The impact of fibres reinforcement on the thermal characteristics of lime-stabilised compressed earth blocks

O impacto do reforço de fibras nas características térmicas dos blocos de terra comprimida estabilizados com cal

DOI: 10.54021/seesv5n1-026

Recebimento dos originais: 16/02/2024
Aceitação para publicação: 01/03/2024

Fidjah Abdelkader
PhD in Mechanical engineering
Institution: Laboratory of Development in Mechanics and Materials (LDMM) - University of Djelfa
Address: Djelfa, 17000, Algeria
E-mail: fidjah.abdelkader@univ-djelfa.dz

Oussama Naimi
Doctor in Polytechnic
Institution: Environmental Technologies Research Laboratory (LTE), National Polytechnic School of Oran Maurice Audin
Address: B.P 1523, El M’naouer, Oran 31000, Algeria
E-mail: oussama.naimi91@gmail.com

Rabehi Mohamed
Doctor in Civil Engineering
Institution: Civil Engineering Department, University of Djelfa
Address: 17000 Djelfa, Algeria
E-mail: rahmoh_m@yahoo.fr

Kezarane Cheikh
Doctor in Mechanical Engineering
Institution: Laboratory of Development in Mechanics and Materials (LDMM), University of Djelfa
Address: 17000, Djelfa, Algeria
E-mail: kezrane@gmail.com

Zitouni Tidjani Ahmed
Doctor in Mechanical Engineering
Institution: Laboratory Mechanics University Brothers Mentouri Constantine 1
Address: Constantine, Algeria
E-mail: zitounitidjani@gmail.com
Tayeb Sakhi  
PhD in Chemical Engineering  
Institution: Departement of Chemical Engineering, University of Science and Technology Houari Boumediene Algeria  
Address: Alger, Algeria  
E-mail: sakhitayebgr@gmail.com

Dahmani Roqiya  
PhD in Environmental Engineering  
Institution: Laboratory of Energy Enviirenment and Information System (LEESI), Ahmed Draia University  
Address: Adrar, Algeria  
E-mail: dah.roqiya@univ-adrar.edu.dz

Chettah Mahieddine  
Doctor in Civil Engineering  
Institution: Department of Civil Engineering, Laboratory of soils mechanic and structures (LMSS), University of Mentouri Constantine 1  
Address: Constantine, 25000, Algeria  
E-mail: mahieddine.chettah@umc.edu.dz

ABSTRACT  
In civil engineering, the use of fibers in construction has spread recently, because of their many benefits in terms of increasing the cohesion of buildings and their thermal insulation. In addition to having several good physical and mechanical properties. Thermal insulation has become an important thing in the field of construction. Because it is linked to increasing the lifespan of buildings and predicting their thermal behavior. It includes increasing energy efficiency and reducing its costs. Fibers are used to increase thermal insulation, because it creates voids inside the structures that are within its content, and thus impedes the transfer of heat, regardless of the type of transfer by convection, radiation, or conductivity. This study aims to determine the amount of thermal insulation in compressed earth bricks with dimensions of $20 \times 10 \times 10 \text{ cm}^3$, to which palm fibers and glass are added in different proportions: 0%, 0.1%, 0.2%, 0.3%, 0.4% and 0.5%. In earthen bricks composed of soil, sand and lime. The study includes the physical, mechanical and thermal properties of these bricks. We focus on thermal insulation in the best samples in terms of hardness. Laboratory samples were taken according to standard experiments in university laboratories. Preliminary results showed a decrease in bulk density between 6% and 8.34%, an increase in mechanical stresses between 42.85% and 45.45%, and an increase in thermal insulation between 26% and 29%. These results give us an overview of the impact of using fibers in construction in terms of increasing weight bearing and predicting the amount of thermal insulation.

