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Assessment of the Mechanical and Thermal Properties of Bricks based on Clay and Stabilized with Reed Fibers from the Drâa-Tafilalet Region

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Abstract. In the field of sustainable construction, it is imperative to find environmentally-friendly materials with optimized performance. The present study examines a comprehensive exploration of the untapped potential for using natural resources in the Drâa-Tafilale region, focusing on the incorporation of reed fibers into traditional clay bricks, a naturally abundant and renewable resource. The design of reed fiber-stabilized bricks was carried out using six distinct mixes, mainly differentiated by their reed fiber content, ranging from 0% to 5%. Initial observations highlighted the promising potential of reed fibers. Increasing the reed fiber content in a mix improves the mechanical strength of clay brick compositions (at 1% reed fiber). However, above this threshold, the inclusion of reed fibers led to a decrease in tensile and compressive strength. In addition, the thermal conductivity of the samples decreased with increasing fiber content. Furthermore, brick density decreased with increasing fiber percentage.

Introduction

In light of growing energy demands and environmental issues, the global focus on energy-efficient buildings has intensified. In Morocco, [1] a significant dependency on energy imports has driven the creation of a national energy strategy, which places special emphasis on the expansion of renewable energy sources and the enhancement of energy efficiency in all sectors, particularly in the construction industry. Despite being a major energy consumer, the construction sector presents a noteworthy potential for energy conservation through the efficient oversight of technical equipment and the optimization of building structures.

The use of natural materials in construction has garnered significant attention, driven by a growing commitment to sustainability and energy efficiency. Among these materials, clay stands out as a readily available and cost-effective resource, prompting extensive research, particularly into its remarkable thermal conductivity and acoustic insulating properties[2] [3] [4]. Its wide accessibility makes it an environmentally responsible alternative to more resource-intensive construction materials. render it a highly appealing option for construction, especially in regions characterized by scorching climates like the Draa-Tafilalet area. However, it is undeniable that, when compared to industrialized construction materials, exhibits several limitations in construction. These materials have significantly lower tensile and flexural strengths compared to industrialized counterparts, rendering them weak against stretching and bending forces. Furthermore, their vulnerability to erosion when exposed to moisture and rain poses a substantial concern, potentially compromising structural integrity. Additionally, the volumetric instability of earthen materials, with the potential for expansion or shrinkage in response to moisture fluctuations, can lead to ongoing maintenance and structural issues. These limitations underscore the need for meticulous planning and construction techniques to ensure the long-term stability and durability of structures employing earthen materials.

In recent years, there has been a notable focus from researchers on investigating and conducting laboratory assessments of the physical and mechanical attributes of adobe materials [5] [6] [7] [8], showcasing their capacity to enhance various crucial properties, including toughness, tensile strength, permeability, and resistance to drying shrinkage cracks. Research involving the utilization of natural fibers has demonstrated encouraging outcomes.S. Ramakrishnan et All [9] found that fibers like banana, jute, and millet improved compressive and tensile strength, alongside reduced thermal conductivity, enhancing resistance to erosion. P. Muñoz et All [10] demonstrated that a 10% inclusion of paper and pulp industry residues (PPR) significantly bolstered compressive strength and lowered thermal conductivity while meeting erosion resistance standards. Millogo, Y et All [11] noted the effectiveness of Hibiscus cannabinus fibers in reinforcing pressed adobe blocks, with a 0.4% fiber content improving compressive strength. Eslami, A. et All [12] explored palm fibers to enhance traditional adobe bricks, with varying optimal contents for different properties. In the research conducted by Hachem, H et All [13], they explored the use of fly bottom ash (FBA) waste and Arundo donax leaves (ADL) as alternatives to cement in mortar composites, with the goal of creating more sustainable building materials. They found that FBA reduced density and thermal conductivity while increasing porosity and water absorption. A 20% FBA replacement achieved a good balance between emissions reduction and strength. The incorporation of ADL fibers further reduced density and thermal conductivity but weakened mechanical properties. However, a low ADL ratio (0.4%) in 20% FBA mortar improved strength and reduced emissions slightly.

