resources are abundant in Tunisian territories, their use is very limited. Plaster, the by-product of heat treatment of gypsum, is used in building as coatings and decorative elements. Despite its satisfactory isolation, it has a weakness in its mechanical strength. In this research study, we focus on the enhancement of the thermo-mechanical properties of plaster by adding Luffa sponge fibers into its Matrix. The experimental studies rely on varying the mass fractions of Luffa sponge fibers chemically treated by an alkaline solution (NaOH) in the plaster matrix and then testing thermo-mechanical and physical properties. The results showed that an adequate optimum compromise linking all properties (mechanical, thermal, and chemical) is reached by CM made up of 1% Luffa sponge fibers for the following condition of chemical treatment of 1% NaOH at a temperature of 50°C for 90 min.

1. Introduction

Tunisia is wealthy in mineral and biological natural resources like gypsum and the Luffa plant. But, it is poorly exploited and undervalued. Therefore, these resources deserve to be used as composite materials (CM) for construction. In this study, we are particularly concerned with the value of CM residing in plaster and Luffa sponge which is the fruit of the Luffa plant. Plaster is derived from the thermal treatment of Gypsum. It is widely used in construction, though it is an extremely fragile material. However, its available quantities and its proven virtues constitute a basic impetus to study it in order to seek the possibility of reducing the effect of this main defect. Some former research had proven that fiber reinforcement significantly reduces its fragility. The plaster is made up of linked calcium sulfate and dihydrate crystals.

It is a thermally treated gypsum. A gypsum network is formed when these crystals entangle. Despite its advantages, gypsum as a building material has several disadvantages, including its brittleness, weight, and low water resistance [1, 2]. These drawbacks can be avoided by the use of many additives to the gypsum matrix such as natural fibers, manufactured fibers, mineral particles, etc. Furthermore, the Addition of agricultural and industrial materials as reinforcement to gypsum-based composites has been reported by several researchers to improve brittleness, thermal characteristics, and mechanical performance [3, 4]. El Marhoune et al [5] used alfa's fibers with a percentage of 1.3% and 5%. They displayed an increasing rate of 5% in thermal conductivity. Djoudi et al. [6] used palm fibers. They revealed the increase of the mechanical properties and the decrease of the thermal conductivity when the rate of added palm fibers increases. Fernea et al. [7] were basically interested in the gypsum composites strengthened with hemp. They found that the thermal conductivity, flexural, and compression strength of the composites decreased. The gypsum composite manufactured with 20% fiber loading displays good flexural strength and thermal stability, which were further proven by

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Selamat et al. [8]. Using the fibers of date palm, Ben Mansour et al. [9] found that date palm fibers underneath 15% fulfill both mechanical and thermal necessities in constructing materials. In addition, Amara et al. [10] demonstrated that when gypsum is pure, its thermal diffusivity is equal to $4.225.10^{-7}$ $m^2.s^{-1}$. However, when using 10% palm fiber, its value decreases to $3.417.10^{-7}m^2.s^{-1}$. Benaniba et al. [11] assessed the mechanical and thermal performance of date palm fiber reinforced with cement and sand. The results revealed that the incorporation of date palm fiber reduces the thermal conductivity composite. Departing from this study, the composite with a weight percentage of date palm fibers of 30% suits both mechanical and thermal requirements in building materials. In the same context, Benaniba et al. [12] carried out a study that determined the changes in thermal conductivity of new composite material based on cement, according to various percentages of date palm fibers, namely (0; 6; 12; 18; 24, and 30%). They proved the decrease in thermal conductivity values. In 2018, Belkadi et al. [13] used vegetable and synthetic fibers as reinforcement in cement. Relying on the results of tests that are conducted by these researchers, it was inferred that the incorporation of different concentrations of vegetable and synthetic fibers in the cement increases the modulus of elasticity and decreases thermal conductivity. Dridi et al. [14] studied the thermal and mechanical properties of concrete reinforced with vegetable and glass fibers at rates of 0.1%; 0.3% and 0.5% relative to the total volume. Cherkiet al. [15] used the asymmetrical transient hot plate method to investigate the thermal characteristics of a gypsum-based composite material with embedded granular cork. Recent research undertaken by Suresh babu et al. [16] has shown the influence of hemp's fiber length and its volume fraction on thermo-mechanical and physical characteristics. Results yielded a better increment in mechanical properties and a significant decrease in the thermal conductivity of CM. In the same respect, Gao and Li [17] studied the mechanical characteristics of a gypsum composite reinforced with straw fibers. Resting on the test results, the wax emulsion of the straw fiber improves the compressive and flexural strengths. They also asserted that modifying the surface of straw fibers improves the water resistance of gypsum composite. The study of [18] centered around the impact of the variety of volume part of fleece on the thermal conductivity, thermal diffusivity, and its influence on the damping factor, temperature lag, and heat flow density. In 2022, Touil et al. [19] examined the thermo-mechanical properties of composite materials based on coffee granules. It seemed that there was a minimization within the thermo-physical properties while maintaining its mechanical properties corresponding to the coffee granules' mass proportion of up to 6%. The effect of chicken feather waste on the thermal properties of mortar composites was investigated by Ouakarrouch et al. [20]. They revealed that chicken feathers improve the thermal properties of reinforced mortar. Sakthieswaran N. and Sophia M. [21] investigated the mechanical properties of the Prosopis Juliflora fibers reinforced with gypsum composites and highlighted that the flexural strength of the composites increased with the addition of 2% weight of Prosopis Juliflora fibers content due to the ability of the fiber to fill up the voids of the composites. Horma et al. [22] explored the effect of the inclusion of Spent Tea fibers in the manufacturing of bio-sourced cement-based mortars and studied its thermal performance. The result was a remarkable improvement in thermal conductivity (67%), thermal diffusivity (57%), density (24%), and compressive strength (97%). Innovative building materials are the main keys to developing building structures. Therefore, prefabricated plaster products have been increasingly employed in construction in recent years, as it is the most economical building material with their environmental safety qualities and excellent physical properties. The main objectives of this research are to investigate the thermal-mechanical and physical properties of a new bio-CM constituted of Plaster and Luffa fibers which are abundant in Tunisia. The development of innovative isolating and robust CM building materials is very appealing in building structures and finishing owing to its economical and environmentally friendly qualities as well as its outstanding physical properties.

