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Research Article

Improving insulation and energy efficiency in arid climate buildings with palm fiber-reinforced adobe: Impact on thermal and mechanical properties

Abdelkader BASSOUD[1,*], Abdelmalek BADA[1], Hamid KHELAFI[1], Abderahemane Mejedoub MOKHTARI[2], Abderrahmane MOULAY-ALI[1], Abdelghani IDDER[1]

[1]*Department of Civil Engineering, Laboratory LaGCEMS, at Ahmed Draia University, Adrar, 01000, Algeria*
[2]*Laboratory of Materials, Soils and Thermic, University of Science and Technology Mohamed Boudiaf, Oran, 31000, Algeria*

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ABSTRACT

Improving the thermal insulation of contemporary cement buildings is a significant challenge, particularly in desert environments subject to high temperatures. Adobe, a raw earth-based material, represents a practical solution due to its natural thermal properties. However, its low mechanical strength, particularly in bending, limits its integration into modern construction. This study demonstrates that a 13 cm layer of adobe reinforced with palm fibers, used as ceiling insulation, improves the thermal insulation of the building by approximately 133%, while reducing annual energy consumption by up to 53%. Furthermore, the impact of the length and dosage of palm fibers on the mechanical and thermal properties of adobe was examined through a series of tests. Four dosages (0.25%, 0.50%, 0.75% and 1% by weight) and four fiber lengths (25 mm, 50 mm, 75 mm and 100 mm) were tested. The results reveal that concentrations between 0.5% and 1% offer the best performance. In particular, the 50 mm fibers at 0.5% increased the compressive strength by about 20%, while the 75 mm fibers at 1% improved the flexural strength by up to 45%, reaching 1.70 MPa.

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INTRODUCTION

Climate change is now one of the most pressing threats of our time, leading to a significant increase in global energy consumption, with alarming forecasts for 2050. In this context, the building sector plays a significant role, accounting for nearly 36% of total energy consumption, according to the International Energy Agency (IEA). This trend is particularly pronounced in arid regions, such as southern Algeria, where the energy consumption of buildings can reach up to 45% [1]. Urban expansion and the transformation of Saharan building practices, driven by the growing demand for housing [2], exacerbate this issue, mainly since heat transfer through building walls directly affects indoor

*Corresponding author.
*E-mail address: bas_aek@univ-adrar.edu.dz

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thermal comfort, leading to increased use of air conditioning and, consequently, higher energy consumption [3].

In response to this challenge, thermal insulation of exterior walls has become essential to limit heat loss and energy consumption [4]. While natural materials insulate better thermally than synthetic ones [5, 6], the optimal thickness of insulation varies depending on climatic conditions and economic factors [7]. Furthermore, the production of many commonly used insulators, whether petrochemical or natural, remains energy-intensive [7, 8].

In this context, earth construction emerges as a sustainable and ancient solution. Present for over 9,000 years [9], earth architecture remains a cornerstone of traditional building practices in many regions, particularly in arid and temperate climates [9, 10]. It is estimated that over 40% of the world's population currently lives in earth-based housing [3], highlighting its resilience, adaptability, and relevance in contemporary sustainable construction. Adobe, a sun-dried raw earth brick, perfectly illustrates the multiple benefits of earth materials [11]. It offers a low environmental impact [12, 13], excellent thermal insulation, affordability, fire resistance, and the ability to absorb indoor pollutants. Adobe also promotes self-construction [9, 11, 14, 15], is fully recyclable [16], and requires minimal energy for production [17].

However, despite its numerous advantages, Adobe has notable drawbacks, primarily its low mechanical strength and vulnerability to seismic activity [18]. Its flexural strength, typically ranging from 0.2 to 0.83 MPa [19, 20], demonstrates its fragility. These structural limitations have led to the increasing adoption of cement-based alternatives [21]. However, these modern materials are associated with significant energy consumption during production [8] and high costs, which can be a barrier in economically disadvantaged regions [22, 23].