One fundamental query permeating this research field concerns the influence of natural fiber inclusion on adobe's mechanical characteristics. Within the literature, an intriguing duality of findings has emerged, giving rise to divergent conclusions. On one hand, certain studies suggest that augmenting fiber content corresponds to an increase in compressive strength [9] [12] [14] [15], signifying the potential for reinforced adobe structures. Conversely, a separate body of research contends that greater fiber content leads to a reduction in compressive strength [16] [17], which poses a challenge to conventional wisdom. Given the diverse and sometimes contradictory findings within the literature, it is clear that additional research is imperative to establish a comprehensive understanding of the ramifications of natural fiber integration on adobe characteristics. A systematic approach to research and data collection is crucial to reconcile the disparities observed thus far, ultimately advancing the field of adobe construction and fostering more informed design and construction practices.

In pursuit of advancement in this direction, this research paper focuses its attention on exploring the impact of reed fiber and quantity on the physical and mechanical characteristics of adobe materials. Specifically, it conducts a series of experiments to assess how the inclusion of reed fibers, at varying percentages, affects the properties of five distinct adobe mixtures that were formulated in the laboratory. The outcomes are then compared to those of conventional adobe materials for reference. The experimental phase of this study includes mechanical evaluations, such as tests for compressive and flexural strength, and the determination of crucial physical attributes like density and absorption. Furthermore, thermal conductivity measurements are carried out to complete the assessment of the adobe samples under scrutiny. The analysis and comparative examination of the experimental findings provide valuable insights into the influence of fiber type and quantity on the characteristics of traditional adobe bricks.

Materials and procedures

Materials used

In this study, the focus was on investigating the feasibility of adobe brick production in the Drâa-Tafilalet region, specifically Errachidia Province in Morocco. The study utilized a variety of materials, including soil, water, and reed fiber. The soil collection process was meticulous, with soil taken from the top 10-40 cm of soil to avoid organic-rich soils. The absence of a musty odor in the soil confirmed its suitability for clay brick production due to its non-organic nature. A sedimentation test confirmed a higher percentage of clay and silt, making it ideal for high-quality clay brick production. Subsequently, soil samples were carefully transported to the laboratory, where X-ray diffractometry (XRD) tests were executed to ascertain their chemical and mineralogical compositions. The outcomes of this examination are graphically represented in *(Fig 2* and *Table 1),* respectively. To ensure compliance with quality and consistency standards, clean and dependable water from the public water supply system was employed for mixing the clay bricks.

The study's foundation lay in the acquisition of reed fiber from giant reed plants, a process that involved harvesting and a comprehensive drying period. These dried fibers were then stored and subjected to refinement, ultimately achieving the precise length required for the study's unique application. The study focused on using reed fiber derived from the tall giant reed plants, scientifically known as Arundo donax, which are found in various regions globally, including Europe, Asia, Africa, and especially around the Mediterranean (Fig. 1)[18]. The process of preparing the reed fiber involved harvesting these giant reed plants and allowing them to naturally dry for about a year without air conditioning. This extended drying period was crucial to achieve the desired dryness level for effective use. After drying, the reed fibers were stored in approximately 40 cm segments and then carefully refined to reduce their length to a range of 5 to 30 mm. This tailored length range was essential to make the fibers suitable for the specific application intended in the study.

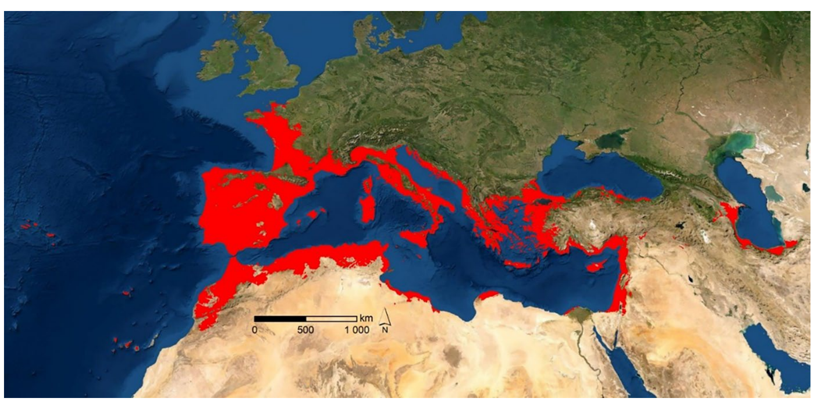

Fig 1. The potential natural habitat distribution of Giant reed (A. donax) [19]