2. Materials and Methods

2.1. Materials

2.1.1. Plaster

The plaster used in this study is prepared by heating the gypsum that is found abundantly in Maknassy, a city in Tunisia. Gypsum ($CaSO_4.2H_2O$) has 2 moles of crystallized water and three-quarters of this water evaporates on careful heating, to a very high temperature of 150°C for an hour. Gypsum (calcium sulfate dihydrate) on heating turns into a white powder (calcium sulfate hemihydrate), which is what we call Maknassy Plaster ($CaSO_4.1/2H_2O$) with a half mole of crystallized water. It is expressed according to the following chemical reaction (1):

$$\underset{\text{(Natural gypsum)}}{CaSO_4.2H_2O} + Heat(150^oC) \rightarrow \underset{\text{(Plaster)}}{CaSO_4.1/2H_2O} + 3/2H_2O \quad (1)$$

2.1.2. *Luffa Sponge*

Luffa is a climbing plant of the Cucurbitaceae family and its fruit before its harvest moves through multiple stages, as shown in Fig.1.

When the fruit is fully ripened, it is very fibrous. The fully developed fruit is the source of the Luffa scrubbing sponge. Luffa sponge is one such material with a complex interconnecting porous structure. The fibers are connected to form a 3-dimensional, highly porous network.

Based on previous studies [23] [24], these percentages of alkaline solution were selected, 0.5, 1, 2, 3, and 5% to better improve the characteristics of fibers. The alkaline treatment aims to remove impurities (hemicellulose and lignin). It is one of the treatment methods commonly applied to alter the surfaces of natural fibers in order to improve the interface compatibility among fiber and plaster matrices. It induces a better contact and bonding mechanism between fiber and plaster matrix.

The tensile strength of treated fibers under such conditions as the concentration of the alkaline solution, time of soaking, and temperature, were tested. Further details are illustrated in [25]. It has been found that the fibers drenched in an alkaline solution of concentration 1% NaOH for 90 minutes at a temperature of 50°C are considered as an optimum condition leading to an increased rate of tensile strength amounting to around 61% compared to untreated fibers. Figure 2 depicts the obtained results.

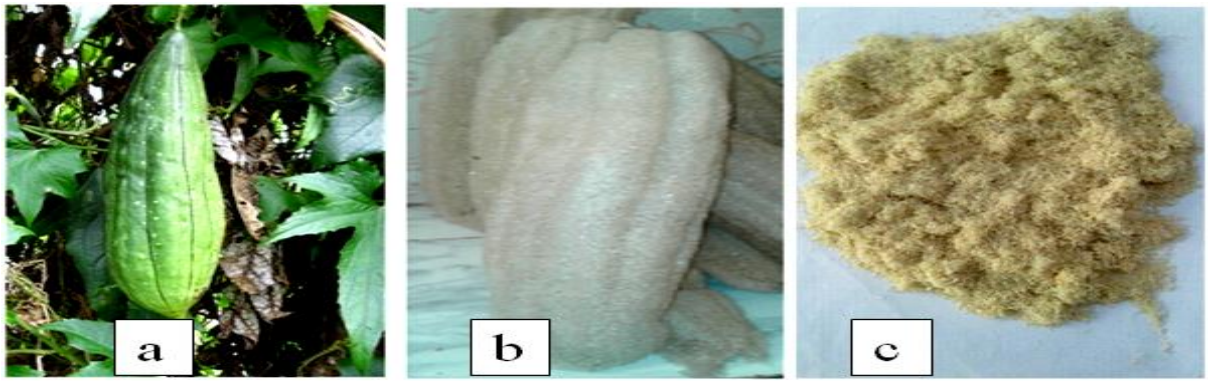
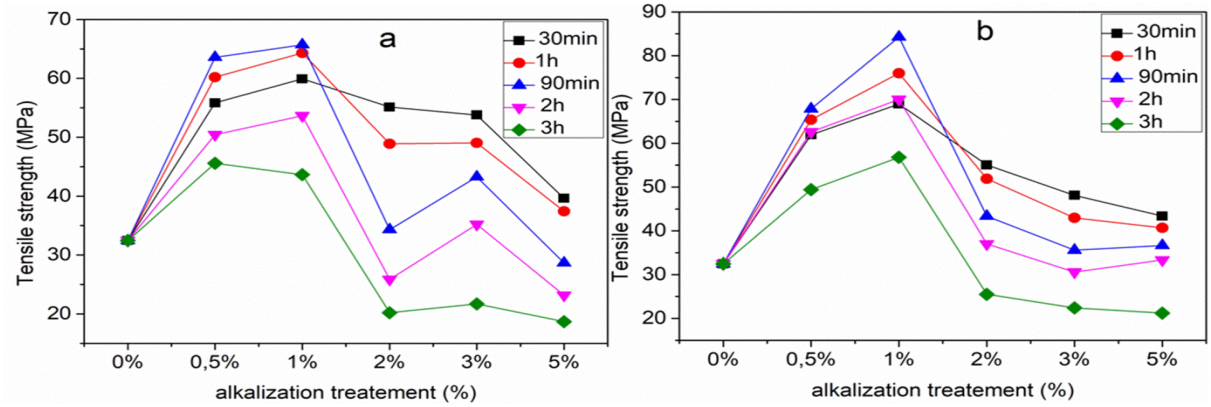