Recent studies have explored the enhancement of adobe bricks through the integration of various types of fibers [9, 10, 24, 25]. This process aims to strengthen the tensile strength and durability of Adobe while preserving its ecological and economic benefits. Fibers (mineral, synthetic, and natural) act as reinforcements, effectively inhibiting or reducing crack propagation [26]. An increasing number of studies have demonstrated promising results with various fibers: the incorporation of 1.75% Shibuya fiber increased compressive strength by 40% and flexural strength by 12% [27] palm fibers improved tensile strength and ductility [27]. Significant improvements in flexural strength have been reported with the use of red millet fibers (0.17 MPa) [22], barley straw (0.28 MPa) [28], eucalyptus pulp (0.45 MPa) [29], and hibiscus fibers (up to 1.13 MPa) [30]. Natural fibers such as straw, rice husk, and kenaf can improve not only the mechanical strength but also the thermal performance of earth materials [31-33].

Incorporating fibers has also been associated with a reduction in drying shrinkage, thus minimizing the risk of cracking during the hardening process [34-35]. including plant-based materials like hemp, jute [36], Grewia optiva [37], Pinus roxburghii, alfa [38], banana [39], Synthetic fibers such as glass-reinforced polymer fibers and polyethylene have also been explored [40].

This diversity of reinforcement materials reflects the growing interest in improving the mechanical performance, thermal behavior, and overall durability of Adobe as a sustainable building material [41-42].

This study aims to improve thermal insulation performance and reduce energy consumption in modern cement buildings in the Sahara by incorporating a layer of palm fiber-reinforced adobe as a thermal sealant at the ceiling level. It also examines the specific role of palm fibers by analyzing the effects of their incorporation, dosage, and length on the mechanical and thermal properties of adobe bricks. The overall goal is to promote the sustainable use of natural resources and encourage the reassessment of local materials, especially in arid and hot regions where clay is readily available.

MATERIALS AND METHODS

Description of the Study Region

The arid zone in Algeria encompasses a vast portion of the Sahara, covering approximately 80% of the country's total surface area. For this study, we selected the province of Adrar, located in the southern region of Algeria. This region is characterized by a desert climate, marked by extremely hot summers and cold winters [43]. *Figure 1* presents our recorded temperature and relative humidity data in Adrar over one year.

In the Adrar region, construction materials are predominantly cement-based, while load-bearing structures are made of reinforced concrete, as illustrated in Figure 2.

Materials

a) Clay & sand

For the production of adobe bricks, clay and sand were sourced from the Adrar region, located south of Algeria. Laboratory tests conducted at the University of Adrar on these local soils yielded the following results:

According to analysis results, clay is classified as highly plastic. It is made up of fine particles; more than 51% of its elements have a diameter of less than 0.080 mm. the sand is very clean, with an almost total absence of fine clay particles and a low SO4 sulfate salt content.

b) Fiber

Palm fibers, which are natural fibers, are characterized by their strength. It is extracted from the palm tree, which is generally found in warm climates, and is used to make rope, fabric and other products. The figure.2. b shows palm fibers. The table.2 shows the physical and mechanical properties.

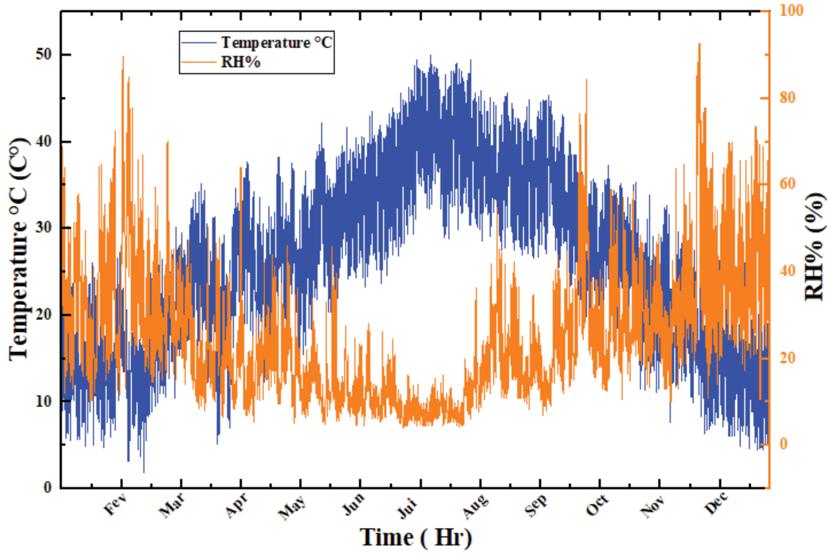

Figure 1. Temperature and humidity in Adrar.

Figure 2. Building materials in Adrar.