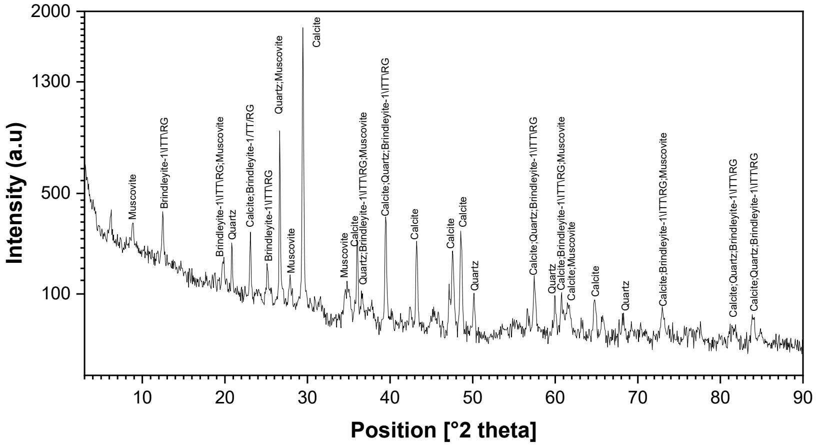

Fig 2. X-ray diffraction pattern

Table 1: Identified Patterns List

Compound Name	Chemical Formula	Scale Factor	Score
Calcite	Ca (CO3)	0,7	79
Quartz	Si O2	0,475	65
Nimesite	(Ni2 Al) (Al Si) O5 (O H)4	0,093	44
Muscovite	H2 K Al3 Si3 O12	0,04	38
Zeolite X	Na17.52 Al24 Si24 O96 H6.48	0,07	20

Samples preparation

Seven distinct types of mixtures were created for thorough thermal and mechanical testing, with each having unique combinations of reed, soil, and water. The aim was to investigate how varying component percentages influenced specific properties. Among these mixtures, one was identified as the reference (C0) with no reed fibers, serving as a consistent benchmark for performance comparisons with the others. *(Table 2 and fig 3)* outline the composition of these mixtures, which include the reference (C0:0%, C1:1%, C2:2%, C3:3%, C4:4%, C5:5%, and C6:5% fiber + 5% cement).

Table 2: Component percentage by mixture

	C0	C1	C2	C3	C4	C5	C6
SOIL(g)	4000	4000	4000	4000	4000	4000	4000
Reed fibre(g)	0	40	80	120	160	200	200
Cement(g)	0	0	0	0	0	0	200

In the experimental setup of this study, custom-designed molds were used to meet the specific requirements of the testing procedures. For thermal assessments, the molds had dimensions of 25 x 25 x 3 cm^3 *(fig 3a)*, while for mechanical tests, cylindrical molds with a diameter of 10 cm and a height of 20 cm were employed*(fig 3b)*. Once the molds were filled with the designated components, the specimens underwent a natural drying process in an open-air environment for a period of 28 days.

Fig 3. Samples preparation, a for thermal tests, b for mechanical tests

Experimental procedures

A series of laboratory tests were conducted to comprehensively evaluate both stabilized and non-stabilized clay bricks. These tests were designed to assess various fundamental properties such as compressive strength, indirect (split) tensile strength, and thermal properties.