Fig. 1.(a) Young Luffa, (b) Luffa sponge; (c) luffa fibers after grinding



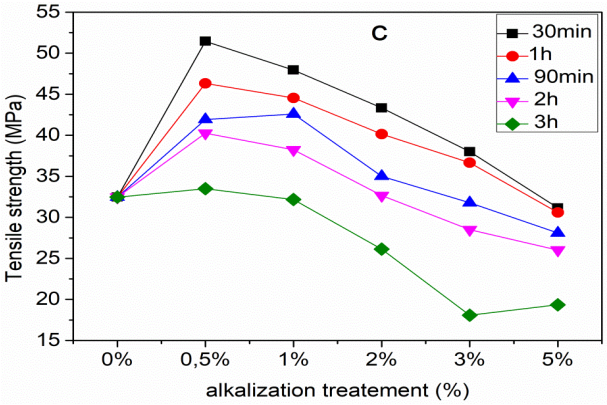


Fig. 2. The effect of NaOH on the tensile strength of luffa sponge's fibers treated with different concentrations and duration (a) for 25°C, (b) for 50°C and (c) for 75°C [25]

2.2. Experimental Methods

2.2.1. Fibers Preparation

After separating fibers manually from the sponge of Luffa, they were soaked in an alkaline solution of 1 % concentration for 90 minutes and 50°C. Afterward, they were dried in the air, and ground to obtain particles of the order of a millimeter (see Fig.1.c).

2.2.2. Plaster Matrix Preparation

The mixture of plaster which is used in this work was prepared by mixing plaster with water, using a water-to-plaster ratio (w/g) of 0.6 in the mixing process. The specimens were prepared with different dimensions (40 mm- 40 mm- 160 mm) in accordance with the requirements of NF EN 196-1 standard, which were intended for mechanical tests bending (Fig. 3. a). Note that, the preparation of the specimens' dimensions (40 mm- 40 mm- 40 mm) were intended for Compression tests (Fig. 3. b). However, for thermal tests, the specimens' dimensions were (270 mm -270 mm -30 mm) (Fig. 3. c). Subsequently, the specimens were stored and dried in the laboratory at ambient temperature for 28 days.

As for the mass fraction, it changes according to the work and depending on the nature of the matrix and the fiber. In this study case, the choices were 1, 3, 5, and 7%. This choice refers basically to the outstanding results of several studies. Yet, practically, it cannot be selected more than 7% due to the difficulty of the mixing phase when choosing a mass fraction exceeding 7%.

In these studies, Amara et al. [10] revealed that the following mass fractions: 2, 5, 8, and 10% were chosen to develop a gypsum material using palm fibers as reinforcement. However, a study performed by Djoudi et al. [6], focused on plaster reinforced with palm fibers (0.5, 1, 1.5, 2, and 2.5%). As for Achour et al. [26], the fibers were added in a mortar with the percentages 0.5, 1, 1.5, 2, 2.5, 3, 3.5, and 4%. Similarly, Braiek et al. [27] emphasized that gypsum composites with palm fibers were obtained with different mass fractions of (0, 5, 10, 15, and 20%). Referring to El Marhoune et al. [5], a study was conducted for a composite material based on plaster, with respect to different percentages of Alfa: 1.3% and 5%.

2.2.3. Resistance Tests

The testing machine ensures a constant loading speed of 2 mm/min and allows the applied load to be measured with an accuracy of 1%. A 3-point bender (resistance to bending) was achieved by the apparatus portrayed in Fig.4.b. To determine the breaking stress (resistance to compression), the apparatus indicated in Fig. 4. a, was used. All tests were carried out in the laboratory at ambient temperature.

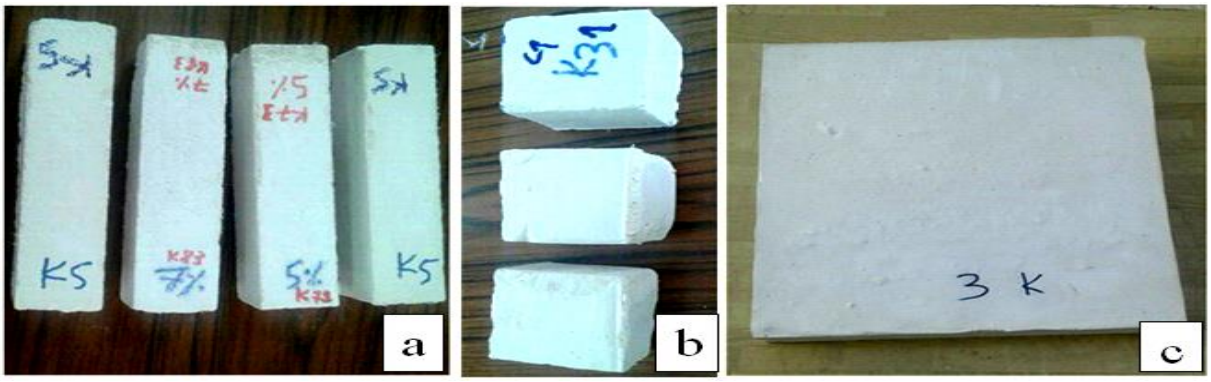


Fig. 3. Specimens prepared for performing (a, b) mechanical; (c) thermal tests

Fig. 4. (a) Compression machine; (b) Three points bending test machine

a. Flexural Strength

The flexural strength of the specimen was tested using a flexural machine (see Fig. 5), which is designed to determine the flexural strength in accordance with Norm: EN 196-1.

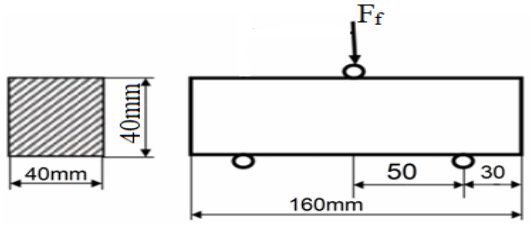


Fig. 5. Sketch of Device for the three-point bending strength test

The flexural strength is represented by the following formula (2):

$$R_f = \frac{3 \times F_f \times L}{2 \times b \times h^2} \quad (2)$$

where:

Rf: flexural strength [MPa].