Table 1. Physical characteristics of materials

	density	Grain size distribution	Fineness modulus	PH [44]	Mica	$CaCO_3$	SiO_2	Salinity		
Sand	2.78 t/m³	89% of the grains are of fine to medium size (0.1 mm - 2 mm)	89%	7.1	1.9%	2.1%	96%	0.03%		
					Plasticity Index (PI) [45]	Kaolinite	Illite	Quartz	Others	Water absorption capacity
Clay	2.59 g/cm³	51%<0.08		8	55.10%	63%	18%	12%	7%	40%

Table 2. Physical properties of palm fiber

Length (mm)	Dimensions(mm)	Specific weight g/cm³	Tensile strength (kg/cm²)
50- 200	0.045	0.632	1832.23

Table 3. Samples composition (Source: authors)

Sample	Fiber%	Fiber length (mm)
A1	0	0
A0.25-25	0.25	25
A0.25-50	0.25	50
A0.25-75	0.25	75
A0.25-100	0.25	100
A0.5-25	0.5	25
A0.5-50	0.5	50
A0.5-75	0.5	75
A0.5-100	0.5	100
A0.75-25	0.75	25
A0.75-50	0.75	50
A0.75-75	0.75	75
A0.75-100	0.75	100
A1-25	1%	25
A1-50	1%	50
A1-75	1%	75
A1-100	1%	100

Adobe Mixing Ratios

To evaluate different sample mixtures, we carefully mixed the clay soil by hand with various parts of drinking water until we obtained a homogeneous adobe mixture. The percentage of water in the mixture varied between 23% and 25%, corresponding to a quantity of water ranging from 160 g to 1850 g.

Seventeen different adobe mixes were prepared for this study; we compared an ordinary adobe brick mix without any additives (0%) to sixteen mixes containing four rates of natural fiber (0.25%, 0.50%, 0.75%, and 1% by weight of dry fiber) and four different fiber lengths (25 mm, 50 mm, 75 mm, and 100 mm). All data are shown in Table.3. The name of the sample includes two numbers, the first indicating the percentage by weight of fibers in the adobe and the second indicating the length of the fibers used in the preparation of the mixture. For each mix, three identical samples were prepared in order to repeat the tests three times. In total, 51 samples were made for each type of test, both thermal and mechanical Figure 3.

Figure 4 shows two scanning electron microscopy (SEM) micrographs of fiber-reinforced adobe. The first image (a) reveals the composition of adobe made from dune sand and fibers. Sand particles, which have retained their

Figure 3. sample preparation a: adobe, b: palm fiber, c: samples [photo by author].

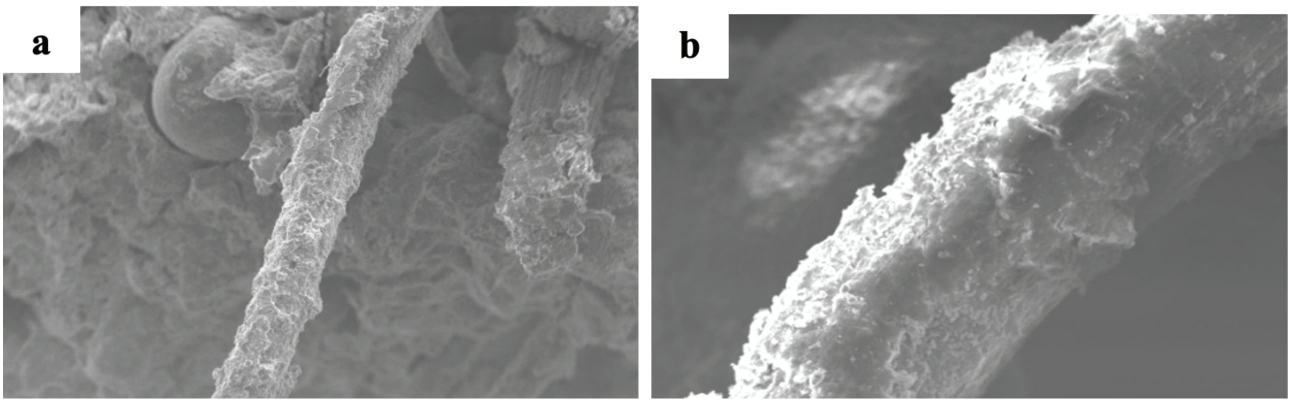

Figure 4. Image according to SEM. a: adobe fiber-reinforced. b: Fiber, x200 µm.