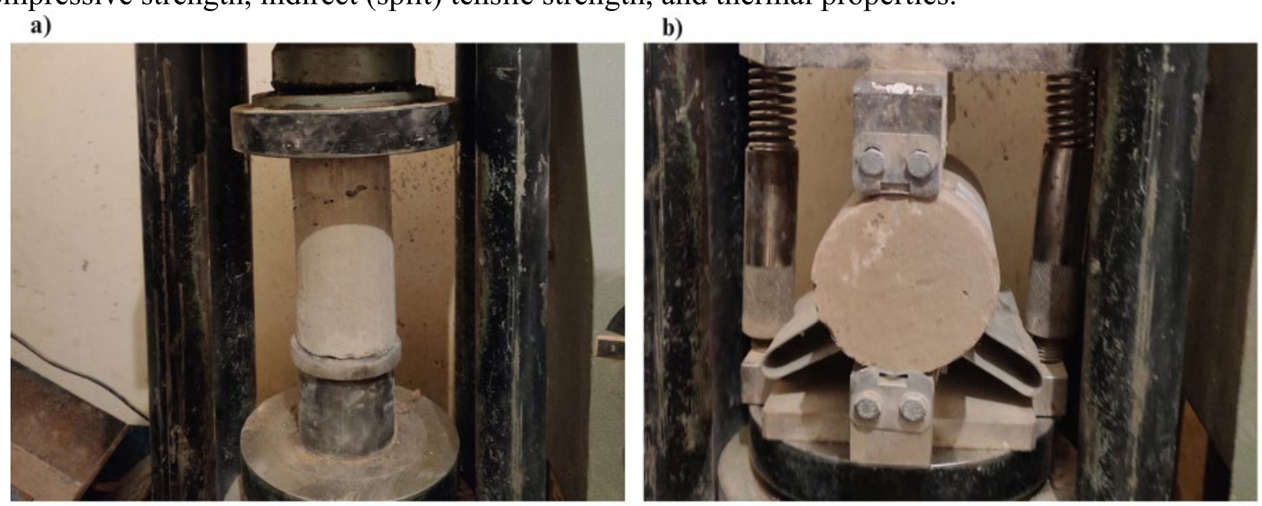

Fig 4. Experimental setup for a. compressive strength, b. tensile splitting

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Uniaxial compression tests

In this test, a compression machine was used to assess the compressive strength of clay bricks samples (*Fig.4a*). The bricks were placed on the machine, and compressive loads were gradually increased until the bricks failed. This process determined the maximum load each brick could withstand. The compressive strength (σ_c) of the adobe bricks was calculated using (Eq1):

$$\sigma_c = {}^{F}/_{S}. \tag{1}$$

where F is the maximum load before failure and S is the cross-sectional area of the specimen.

Tensile splitting test

The tensile splitting test is a commonly employed method for assessing the tensile strength of clay-based bricks *(Fig 4b).* It involves preparing cylindrical specimens with a standard diameter of 10 mm and a length of 20 mm, akin to those used in unconfined compression testing. The testing apparatus used for Uniaxial compression tests (UC) is also utilized for this test, with adjustments made to ensure the samples are loaded horizontally to their axes. A crucial aspect of the test is guaranteeing that the split line, where the tensile forces are applied, aligns along the specimen's diameter. The tensile splitting strength (σ_t) is calculated using the (Eq2)

$$\sigma_t = {}^{2F}/_{\pi D h}. \tag{2}$$

F represents the maximum load before failure, while D and h stand for the specified specimen diameter and length, respectively.

Thermal test

The thermal conductivity of reed fiber samples was investigated in a specialized insulated house *(fig 5)*, measuring 400 x 400 x 400 mm with a removable lid insulated with 5 cm thick polystyrene. Square openings (210 x 210 mm) in the house's side walls were sealed with the samples, which were held in place by two tensioning screws. The house had foam-insulated orifices in each corner for inserting thermocouples. A 100 W light bulb connected to a thermal regulator was used to maintain the house's internal temperature at around 50°C. Thermocouples were placed inside and outside the sample walls to record temperatures (Tpi internal and Tpe external). The ambient temperature in the laboratory was kept constant at 23°C using an air conditioner.