Keywords: compact earthen bricks, fibres, stresses, thermal insulation, thermal properties.
RESUMO
Na engenharia civil, o uso de fibras na construção civil se espalhou recentemente, devido aos seus muitos benefícios em termos de aumento da coesão dos edifícios e seu isolamento térmico. Além de possuir várias boas propriedades físicas e mecânicas. O isolamento térmico tornou-se uma coisa importante no campo da construção. Porque Está ligado ao aumento da vida útil dos edifícios e à previsão do seu comportamento térmico. Inclui o aumento da eficiência energética e a redução de seus custos. As fibras são utilizadas para aumentar o isolamento térmico, pois criavazios no interior das estruturas que estão dentro do seu conteúdo, e assim impede a transferência de calor, independente do tipo de transferência por convecção, radiação ou condutividade. O presente trabalho tem como objetivo determinar a quantidade de isolamento térmico em tijolos de terra comprimida com dimensões de 20 × 10 × 10 cm3, aos quais são adicionadas fibras de palmeira e vidro em diferentes proporções: 0%, 0.1%, 0.2%, 0.3%, 0.4% e 0.5%. In tijolos de barro compostos por terra, areia e cal. O estudo inclui as propriedades físicas, mecânicas e térmicas desses tijolos. Focamos no isolamento térmico nas melhores amostras em termos de dureza. Amostras de laboratório foram coletadas de acordo com experimentos padrão em laboratórios universitários. Os resultados preliminares mostraram uma diminuição na densidade aparente entre 6% e 8,34%, um aumento nas tensões mecânicas entre 42,85% e 45,45% e um aumento no isolamento térmico entre 26% e 29%. Esses resultados nos dão uma visão geral do impacto do uso de fibras na construção em termos de aumento da sustentação de peso e previsão da quantidade de isolamento térmico.

Palavras-chave: tijolos de barro compactos, fibras, salienta, isolamento térmico, propriedades térmicas.

1 INTRODUCTION
In the field of civil engineering, engineers use modern materials in construction in order to increase the cohesion of buildings and increase their thermal insulation [1], because thermal insulation is associated with saving cooling and air conditioning energy in modern buildings [2]. Heat-insulating materials can be defined as materials that reduce heat transfer from the external medium to the internal medium compared to other materials [3]. However, their efficiency, cost, and sustainability are decisive factors in choosing these materials. Therefore, researchers have turned to the use of low-cost and low-impact materials and resistant to fires [4]. Some researchers used plant-based materials, such as palm trunks, as an insulating material [5], and others used animal-based materials for thermal insulation, such as sheep wool [6]. Some have turned to the use of synthetic fibers such as carbon fiber [7]. In addition, earthen construction has
become widespread in some regions of the world, such as Morocco in North Africa [8]. In the country of India in the south of Asia [9] and in South America, we find Brazil as an example of this [10].

Compacted earth technology is known as the best way to increase the cohesion and hardness of earth bricks. This technique is widespread in construction in areas known for rainfall. Moreover, other materials are added to it to increase its connections; the researcher confirms Tausif E Elahi. and others by adding cement to the soil [11]. Also confirmed by the researcher Barbero-Barrera, when adding lime to the soil [12].

In this research, we study the effect of adding palm fibres and glass on the thermal insulation of bricks composed of soil and sand; lime is added as a stabilizer. We change the ratio of these fibres between 0.0%, 0.1%, 0.2%, 0.3%, 0.4% 0.5% . We limit the experiments to studying the change in density, the amount of stresses required to break the samples, and their relationship to thermal insulation in buildings of this brick. We divide the work into three sections: the first describes the materials used in manufacturing bricks, and the second is devoted to the experimental aspect and discussion. The third part will be to extract the results and conclusions. The work revolves around answering two main questions: How much thermal insulation do fibers add to earthen bricks? and What is the best type of fibers in this field?

2 MATERIALS AND METHODS

2.1 MATERIALS

2.1.1 Soil

In these experiments, we use the soil of the Bachar region in the south of Algeria. Which is characterized by the physical and chemical properties shown in Table 1 [13].

2.1.2 Sand

We use dune sand, which is a yellow sand free of organic substances and characterized by the physical and chemical properties shown in Table 1 [14].
2.1.3 Lime

In the experiment we use a zone gear that will return. Which is characterized by the characteristics shown in Table 1[14].

2.1.4 Palm Plant Fibres

We use palm fibres, which is widely used in the south of Algeria. In addition, it has good thermal properties. Compared to its cost. The physical and chemical properties are shown in Table 2[15].

2.1.5 Glass Fibres

We use E-Class glass fibres obtained from the remnants of optical fibres intended for the internet. It is considered a composite fiber with good mechanical properties and good heat resistance. The physical and chemical properties are shown in Table 2[16].

2.1.6 Water

We use pine water, which is characterized by the presence of mineral elements in different proportions, such as Na++(200 mg/L), and Ca++(200 mg/L), and Cl-(500 mg/L), and SO4--(400 mg/L), Mg++(150 mg/L), Ka+(12mg/L), in 30°C.