Ff: force applied [N].

b: width of specimen [mm].

h: thickness of the specimen [mm].

L: Length of the specimen [mm].

b. Compressive Strength

The compressive strength of the mortar is determined according to standard EN 196-1, using a hydraulic press. Concerning the half-prisms of the specimen, they are broken in bendings, to be subsequently fractured in compression, as displayed in Fig. 6.

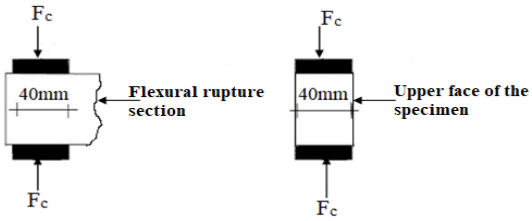


Fig. 6. Sketch of Device for the rupture test in compression

The formula for compressive strength is denoted by:

$$R_C = \frac{F}{L \times h} \quad (3)$$

where:

Rc: compressive strength [Mpa].

F: Force applied [N].

L: Length of the specimen [mm].

h: thickness of the specimen [mm].

2.2.4. Porosity Calculation

Porosity is defined as the ratio of the volume of non-solid phases (liquid, gas, vacuum) to the total volume of the specimen.

$$P = \frac{\text{Non-solid volume}}{\text{Total volume}} \quad (4)$$

In this case, to determine the porosity of different specimens, we followed the following steps were undertaken:

- ✓ Weigh each specimen in the dry state (g).
- ✓ Submerge each specimen in water for 48 hours.
- ✓ Weigh each specimen in the wet state (g).
- ✓ Determine the void volume of each specimen by calculating the difference between the wet mass and the solid mass and dividing by the density of water.
- ✓ Determine the apparent volume of the specimen.
- ✓ Determine the porosity (ratio between void volume and apparent volume).

$$P = \frac{\text{void volume}}{\text{Total volume}} \quad (5)$$

2.2.5. Density

After the materials had been dried, the density (ρ) was determined. It is the standard mass volume unit of the material that constitutes the aggregate, considering the voids that may exist in or between the grains. The density (ρ) is calculated according to the equation below:

$$\rho = \frac{M}{V} \quad (6)$$

where:

M is the total mass of the specimen (g).

V is the volume of the specimen (m^3).

2.2.6. Thermal Apparatus

This method is determined using the LEI700 measuring cell called the "blue box". The measuring device consists of a highly insulated enclosure "A", which is kept at a low temperature by cooling with glycol water flowing from a cryostat. Two similar and independent measuring boxes, namely "B1" and "B2" are insulated with polystyrene inside (see Fig.7). One of them is used to measure steady-state thermal conductivity, and the other one is used to determine transient thermal diffusivity.

a. Thermal Conductivity

The measurement of thermal conductivity using the box method in a steady state consists in creating two atmospheres: hot and cold, on both sides of the material to be tested (a low temperature and highly insulated enclosure) and a box equipped with a heating film controlled by a rheostat in order to maintain a temperature close to ambient temperature. The surface temperatures of the specimen, both hot and cold faces as well as the ambient temperature are controlled and measured, as exhibited in Fig. 8.

Fig. 7. Photo of EI700 measuring apparatus

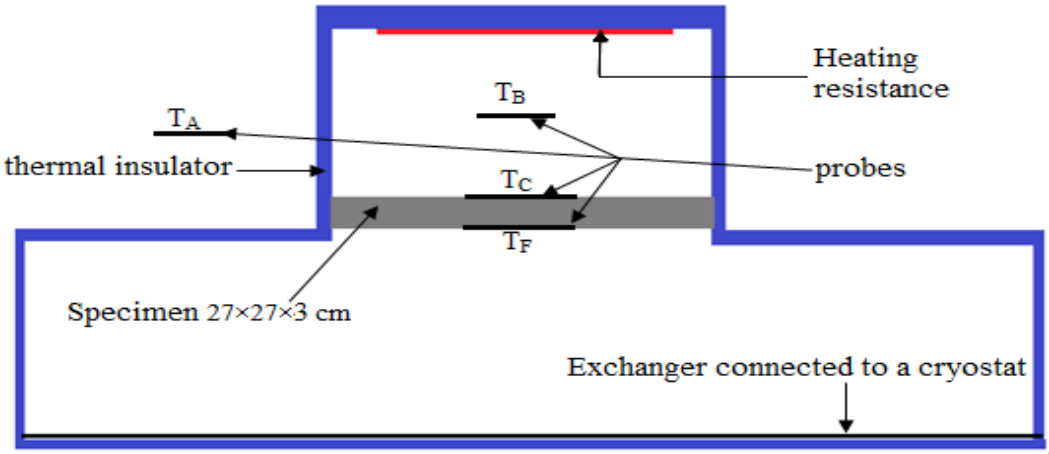


Fig. 8. Descriptive diagram of the device for measuring thermal conductivity

In a steady state, the heat transfer takes place along the flow lines perpendicular to the faces. It is a one-dimensional type flow with temperature T varying linearly in x, as displayed in Fig. 9.

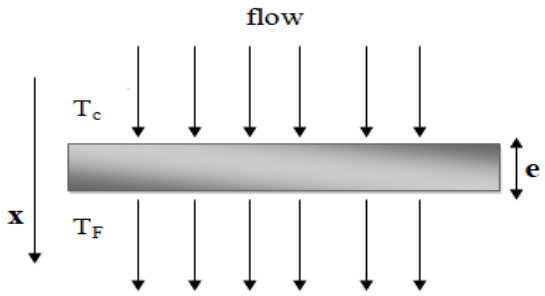


Fig. 9. Descriptive diagram of heat transfer through the specimen

When the temperatures stabilize with a variation of the order of 0.1 degrees in one hour, we suppose that we reach a steady state. This lies usually between 3 and 5 hours after mounting the specimen.