characteristic granular morphology, are predominantly larger than the fibers. This granulometric distribution influences the density, porosity and mechanical properties of the composite material. The second micrograph focuses on the fiber-matrix interface, showing significant roughening of the fiber surface. This morphological feature is crucial to the mechanical properties of the composite. As indicated in [46], increased roughness promotes better mechanical anchorage with the surrounding soil particles. This microscopic interlocking phenomenon improves fiber-matrix adhesion, increases resistance to raveling, enables better stress distribution and contributes to an increase in the material's toughness. These microscopic observations provide valuable insights into the reinforcement mechanisms at work in fiber-reinforced adobe.

Experimental Tests

Mechanical test

Uniaxial compression testing was carried out on the prepared samples to determine their compressive strength. Tests of mechanical compressive strength were conducted according to EN:101511 [47], a loading speed of 0.01 MPa/s was selected. each specimen was subjected to an increasing load at constant speed until it failed, as illustrated in Figure 5.b.

The flexural strength of the samples was determined in accordance with European standard EN1015-11 [48].

The test protocol involves applying a concentrated load to the center of a prismatic specimen, supported at both ends, as shown in Figure 4a. This configuration, known as a three-point bending test, creates a maximum bending moment at the center of the specimen. For our study, we used specimens of standard dimensions 40x40x160 mm³.

Thermal properties

We determined the thermal characteristics of the samples by conducting tests at the University of Adrar using an HM150 apparatus figure 6. Employs the thermal flow meter technique by the following standards: ASTM C518, ISO 8301, and DIN EN 12667 [49, 50]. We subjected the samples, measuring 400 × 400 × 40 mm³, to controlled measurements. (Fig. 8)

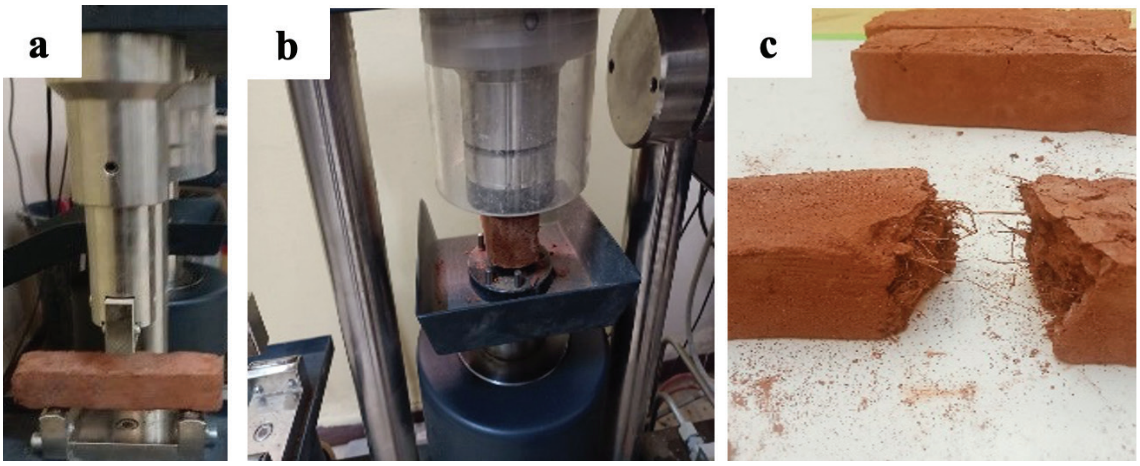

Figure 5. Experimental tests: (a) Bending test, (b) Compression test, and (c) Specimen failure after testing.

Figure 6. Thermal test.

Building simulation

To evaluate the impact of fiber-reinforced adobe on thermal insulation by selecting a typical building model from the Saharan region (Fig. 7). We incorporated fiber-reinforced adobe as an insulating layer on the ceiling and modeled the building's thermal performance using TRNSYS 18 (Tab.4). The simulation allowed us to assess how fiber-reinforced adobe helps maintain stable indoor temperatures in the extreme climate of the Saharan region.

Two floor variants were investigated in this study. The first represents the standard waterproofing system commonly used in the Saharan region, while the second variant incorporates a fiber-reinforced adobe layer, as detailed in the table 5.