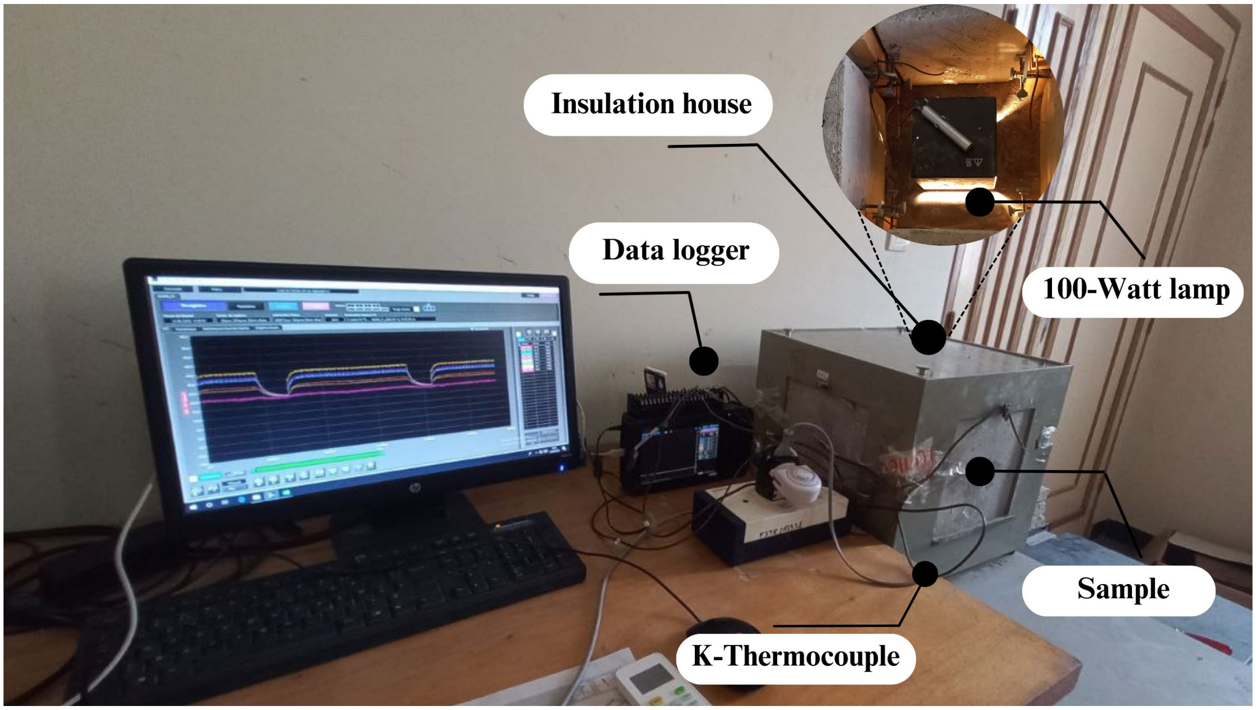

Fig 5. Heat Insulation House

In the realm of thermal analysis and the study of heat transfer, numerous fundamental principles and equations are employed to comprehensively understand and quantitatively describe heat transfer processes. Convection, a vital mechanism, characterizes the exchange of thermal energy between a fluid, such as indoor air, and the surface of a solid, such as an interior wall of samples. This exchange can be effectively calculated using Newton's Law of Cooling or the convective heat transfer equation (Eq 3).

$$\varphi_{cond} = \mathrm{h}_i.\,\mathrm{S}(\mathrm{T_{i,air}} - \mathrm{T_{i,wall}}). \qquad (3)$$

- The convective heat transfer coefficient, h_i= 8.1 W/(m²·K) in our study, characterizes heat transfer between interior air and a wall's interior surface.
- S: representing the surface area of the sample where heat flux passes through, in (m²).
- $\mathrm{T_{i,wall}}$: representing the interior wall surface temperature, in (K).
- $\mathrm{T_{i,air}}$: representing indoor air temperature, in (K).

Therefore, the heat flux through the wall is described by (Eq 4), which outlines the propagation of heat within the sample.

$$\varphi_{conv} = \lambda.S\frac{(\mathrm{T_{i,wall}}-\mathrm{T_{e,wall}})}{e}. \qquad (4)$$

- λ : which stands for the thermal conductivity of the studied sample, in (W/(m·K)).
- $\mathrm{T_{e,wall}}$: wall, representing the exterior wall surface temperature, in (K).
- e, representing the sample thickness,in (m).

To calculate thermal conductivity λ (in W/m.◦C), one-dimensional heat transfer has been assumed, Thermal conductivity is calculated using the conservation of heat flow in steady-state thermal conditions:

$$\lambda = \frac{h_i.e(T_{i,air} - T_{i,wall})}{T_{i,wall} - T_{e,wall}}. \tag{5}$$

Results and discussions

Mechanical Test

In the context of the presented findings, several notable conclusions can be drawn. The results provide a comprehensive assessment of the mechanical properties of clay-based bricks fortified with reed fibers. It is evident that bricks incorporating fibers exhibit superior consistency following mechanical testing compared to pure clay bricks (*Fig 7*).