The thermal conductivity is indicated by the following formula (7):

$$\lambda = \frac{e}{S(T_C - T_F)}\left[\frac{U^2}{R} - C(T_B - T_A)\right] \quad (7)$$

where:

e is the thickness of the specimen, (m).

S is the area of the specimen, (m^2).

A is the value of the heating resistor (Ω).

C is the heat loss coefficient (W/K).

U is the voltage across the resistor (V).

T_C and T_F are the temperatures of the hot side and the cold side (°C).

T_B and T_A are the temperatures inside the box and ambient (°C).

b. Thermal Diffusivity

Concerning the measurement of thermal diffusivity in a transient state, a measurement cell is made up of two identical boxes, perfectly symmetrical (see Fig.10) and strongly insulated from the external environment by polystyrene. To send a heat flux, a constant high-power halogen lamp (1000W) was used for a controlled duration on the upper face of the specimen.

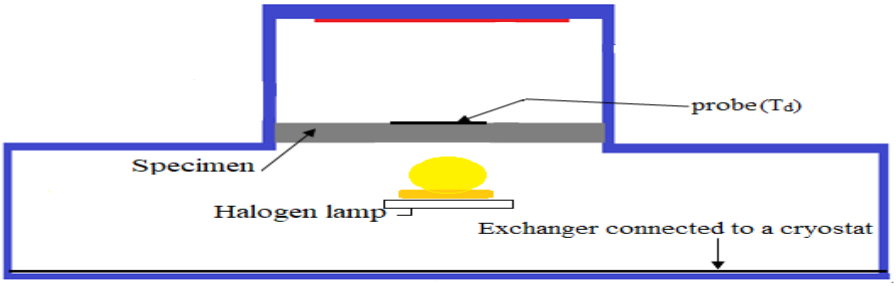


Fig. 10. Descriptive diagram of the device for Thermal diffusivity measurement

To determine the thermal diffusivity from the experimental thermogram (Fig. 11), we applied two different models, the PARKER model, and the DEGIOVANNI model, in order to compare the obtained results.

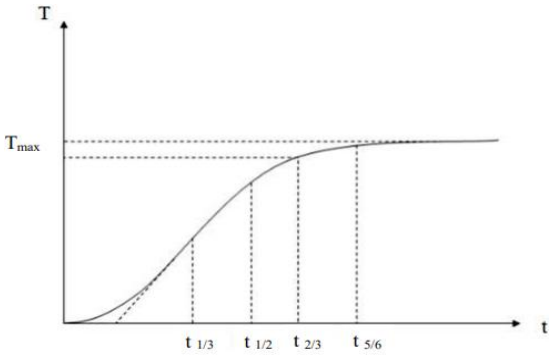


Fig. 11. Typical thermogram for the determination of thermal diffusivity [28]

➢ *Degiovanni Model*

In order to specify the thermal diffusivity, the DEGIOVANNI model was applied. Equations (8) to (11) make it possible when we estimate the thermal diffusivity by estimating the times for which several pairs of points have been considered, at characteristic times: $t_{1/3}$, $t_{1/2}$, $t_{2/3}$, and $t_{5/6}$. This is achieved by considering heat losses during diffusivity measurement [29].

$$\propto_1 = \frac{e^2}{t^2_{\left(\frac{5}{6}\right)}}\left(\left(1{,}15 \times t_{\frac{5}{6}}\right) - \left(1{,}25 \times t_{\frac{2}{3}}\right)\right) \quad (8)$$

$$\propto_2 = \frac{e^2}{t^2_{\left(\frac{5}{6}\right)}}\left(\left(0{,}761 \times t_{\frac{5}{6}}\right) - \left(0{,}926 \times t_{\frac{1}{2}}\right)\right) \quad (9)$$

$$\propto_3 = \frac{e^2}{t^2_{\left(\frac{5}{6}\right)}}\left(\left(0{,}761 \times t_{\frac{5}{6}}\right) - \left(0{,}862 \times t_{\frac{1}{3}}\right)\right) \quad (10)$$

$$\propto = \left(\frac{\propto_1 + \propto_2 + \propto_3}{3}\right) \quad (11)$$

➢ *Parker Model*

In order to determine thermal diffusivity, the PARKER model was applied. Equation (12) allows this when estimating the thermal diffusivity by specifying the thickness of the specimen and measuring the half-rise time.

$$\alpha = \frac{1{,}37}{\pi^2} \times \frac{e^2}{t_{\left(\frac{1}{2}\right)}} \quad (12)$$

where:

$t_{1/2}$ is the maximum half-rise time of the temperature of the unsolicited face.

e is the thickness of the specimen (m).

c. Thermal Effusivity

One of the intriguing ideas regarding how thermal insulation materials operate is thermal effusivity. It describes the material's capacity to both absorb and release heat from its surface. High thermal effusivity materials can't retain heat for very long since they lose it rapidly from their surface when the surrounding temperature decreases.

Relying on the relation between thermal conductivity and thermal diffusivity measurements, the thermal effusivity of the investigated composite materials is currently considered using equation (13):

$$E = \frac{\lambda}{\sqrt{\alpha}} \quad (13)$$

Where:

E is thermal effusivity ($J.K^{-1}.m^{-2}.s^{-1/2}$).

λ is thermal conductivity ($W.m^{-1}.K^{-1}$).

α is thermal diffusivity ($m^2.s^{-1}$).

d. The Specific Heat Capacity

An essential factor that describes the thermal inertia of materials is the specific heat capacity. It is obvious to estimate the specific heat capacity of composite material whenever its density, thermal conductivity, and diffusivity are measured. The relationship is expressed as follows (14):

$$C_P = \frac{\lambda}{\rho \cdot \alpha} \quad (14)$$

where:

Cp is specific heat capacity ($J.kg^{-1}.K^{-1}$).

ρ is density (kg/m^3).

3. Results and Discussion

The experimental findings for each specimen are outlined in Tables 1 and 2.