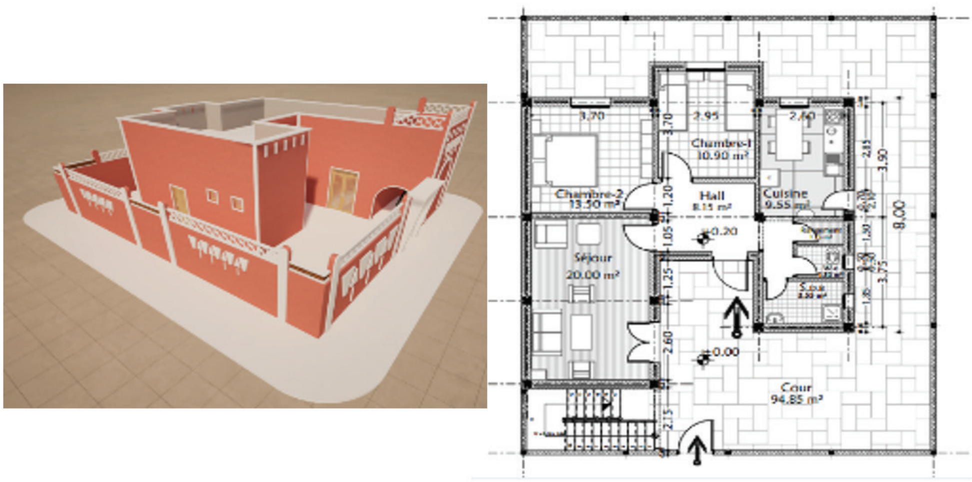

Figure 7. Saharan building.

Table 4. TRNsys Types

TRNSYS18	Building Modeling	Building Data	Climatic Data	Ground Temperature	Result

Table 5. Constituents of variants of floor

Element	Wall	Floor	
		Variant 1	Variant 2 With Fiber-Reinforced Adobe
Constituents	1.5 cm External Plaster 15 cm Brick 5 cm Air Gap 10 cm Brick 2 cm Internal Plaster	2 cm Tiles 2.5 cm Mortar Bed 10 cm Sand 3 cm Mortar 5 cm Reinforced Concrete 16 cm Concrete Slab 2 cm Plaster	2 cm Tiles 2.5 cm Mortar Bed 13 cm Fiber-Reinforced Adobe 5 cm Reinforced Concrete 16 cm Concrete Slab 2 cm Plaster
Total thickness	33.5	40	40
U W/m²k	0.653	1,855	0.604

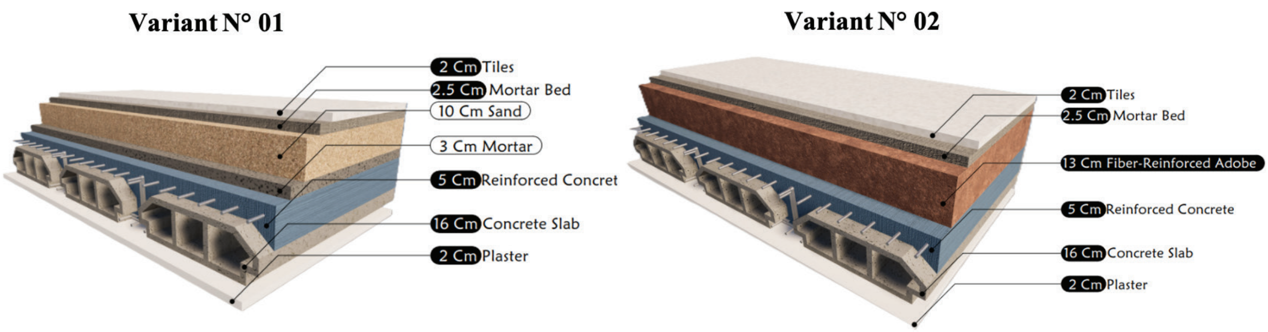

Figure 8. Components of thermal seals. V1: Saharan seal. V2: Sealing with fibered adobe.

