Thermophysical and mechanical characterization of clay bricks reinforced by alfa or straw fibers

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Abstract. This work is part of the valuation of local materials such as clay (earth), alfa fiber and straw fiber. The goal is to use these materials as bricks in rural construction. These materials are abundant, natural, and renewable. The objective of this work is to study the thermal and mechanical behavior of a new material by mixing clay (chosen as the binder) with different mass percentages of alfa fiber (0.5%, 1%, 2%, 3%, 4%), and to compare these results with those of materials often used in the construction of individual houses in rural Morocco (clay + straw). The results obtained prove to us that using straw fibers can reduce the thermal conductivity compared to alfa fiber, which allows to have energy savings of 2% to 7%. By against, alfa fibers can improve the mechanical behavior of clay-based materials when compared to the clay + straw material (an increase of 8% to 17% in the tractive resistance by bending and 6% to 18% for compression resistance). These results also specify the optimal usage conditions of these fibers (alfa and straw) in the clay bricks.

1. Introduction
Because of their abundance and thermal insulation, clay [1] and straw fibers [2] are the two most used materials in the construction of rural houses in Morocco. However, there are other local materials, such as alfa fiber[3], that are abundant in the northern region of Morocco and are unused in construction, despite their benefits and the in prices which are much less expensive than straw fibers.

The manual and visual comparison between the Straw fibers and the fibers alfa has led us to point out that the rod of alfa is more hard than that of straw and that the surface of the stems of alfa is rough [4] (Figure 1) compared to the surface of the stems of straw which is thin . This will allow to create a very good connection between clay and fiber alfa. This adhesion will reduce the voids and consequently improve mechanical behavior.

By against, straw fibers contain more voids inside [2] than alfa fibers (Figure 2). This which will favor the thermal behavior of material clay + straw relative to alfa + clay material.

Based on these remark of departure, we began to work on both (clay + esparto and clay + straw) materials.

To characterize composite materials, we based primarily on the method of the plan hot in permanent regime [5] [6] to determine the thermal conductivity and the compression and tensile tests [7] [8] to get an idea about the mechanical behavior of these two materials.
The final objective is twofold: firstly valorize local materials and also lower energy expenses (cooling and heating), thus contributing to a sustainable environment.

**Figure 1.** Image MEB of an alfa fiber

**Figure 2.** Straw bundle, cross section, transmission electron microscopy (TEM)

### 2. Materials used

#### 2.1 Clay (earth)

In this study, we are using a clay soil from the Ksar-Elkebir area (northern Morocco), whose chemical analyses are given in Table 1.

#### Table 1. Chemical analysis of used clay.

| Constituents | Percentages (%) |
|--------------|-----------------|
| SiO₂         | 45.79           |
| Al₂O₃        | 15.68           |
| Fe₂O₃        | 12.83           |
| MnO          | 0.17            |
| MgO          | 6.26            |
| CaO          | 9.6             |
| Na₂O         | 3.54            |
| K₂O          | 1.39            |
| TiO₂         | 2.84            |
| P₂O₅         | 0.6             |
| P.F          | 0.31            |
| Total        | 99.01           |

#### 2.2 Alfalfa and Straw

The Straw fibers and alfa (Figure 3a, 3b) are retained for reasons of availability and economy. The physical characteristics of these two fibers are shown in table 2:

#### Table 2. Physical characteristics of the fiber used physical

| Characteristics | Unit      | Alfa fibers | Straw fibers |
|-----------------|-----------|-------------|--------------|
| apparent density | Kg/m³    | 140         | 215          |
| Diameter        | mm       | 0.9-1.2     | 1-4          |
| Length          | mm       | 10-50       | 10-50        |

#### 2.3 Mixing water

After several tries of estimate of the quantity of necessary water to thin the pate of clay and have a normal consistency, we found that the quantity of water must prove following relation:

\[
\frac{W}{C} = 0.20
\] (1)

With \( W \) and \( C \) are respectively the quantity of water (g) and the quantity of clay dryness (g)
2.4 Preparation of samples

The mixtures were done manually in the salt LEME laboratory. The amount of water added to the mixture was selected in order to get a normal consistency. We took a quantity of clay and varied the fiber mass percentage (0% – 0.5% – 1% – 2% – 3% – 4%).

There are three types of samples used in this study:
- Parallelepiped dimensions (11cm x 11cm x 3cm) to perform the thermal tests (Figure 3).
- Cylindrical dimensions (11cm x 22cm) to perform compression tests according to NF P18-406 (Figure 4).
- Prismatic dimensions (4cm x 4cm x 16cm) to perform the Tensile Test by bending according to NF P18-40 (Figure 5).

Samples are then kept in a etuve in a temperature of 60°C. They is dried up to a constant mass. Then the mass dried being measured and then they were wrapped in bags of plastic has at the end that they support a rate of humidity close to zero.

3. Results and interpretation

3.1 Thermal Conductivity by asymmetrical method in permanent regime

Figure 6 shows the evolution of the two thermal conductivities depending on the fiber percentages.
The thermal conductivities tend to decrease as a function of the percentage of fibers, this is perfectly logical, more than the percentage of fibers is high, more than the material contains pores which are the cause of this decrease.

We also point out that the thermal conductivity of our material (clay+paille) is always lower than that of clay with alfa (figure 6). This is due to the shape of the stems of the straw (figure 1) which allows to store a large quantity of empty has the inside . The presence of straw fibers improves so the thermal insulation of the samples compared to alfa fiber.

The measurement error was calculated by using the method three times for each sample, followed by taking the average of these three trials (it does not exceed 1%).