Table 1. Data on physical, thermal, and mechanical properties

Specimen	Porosity (%)	Compressive Strength [MPa]	Flexural Strength [MPa]	Density [kg/m^3]	Thermal diffusivity (m^2/s)	Thermal Conductivity [W/mK]
Plaster	38	9.8	1.3	1168	2.8 10^{-7}	0.27
Plaster+1 % Luffa	40	10.4	1.5	1137	2.7 10^{-7}	0.255
Plaster+ 3 % Luffa	46	8.9	1.4	1079	2.36 10^{-7}	0.213
Plaster+5 % Luffa	51	8.2	1.2	1018	2.14 10^{-7}	0.183
Plaster+7 % Luffa	57	7.8	0.9	947	1.96 10^{-7}	0.162

Table 2. Data on thermal effusivity and specific heat capacity

Specimen	Thermal effusivity (J.K^{-1}.m^{-2}.s$^{-1/2}$)	Specific heat capacity (J.kg^{-1} .K^{-1})
Plaster	510.25	825.58
Plaster+1% Luffa	490.75	830.65
Plaster+ 3% Luffa	438.454	836.46
Plaster+5% Luffa	395.589	840.02
Plaster+7% Luffa	365.92	872.7

3.1. Compressive and Flexure Tests

Departing from Figure .12, the different variations of the mechanical properties, namely the resistance to bending and to compression, are plotted as a function of the fibers' mass fraction of the treated luffa sponge. It traces the evolution of the resistance to bending and compression with the increase in the percentage of fibers. At 1% reinforcement, the bending strength reaches its maximum value of 1.5 MPa, also the compressive strength achieves its maximum at a value of 10.4 MPa. The analyses of mechanical test results revealed that the resistance to compression and bending of the plaster strongly depends on the percentage of the fibers embedded, and 1% of fibers is the optimal quantity to lead to maximal straightening considering the pure plaster. Other research works [6, 30] highlighted observed that the addition of biological materials can also boost the mechanical property of CM. Cheboub et al. [31] asserted that when different percentages of olive kernel shells are incorporated in mortar, the compressive strength of the formulated mortars drops at 91 days of curing. These values are lower by 39; 46; 63 and 75% for the 25; 50; 75 and 100% composites, respectively, compared to those of the pure self-compacting reference mortar. In the same context, Touil et al. [32] demonstrated that the increase of fiber embedded in the plaster matrix decreases the resistance to bending in spite of enhancing the failure mechanism that leads to nonlinear and ductile behavior.

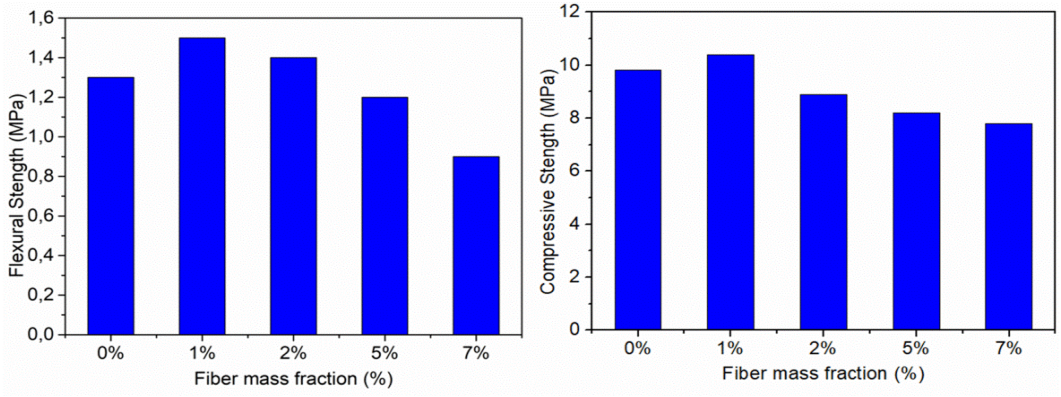


Fig. 12. Effect of reinforcement rate on flexural; compressive strength

3.2. Porosity

Figure 13 traces the evolution of the porosity of a plaster mortar reinforced with luffa sponge fibers. It is noticeable that porosity increases depending on the increase in the percentage of sponge fiber, which refers to the high volume of void generated by the addition of fibers owing to their nature. Porosity evolves from 38% in pure plaster to 57% with 7% reinforcement concentration. Porosity is a very critical characteristic that affects positively the thermal conductivity and inversely the mechanical properties of CM. Similar results were reported by [6, 33] in their research on plaster concrete reinforced with date palm fibers. They found that the incorporation of fibers increases the CM porosity. The porosity of the material increases as the rate of fibers increases. This increase in porosity (which includes both the porosity of fibers and that of plaster) refers basically to the existence of voids in the composites, which results in a decrease in thermal conductivity.

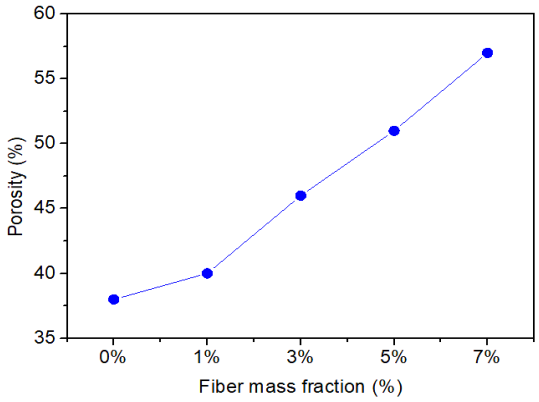


Fig. 13. Reinforcement rate effect on porosity

3.3. Density

In Figure 14, the evolution of the density function of CM by the mass fraction of added sponge fibers is plotted. It reveals that the density decreases progressively and simultaneously with the increase in the percentage of fibers. The density values of the mixtures vary between 1168 kg/m^3 in pure plaster to 947 kg/m^3 with 7% reinforcement concentration. It indicated that increasing the percentage of Luffa sponge fiber in the CM acts inversely on the density when compared to the reference material in all situations. This result goes in good agreement with those recorded in the study of Djoudi et al [6] who clarified that the increase of 2% of the natural fibers in the matrix of the plaster offers a decrease in the density of the composites.