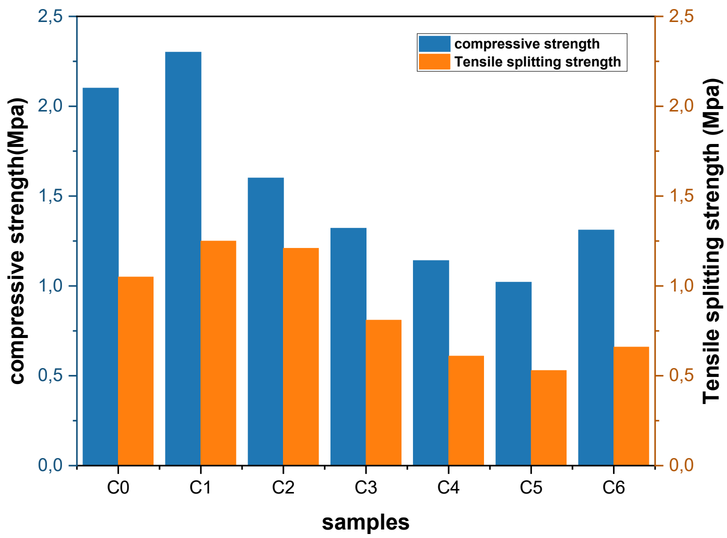

Fig 6. Mechanical strength of samples

Particularly, an initial 1% fiber content (referred to as C1) yields a significant increase of approximately 9.5% in compressive strength and a notable 19% improvement in tensile splitting strength when compared to the reference sample without fibers (designated as C0). This underscores the positive impact of a lower fiber content. However, as the fiber content surpasses 1%, there is a progressive reduction in both compressive and tensile splitting strengths, with the most significant declines occurring at a 5% fiber content. For the sake of clarity and improved presentation, a visual summary is included in Figure 5 for both compression and tensile splitting tests. Notably, the introduction of additional cement at a 5% concentration, combined with a 5% fiber content (referred to as C6), results in an enhanced compressive strength of 4.8% and a remarkable 25.7% increase in tensile splitting strength when compared to the 5% fiber-only sample (C5). This suggests the potential benefits of the composite approach for specific applications.

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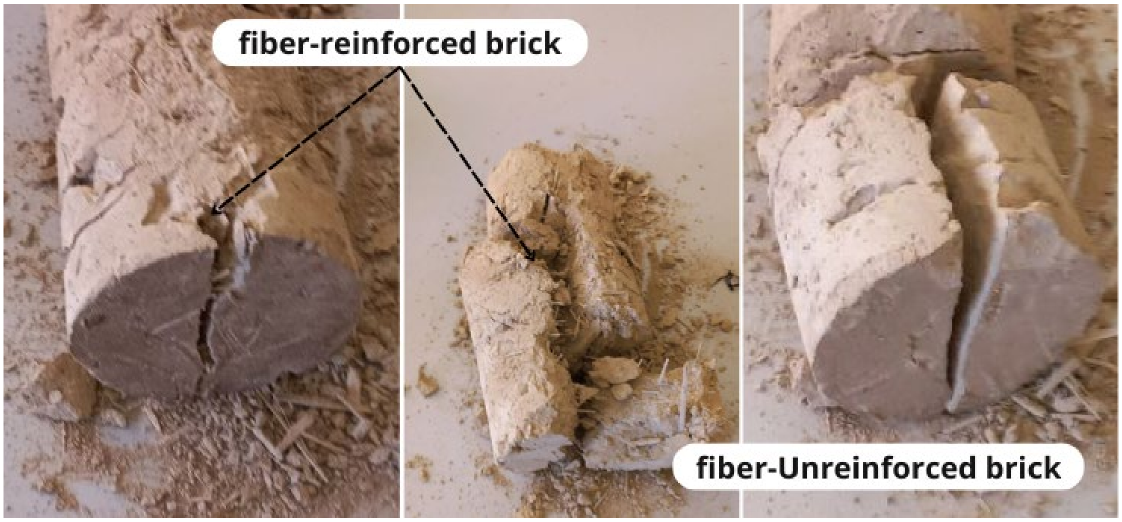