Table 1. Chemical and physical properties of the materials used[13-14]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical properties</td>
<td>Chemical properties</td>
<td>Chemical properties</td>
<td>Chemical properties</td>
</tr>
<tr>
<td>Components</td>
<td>%</td>
<td>Components</td>
<td>%</td>
</tr>
<tr>
<td>Carbonates (CO3²⁻)</td>
<td>6.8</td>
<td>SiO2</td>
<td>1.07(%)</td>
</tr>
<tr>
<td>Sulfates (SO4⁻²)</td>
<td>Traces</td>
<td>Al2O3</td>
<td>0.31(%)</td>
</tr>
<tr>
<td>Chlorides (Cl⁻)</td>
<td>0.39</td>
<td>Fe2O3</td>
<td>0.14(%)</td>
</tr>
<tr>
<td>Insoluble</td>
<td>92.81</td>
<td>CaO</td>
<td>57.22(%)</td>
</tr>
<tr>
<td>VBS</td>
<td>1.2</td>
<td>MgO</td>
<td>0.57(%)</td>
</tr>
<tr>
<td>Activity coefficient Ca</td>
<td>0.87</td>
<td>SO3</td>
<td>0.06(%)</td>
</tr>
<tr>
<td>Physical properties</td>
<td>K2O</td>
<td>Fe2O3</td>
<td>0.07(%)</td>
</tr>
<tr>
<td>Absolute density (g/cm³)</td>
<td>2.7</td>
<td>Na2O</td>
<td>0.02(%)</td>
</tr>
<tr>
<td>Apparent density (g/ cm³)</td>
<td>1.3</td>
<td>Loss on ignition</td>
<td>40.21(%)</td>
</tr>
<tr>
<td>Sand equivalent ES (%)</td>
<td>11.58</td>
<td>Physical properties</td>
<td>Physical properties</td>
</tr>
<tr>
<td>Liquidity limit (%)</td>
<td>19.45</td>
<td>&lt;0.08mm</td>
<td>25(%)</td>
</tr>
<tr>
<td>Limit of plasticity (%)</td>
<td>11.36</td>
<td>0.08–1.00mm</td>
<td>27(%)</td>
</tr>
</tbody>
</table>
### Table 2. Characteristics of used fibers[15-16]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chemical Properties</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellulose(%)</td>
<td>27</td>
<td>Density (g/cm³)</td>
</tr>
<tr>
<td>Hemicellulose(%)</td>
<td>37</td>
<td>Filament diameter (mm)</td>
</tr>
<tr>
<td>Lignin(%)</td>
<td>28</td>
<td>Diameter (μm)</td>
</tr>
<tr>
<td>Fats(%)</td>
<td>7</td>
<td>Tensile strength (MPa)</td>
</tr>
<tr>
<td><strong>Mechanical Properties</strong></td>
<td></td>
<td>Lengthen at break (%)</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>170 – 275 MPa</td>
<td>Modulus of elasticity (Mpa)</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>5 – 12 GPa</td>
<td></td>
</tr>
<tr>
<td>Elongation</td>
<td>5 - 10%</td>
<td></td>
</tr>
</tbody>
</table>


---

2.2 METHODS

2.2.1 Preparation of Samples

We sift the soil and sand using a sieve with a less than 2 mm pore.

We mix 50% soil, 22% sand, 14% lime, and 14% water.

We get these results from previous experiments. In addition to determining the percentage of lime according to the standard (The optimum Procto)[17] Associated with volumetric mass. 14% represents the best percentage of grinding the best density of earth bricks.
Mix the soil with sand using an electric mixer for 3 minutes and then add palm fibers or glass fibers according to the samples to be obtained. Then, gradually add the water and continue mixing.

We select the dry mass of the soil 2000 g. and 880 g of sand, and 560 g of lime and 560 cl water.

Wet mixture weight 4000g.

We compress the mixture into a 2.5 MPa metal mold using a hydraulic press equipped with a reading screen for 2 minutes.

We stop the pressing machine and release the resulting brick.

Dimensions of the resulting brick 20×10×10 cm³.

Table 3 represents the composition of the soil samples.

<table>
<thead>
<tr>
<th>Soil (%)</th>
<th>Sand (%)</th>
<th>Lime (%)</th>
<th>Water (%)</th>
<th>Palm fibres (%)</th>
<th>Glass fibres (%)</th>
<th>Compression (MPa)</th>
<th>samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>22</td>
<td>14</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>FW</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>2.5</td>
<td>PGW0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.1</td>
<td>0</td>
<td>2.5</td>
<td>PW1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2</td>
<td>0</td>
<td>2.5</td>
<td>PW2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.3</td>
<td>0</td>
<td>2.5</td>
<td>PW3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.4</td>
<td>0</td>
<td>2.5</td>
<td>PW4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
<td>0</td>
<td>2.5</td>
<td>PW5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0.1</td>
<td>2.5</td>
<td>GW1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0.2</td>
<td>2.5</td>
<td>GW2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0.3</td>
<td>2.5</td>
<td>GW3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0.4</td>
<td>2.5</td>
<td>GW4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0.5</td>
<td>2.5</td>
<td>GW5</td>
</tr>
</tbody>
</table>

Source: Prepared by the authors (2024).