Table 6. Equipment Intensity

Equipement	Zone	Occupancy time	Power W	Power W (KJ/h)
Computer	Bedroom	Occupation	230	828
Television	Living room	Occupation	150	540
Cooking appliances	Kitchen	occupation	700	2520
Refrigerator 200 L	Kitchen	24/7	87.5	315

Table 11. Lighting gains [51]

Local	Recommended light intensity lux	Power output of lamps or tubes w/m²	
		Incandescent lamps	Fluorescent lamps
Rooms	120	25	8

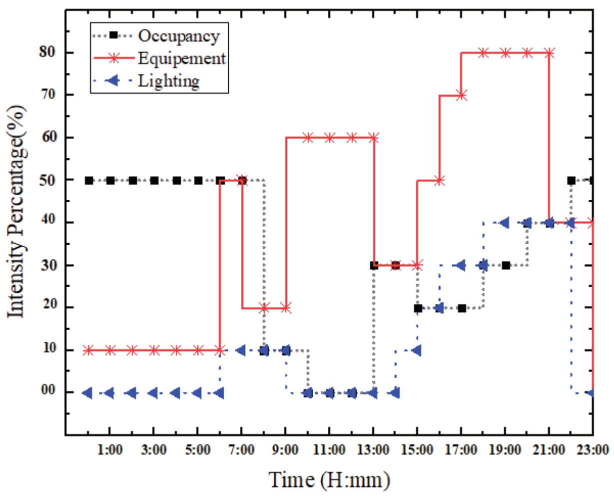

Figure 9. Occupancy intensity.

Internal Gains

The sensible power dissipated per person is estimated at 100 W/person according to the current standards (DTR3-4) [51]

Lighting gains based on lamp type are presented as follows:

The figure 9 illustrates the percentage of occupancy intensity, equipment use, and lighting in a Saharan building during a typical day, from 1 a.m. to midnight. Occupancy levels fluctuate, peaking during daylight hours and decreasing at night. Equipment use increases with occupancy. Lighting use follows a similar trend, increasing as daylight diminishes and peaking in the evening.

Energy Needs

We assessed the cooling energy demand during summer to maintain indoor conditions at 27 °C and 50% relative humidity, and the heating energy demand in winter to maintain 20 °C. These comfort conditions are defined by the Algerian thermal regulation standard DTR C3.4. [51]

Research Uncertainty and Limitations

This study presents certain limitations and uncertainties. The hypothesis of a uniform distribution of palm fibers simplifies reality. However, ensures a replicated experimental framework. We conducted our tests with three replicates per mixture, thereby reducing the influence of random errors, although total variability may not be fully accounted for. Modeling has taken into account only floor variation, which highlights its specific role but does not reflect all actual conditions. Finally, the energy assessment is based on DTR regulatory comfort temperatures (25°C in summer, 20°C in winter), although occupant preferences may differ. These limitations serve to delineate the scope of the present study while simultaneously highlighting directions for future research.

RESULTS AND DISCUSSION

Compressive Strength

Figure 10 shows the evolution of the compressive strength of adobe samples as a function of the percentage (0%, 0.25%, 0.5%, 0.75%, 1%) and length (25, 50, 75, 100 mm) of palm fibers incorporated, compared with the control sample without fibers (0%). For fibers of 25 mm length, a reduction in compressive strength was observed, reaching 6%, 10%, and 20% depending on the dosage. The 0.5% dosage yielded the most promising results, with a 20% increase in strength for 50 mm fibers, followed by 10% and 2% increases for 75 mm and 100 mm lengths, respectively. In contrast, the 0.25% and 1% dosages showed a slight reduction of 2% and 4% at 100 mm, but more significant decreases of 10% and 25% for shorter fiber lengths. These results suggest that fiber length can have a positive effect on compressive strength at lower dosages. However, the 0.75% dosage consistently produced adverse effects on compressive strength across all fiber lengths. The optimal configuration identified was 0.5% fiber content with a length of 50 mm. Additionally, the uniformity of fiber dispersion within the matrix plays a critical role in maintaining mechanical integrity. These findings align with those of Gao et al. [52, 53], who reported a non-linear relationship between fiber length and mechanical strength, as well as the existence of an optimal fiber length that maximizes load transfer within the material.

When compared with other natural fibers reported in the literature, palm fiber reinforced adobe exhibits competitive performance. For example, wheat long straw at a 1% dosage achieved a compressive strength of 4.98 MPa [54], while wheat crushed straw at the exact dosage reached 19.11 MPa [54], and doum fiber achieved 19.91 MPa at 1% [55]. Lavender straws, used at a higher dosage of 6%, yielded 3.9 MPa [56]. Sawdust fibers at 1% reached 8.11 MPa [57], and neem straw at 2% attained 6.35 MPa [58]. These comparisons highlight that while palm fibers may not attain the very high compressive strengths of specific agricultural residues like crushed wheat straw or doum fiber, they still offer a viable and sustainable reinforcement, especially when dosage and fiber length are carefully optimised.