Fig 7 . Failure of clay brick under tensile force

Thermal test

The results of the assessment of the thermal properties of bricks made from clay and stabilized with varying percentages of reed fibers reveal important insights. As the content of reed fibers increases from C0 (0% fibers) to C6 (5% fibers), the density of the bricks gradually decreases. This reduction in density can be attributed to the lower density of reed fibers compared to clay. In terms of thermal conductivity, an equally intriguing trend emerges. The thermal conductivity of the bricks tends to decrease as the proportion of reed fibers increases (*Fig. 8 and Table 3*). This means that bricks with higher fiber content exhibit improved insulating properties, which is advantageous in applications where thermal insulation is a crucial factor. These findings suggest that the addition of reed fibers not only reduces the density of the bricks but also enhances their thermal insulating capabilities(*Fig 8.b*)., making them potentially suitable for construction projects where thermal efficiency and reduced heat conduction are desirable.

Table 3: Thermophysical properties of samples.

samples	Density	conductivity
C0	2253	0.811
C1	2114	0.753
C2	1986	0.620
C3	1871	0.504
C4	1789	0.472
C5	1687	0.361
C6	1700	0.382

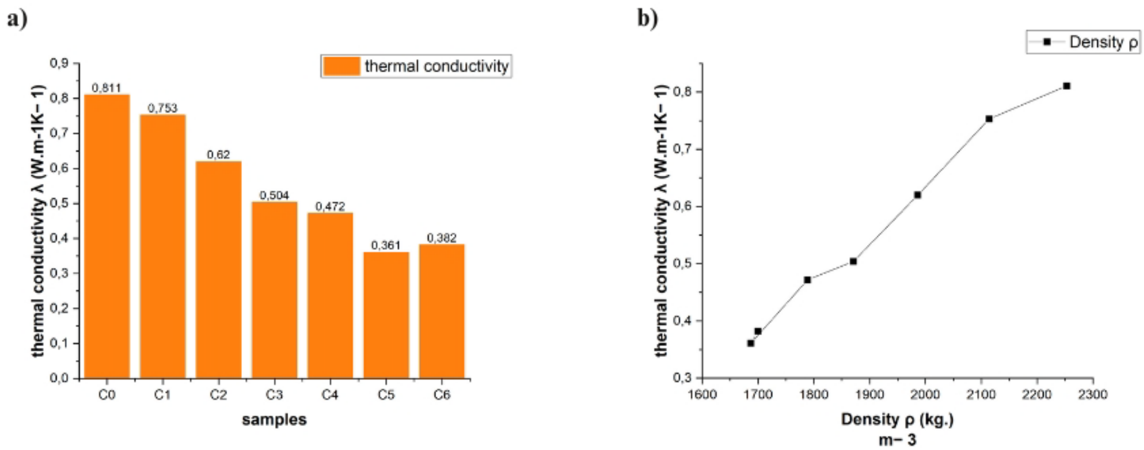

Fig 8 a Thermal conductivity of samples, b Figure 2 shows the variation of thermal conductivity as a function of density.

Conclusion

In conclusion, this study shows an inverse relationship between fiber percentage and thermal conductivity, demonstrating that increasing fiber content leads to a decrease in conductivity. The incorporation of reed fibers in clay mixes led to a reduction in indirect tensile and compressive strength, particularly in mixes containing a high proportion of fibers, i.e. 1%. However, it is important to note that adobes containing fibers maintained better cohesion after mechanical testing compared to clay alone, suggesting that the fibers contributed to enhancing the strength and cohesion of the bricks. This improvement in adobe cohesion due to fibers has important implications for improving the earthquake resistance of adobe structures. In addition, the addition of cement with a 5% fiber content was associated with a significant improvement in compressive and indirect tensile strength. In sum, the incorporation of reed fibers into adobe mixes offers significant potential for enhancing the mechanical properties of these building materials.

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