We leave the samples to dry 40 days and then we do experiments.

2.2.2 Density Measurement

To measure the change in density, we weigh the samples with a fine scale and then measure their dimensions.

We use the general relation 1 to measure the volumetric mass

\[ \rho = \frac{m}{\nu} \] (1)
2.2.3 Measuring Stresses

We use a hydraulic pressure machine equipped with a screen. The type of stresses is vertical, and the application area is 200×100 (20000) mm². with an estimated speed of 0.6 MPa/ s.

We use relation 2 to measure the value of stresses.

\[ \sigma = \frac{F}{A} \]  

(2)

The machine automatically stops when the samples break. The screen gives us values of the amount of stress applied to the samples to break them.

2.2.4 Thermal Insulation Measurement

To measure the thermal insulation, we choose the best samples in terms of rigidity and we build three miniature buildings measuring 70×70 cm².

The first building: the used bricks are compressed without adding fibres.

The second building: the used bricks are compacted, the palm fibres contains a percentage of 0.3%.

The third building: the used bricks are compressed containing glass fibres with a ratio of 0.2%
We measure the temperature inside and outside the two buildings in the period between 12 am to 17 pm.
We measure the internal and external temperature every 30 minutes.
Figure 4 represents the house built with a brick containing palm fibres.

Figure 4. Measurement of thermal insulation in a mini-house 70×70 cm²

Source: Prepared by the authors (2024).

3 ANALYSIS AND DISCUSSION
3.1 DENSITY

Figure 5 represents the change in the bulk density value in the samples when palm fibres and glass are added. The density decreases with the addition of fibres.

The density of uncompressed samples (FW) is 1587 kg/m³. The density of compressed samples without the addition of fibres (PGW0) is 1850 kg/m³.

Figure 5C1 represents the change in density when palm fibres is added.
• Comparison with uncompressed FW samples:
  The density increases from 6.3% to 12.65% (1817-1587) kg/m³. The increased weight of the samples explains this: The pressure increases the amount of material collected inside the mold and thus increases the weight.
• Comparison with fiber-free compressed samples PGW0.
The density decreases between 1.78% to 8.43% (1850-1694) kg/m³, and adding palm fibres makes pores inside the earthen bricks. This is what makes the brick size bigger. This is consistent with previous research [18].

Figure 5 C2 represents the change in density when adding glass fibres to earth bricks.

When comparing compressed samples with uncompressed samples, FW
The density increases between 8.74% to 13.18%(1828-1587) kg/m³. This is explained in the same way as the addition of palm fibres with a difference in proportion. Compression works to accumulate a larger mass within the exact finite dimensions.

Figure 5. Change in the value of the bulk density

![Figure 5](image)

Source: Prepared by the authors (2024).

- When comparing glass fibres samples with compressed fibres-free samples, PGW0
Density decreases between 1.18% to 6% (1850-1739) kg/m³. Palm fibres and vitriol increase the number of pores in the earthen bricks. The decrease in density is greater with palm fibres because the thickness of palm fibres is greater than the thickness of glass fibres.

3.1.1 Stresses

Figure 6 represents the change in the value of the mechanical stresses of the earthen brick when palm fibres and glass are added.
Uncompressed samples break at 0.8 MPa, and compressed samples without fibres addition at 1.2 MPa.

When analyzing Figure 6C1, it turns out that the stresses increase when adding palm fibers up to 0.3% and then decrease.

The value of stresses increases between 33.33% to 61.9% when we compare the strength with non-compressed samples (2.1 -0.8) MPa.

It increases from 20% to 42.85% compared to fibres-free compressed samples.

When comparing all the eyes, it becomes clear that adding palm fibres positively increases the hardness in the earthen bricks. This corresponds to the result of the research of El-Emam, M, and others [19].

Figure 6 C2 represents the change in the value of stresses when we add glass fibres. We notice an increase in the value of stresses up to a value of 0.2% and then a decreasing.