![Figure 6. Evolution of thermal conductivity based on the percentages of fibers](image)

To determine the economy of energy which can bring the straw fiber compared to fiber alfa. We will consider 2 exterior walls formed by (the material clay + alfa and the other in clay + straw) having the same thickness and are subjected to the same temperature gradient, We can be deduced from the report of the flow of heat which passes through two of these walls:

\[
\frac{\theta_{\text{clay} + \text{straw}}}{\theta_{\text{clay} + \text{alfa}}} = \frac{\lambda_{\text{clay} + \text{straw}}}{\lambda_{\text{clay} + \text{alfa}}}
\]

This allows us to calculate the energy savings that are gained by the (clay + straw) material compared to the material (clay + alfa):

\[
Energie_{\text{saving}} = 100\times\left(1 - \frac{\theta_{\text{clay} + \text{straw}}}{\theta_{\text{clay} + \text{alfa}}}\right)
\]

We apply the relations (2) and (3) to the different samples, we get the energy savings based on the fiber percentages (Table 3).

| Samples    | Energy savings (%) |
|------------|--------------------|
| EP1: 0.5% Straw | 5.71               |
| EP2: 1% Straw    | 4.37               |
| EP3: 2% Straw    | 9.43               |
| EP4: 3% Straw    | 9.78               |
| EP5: 4% Straw    | 8.60               |

Based on Table 3, we can conclude that the use of material (clay+straw) like bricks can give an energy saving of 4% to 9% compared to material (clay+alfa).
3.2 Tensile test by bending

The results of the bending tension tests are shown in Table 4 and Figure 7. By breaking the specimen, the resistance to tension is determined. The resistance to tension is the average resistances obtained from at least three specimens.

Figure 7 shows two areas. In 0% to 2% fiber mass, we observed an increase in the tensile strength by bending, this increase is due to the role played by the fibers (alfa fiber resists well tractive effort and also a good adhesion between fibers and clay). From 2% fiber mass, the tensile strength by bending starts to decrease, because of the adhesion between the fibers and the clay paste, which becomes weak because of the increased fiber percentage and the reduced binding to the clay.

![Figure 7. Evolution of the tensile strength by bending of samples in function of the mass percentages of fibers.](image)

In addition, the clay + alfa material has a tension resistance that is greater than that of the straw + clay (Table 4). This is due to the hardness of the alfa fiber rod compared to that of the straw fiber.

Alfa fiber is better than straw in terms of mechanical behavior (the difference between the two resistances can reach 17.72%).

| Samples       | Average tensile Strength of clay+ alfa (Mpa) | Average tensile Strength of clay+ straw (Mpa) | Gap to tensile strength of clay+alfa compared to that of clay +straw( %) |
|---------------|---------------------------------------------|---------------------------------------------|-----------------------------------------------------------------------|
| ER :100%clay  | 1.15                                        | 1.15                                        | -                                                                     |
| 1% fibre      | 1.58                                        | 1.3                                        | 17.72                                                                |
| 2% fibre      | 2.01                                        | 1.66                                        | 17.41                                                                |
| 3% fibre      | 1.75                                        | 1.53                                        | 12.57                                                                |
| 4% fibre      | 1.59                                        | 1.46                                        | 8.17                                                                 |

3.3 Compression test

The results obtained from compression tests on different mixes are shown in Table 5. The compressive strength is an average of resistances obtained from three samples. Overall, these resistances, in comparison to concrete, remain low and in the order from 2.35 Mpa to 4.63 Mpa.
According to Figure 8, the increase of fiber percentages in clay samples has a negative influence on the compressive strength. Also, the samples containing alfa fibers have higher compressive strength compared to clay with straw (Table 5). This is due to the rough surface of the alfa fiber which guarantees a better adherence to the clay, and which reduces the voids between the alfa fiber and the clay.

**Table 5.** The compressive strength of the two materials: clay + alfa and clay + straw

| Samples         | Average value of the compressive strength of clay + straw (Mpa) | Average value of the compressive strength of clay + straw (Mpa) | Gap of the compressive strength of clay + esparto compared to that of clay + straw (%) |
|-----------------|------------------------------------------------------------------|------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| 100% clay       | 4.63                                                             | 4.63                                                             | -                                                                                    |
| 0.5% fibre      | 4.5                                                              | 4.2                                                              | 6.66                                                                                 |
| 1% fibre        | 4.42                                                             | 3.95                                                             | 10.63                                                                                |
| 2% fibre        | 4.05                                                             | 3.54                                                             | 12.59                                                                                |
| 3% fibre        | 3.5                                                              | 2.95                                                             | 15.71                                                                                |
| 4% fibre        | 2.9                                                              | 2.35                                                             | 18.96                                                                                |

4. **Conclusions**

The article is a comparative study of the thermo-mechanical properties of two materials: clay + alfa and clay + straw. We have shown that increasing the percentages of fibers (alfa or straw) improves the thermal and mechanical properties of both materials (a decrease in thermal conductivity with an increase in the tensile strength by bending), as long as the percentage of fibers does not exceed 2%. The fiber percentage of 2% remains the optimal condition for using these fibers in clay bricks.

In others, we found that straw fiber and clay materials can bring energy savings of 4% to 9% compared to that of the material (clay + alfa). However, the material alfa+ clay can increase the mechanical resistance by 8% to 17% for the tractive resistance by bending and 6% to 18% for the compressive strength compared to that of straw fiber.

This study provides indices for the selection of local materials in rural construction in northern Morocco. However, other criteria such as thermal effusivity, thermal diffusivity, and mass heat are needed for the final choice of materials, and also the impact of rain water on the thermal and mechanical properties of the two composites to control durability.

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