This stands for one of the advantages of using Luffa sponge fibers in an obtained plaster-based material which is much lightweight.

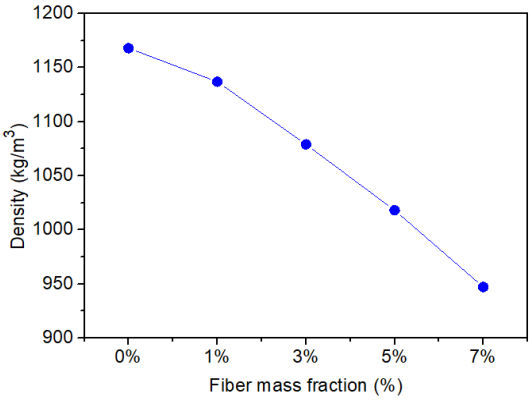


Fig. 14. Effect of reinforcement rate on density

3.4. Thermal Conductivity

The influence of the reinforcement rate of Luffa sponge fiber on the thermal conductivity of CM, is portrayed in Fig. 15. It is obvious that as the percentage of Luffa fiber increases, the thermal conductivity decreases because the conductivity of CM decreases while the porosity increases. In the current study, the thermal conductivity of the CM ranges from 0.27W.m^{-1}.K^{-1} when the material is fibreless to 0.162W.m^{-1}.K^{-1} with 7% of fiber reinforcement. This is suggestive that the fibers improve thermal insulation significantly. It's worth noting that 7% of Luffa sponge fiber has the best thermal behavior and the lowest density. A similar result was obtained by Manuel et al. [33] who revealed that the thermal conductivity of the plaster material reinforced with wood and plastic decreases with the increase of porosity in CM. The study performed by Benmansour et al. [34] disclosed that when cement is pure, its thermal conductivity is equal to 0.75 W.m^{-1}k^{-1} while with 30% palm fibers, its value becomes 0.3 W.m^{-1}k^{-1}. In the same regard, Nasry et al. [35] argued that the thermal conductivity reaches 0.86 W.m^{-1}k^{-1} when the percentage of glass powder reaches 60%, while it is 1.11 W.m^{-1}k^{-1} for pure cement.

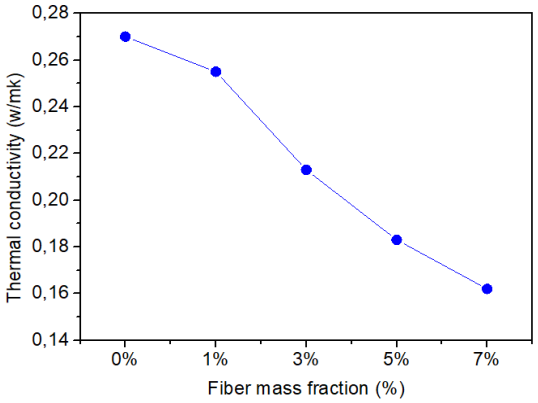


Fig. 15. The effects of thermal conductivity as a function of the number of luffa fibers

3.5. Thermal Diffusivity

In Figure 16, the variation of thermal diffusivity, according to both models, is plotted as a function of the mass fraction of added fibers. It is indicated that the diffusivity of composite material decreases with the increase in the percentage of reinforcement fibers.

Using Parker's model, the diffusivity decreases from $2.84.10^{-7}$ $m^2.s^{-1}$ to $2.41.10^{-7}$ $m^2.s^{-1}$ for pure plaster to 7% of reinforcement, respectively. The same results, achieved using Degiovanni's model, vary from $2.8.10^{-7}m^2.s^{-1}$ to $1.96.10^{-7}m^2.s^{-1}$. This discrepancy is assigned to the assumptions of each model. Parker's model doesn't consider heat losses.

However, Degiovanni's model does. In the same respect, Amara et al. [10], it is emphasized that when gypsum is reinforced by palm fiber, its thermal diffusivity decreases compared to pure gypsum.

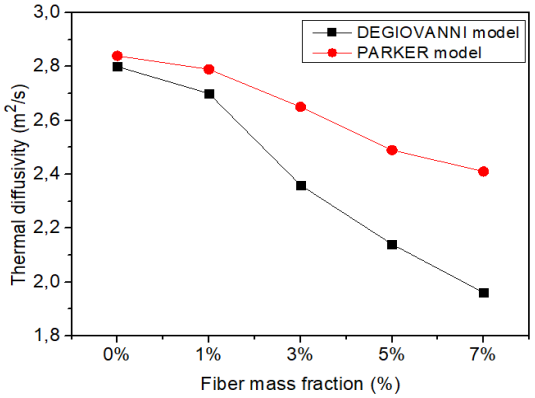


Fig. 16. Comparison of thermal diffusivity results according to two models

Figure 17 depicts the influence of porosity on thermal conductivity and thermal diffusivity when observing the thermal decrease with increasing porosity.

On the other side, Fig. 18, shows that density and porosity act inversely.