Compared with non-compressed samples, the value of stresses increases between 52.9% and 61.9% and increases between 29.41% and 45.45% compared with fibres-free samples.

Figure 6. The change in the value of mechanical stresses

![Graph showing stress changes](source)

Source: Prepared by the authors (2024).

The amount of stress is more with glass fibres, 4.5% better than glass fibres (2.2-2.1) MPa. This explains that the tensile strength of glass fibres are greater than palm fibres (3500>275)MPa. see Table 2.
When talking about the hardness of earthen bricks, it is necessary to recall the role of lime material. The lime reacts with the soil and produces compounds such as CaSiO$_3$ and NaAlO$_2$. These compounds increase the strength of soil cohesion by up to 13% [20].

### 3.1.2 Thermal Insulation

Figure 7 represents the change in temperature inside and outside three earthen buildings.

Previous experiments found that compressed bricks are better than uncompressed bricks in terms of mechanical properties. So, we will continue to study only pressed bricks. The experiments will be carried out in July in the city of Adrar in southern Algeria.

![Figure 7. Temperature changes outside and inside buildings.](image)

The outside temperature varies between degrees 45 C$^0$ and 48 C$^0$.

The first building: the used bricks are compressed, not fibres-reinforced

When measuring the temperature inside the first building for five hours, the temperature ranged from 36.2 C$^0$ to 38.1 C$^0$.

This means that this building insulates heat between 19% to 22%

The second building: the used bricks are compressed with 0.3% palm fibres.
When measuring the internal temperature in the second building, we note that the temperature ranges between 32.4 °C and 34.6 °C. The building insulates 27% to 29% from external heat.

The third building: the used bricks are compressed with 0.2% glass fibres. We find the internal temperature in the third building between 33.9 °C and 36.1 °C. So it insulates heat between 24% and 26%.

From the analysis of all the results, it becomes clear that a building with palm fiber has the most excellent thermal insulation compared to others.

This explains the fact that palm fibres are plant-based, and its thermal conductivity is low compared to glass fibres [21].

The thermal conductivity of materials is essential in the field of thermal insulation. When heat is transferred through the walls, the value of the carrier is related to the area exposed to heat (A), the thickness of the brick (I), the duration of exposure to heat, the external temperature (T1), and the amount of heat (Q)

Relation 3 shows the factors influencing the change in thermal conductivity.

\[ \lambda = \frac{IQ}{A(T1-T2)} \]  

From previous studies, it is clear that the thermal conductivity decreases when adding fibres [22], and this is explained by the fact that the increase in pores inside the brick as a result of an increase in the percentage of fibres increases the voids between the particles and hinders heat transfer.

Heat is transferred inside the earthen brick by convection, conduction, and radiation. The bulk density is among the factors influencing the heat transfer in an earthen brick. Organic matter content, water content, soil properties, and composition we notice that the mineral elements inside the soil have an essential role in heat transfer. Adding sand to the soil increases the percentage of quartz in the soil and makes it more thermal conductivity than other soils.

4 CONCLUSION

In this research, we studied the effect of adding palm fibres and glass on changing the value of density, stresses, and thermal insulation in compressed
earth bricks composed of soil, sand, and Lime. We found that adding these fibres has a positive effect on these variables, and we can derive the following points:

1. The addition of fibres makes the earthen brick More Light, better hardness, and more thermal insulation.
2. The addition of fibred makes the brick light, and this is the result of a decrease in density of 8.34% palm fibres and 6% glass fibres.
3. The durability of earthen bricks increases by up to 42.85% with palm fibres and 45.45% with glass fibres.
4. The ratio of palm fibers in this experimental composition is 0.3% and 0.2% for glass fibers.
5. The addition of fibres increases thermal insulation by 29% with palm fibres and 26% glass fibres in a thickness of 10 cm.
6. The addition of Lime has a positive effect in increasing soil cohesion and increasing thermal insulation.

This brick can be used in the field of construction while improving some physical properties, such as reducing the percentage of water absorption.

Based on these results, we can answer the two main questions in the study. It has been shown that palm fibers are thermally insulated (29%) better than glass fibers (26%), by 10% at a specific percentage, and this is related to the thermal properties of palm fibres. In the future, we can make composite synthetic fibers that combine mechanical properties (increased durability) and thermal properties (low thermal conductivity). We also recommend using soil stabilizers that increase the durability of the soil, such as using cement or gypsum. This is what makes us open the door to the production of composite materials that make earthen bricks compatible with the present, reduce the risk of cement creep, and reduce energy consumption.
REFERENCES