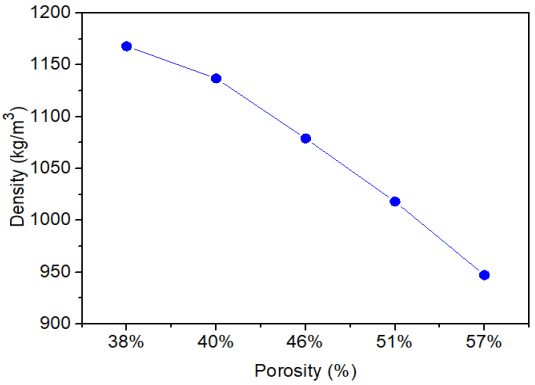


Fig. 18. Porosity as a function of density

3.6. Thermal Effusivity

Variation of thermal effusivity is summarized in Fig. 19. It reveals that the thermal effusivity of the composite materials decreases accordingly with the increase of the percentage of luffa fiber in the plaster matrix. It can drop to 28.28% when the reinforcement fibers are at maximum with a rate of 7%. It is concluded that plaster reinforced with luffa sponge fibers exhibits certain weaknesses in exchanging heat with its environment compared to pure plaster. A similar finding was obtained by [36] who reported gypsum reinforced with the DPF mesh. In the same line, Boumhaout et al. [37] reported cement reinforced with the date palm fiber mesh.

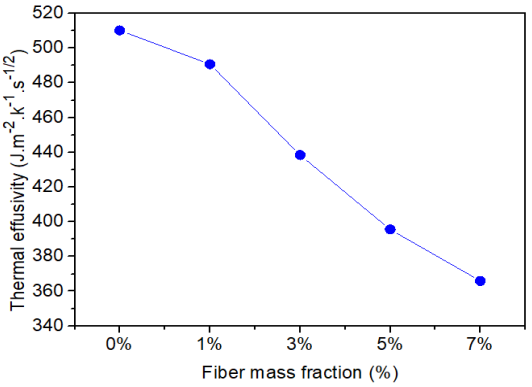


Fig. 19. Variation of the thermal effusivity of plaster for different percentages of fibers

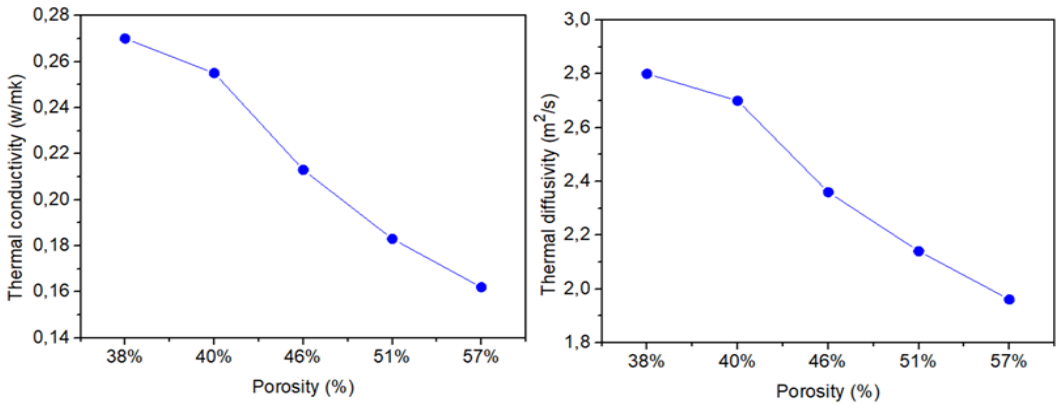


Fig. 17. The effect of porosity on thermal conductivity and thermal diffusivity

3.7. The Specific Heat Capacity

Figure 20 illustrates the evolution of the specific heat capacity of the plaster reinforced with luffa sponge fibers. It can be noted that the specific heat capacity increases to 5.7%. This increase refers is owing to the combined effects of thermal conductivity, density, and thermal diffusivity. The specific heat capacity evolves from 825.58 ($J.kg^{-1}.K^{-1}$) in pure plaster to 872.7($J.kg^{-1}.K^{-1}$) with 7% of reinforcement concentration.

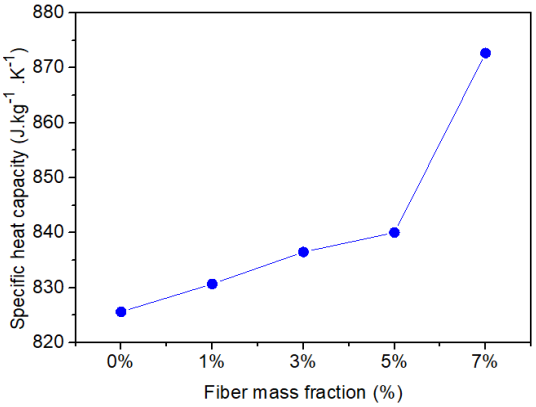


Fig. 20. The effects of thermal capacity as a function of the number of luffa fibers

4. Conclusion

In the current study, the microstructure of the plaster matrix was elaborated in order to improve its mechanical behavior through compression and bending tests, since the plaster is known for being mechanically weak.

In addition, this plaster was used as a matrix of a composite material reinforced with Luffa sponge fibers, which are characterized by strong mechanical tests according to the obtained results of the current study.

Therefore, the alkaline treatment proved to be much more beneficial to improve the adhesion between the matrix and the reinforcement, which decreases the fragility of plaster and improves its resistance to compression.

The mechanical property is equal to a maximum value of 10.4 MPa and the flexural strength reaches its maximum with a value of 1.5 MPa, at 1% of reinforcement. In terms of thermal properties, such as conductivity and diffusivity, test results corroborated that plaster is a good insulator and its thermal properties are enhanced by its reinforcement.

Indeed the addition of 7% of the sponge of Luffa fibers to the composite provides optimal results, with a conductivity equal to 0.162 $W.m^{-1}.K^{-1}$ and a diffusivity equal to $1.96.10^{-7}$ $m^2.s^{-1}$. As a final note; this composite material based on plaster reinforced with fibers of Luffa exhibits effective thermal properties that offer comfortable living.

This study offers a better and deeper insight into a durable and robust bio-composite material (Plasterboards) that can be used for isolating and finishing. In such a case, its outstanding mechanical properties allow Plasterboard, to have a large sizing, which makes it stand out not only as a safe tool but also as an easy and quick-to-install material.

The Use of plasterboard can decrease a project's carbon footprint. In addition, plasterboard is so lightweight that it allows reducing transport costs.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this manuscript.

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