Flexural Strength

Figure 11 shows the flexural strength of adobe samples as a function of the dosage (0%, 0.25%, 0.5%, 0.75%, 1%) and length (25, 50, 75, 100 mm) of incorporated palm fibers, compared to a control sample without fibers.0%

The results reveal a substantial improvement in flexural strength for all fiber dosages. The 1% dosage showed the most pronounced increase, ranging from 20% to 45%. The 0.75% dosage follows closely with an improvement ranging from 13% to 43%. The 0.5% dosage shows a moderate increase from 12% to 20%. Even the lowest dosage of 0.25% shows a positive increase, albeit more modest, from 4% to 20%.

These data highlight the significant influence of palm fiber dosage on the flexural strength of adobe. Fiber length has an important role to play, particularly for the 1% dosage, where the effect is most noticeable.

The addition of palm fibers considerably improves the bending strength of adobe. This improvement depends on both the dosage and the length of the fibers used. This

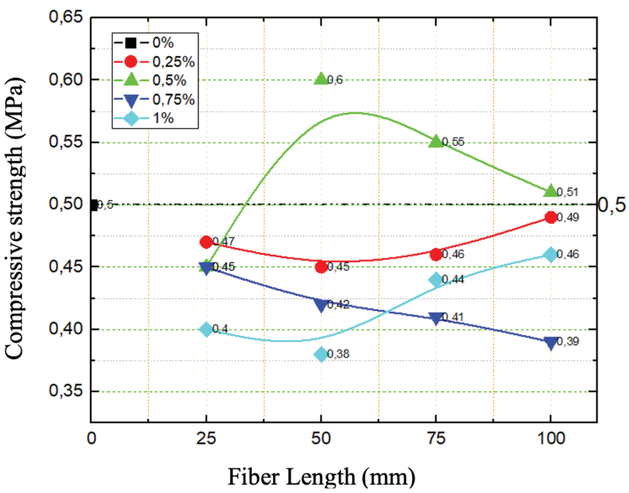

Figure 10. Compressive strength.

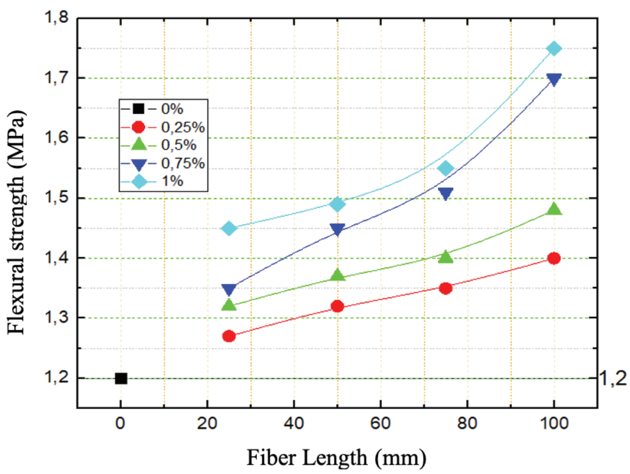

Figure 11. Flexural strenght.

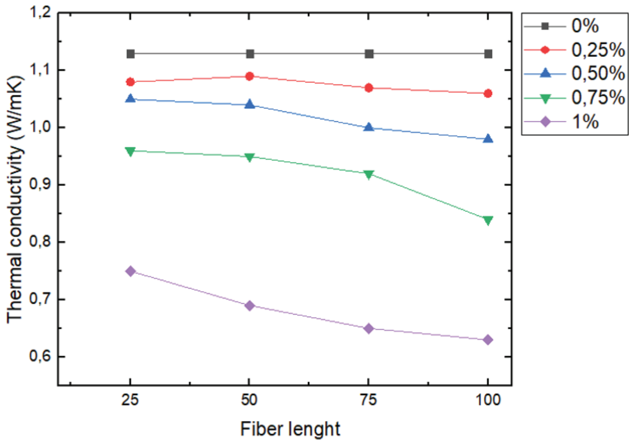

Figure 12. Thermal conductivity.

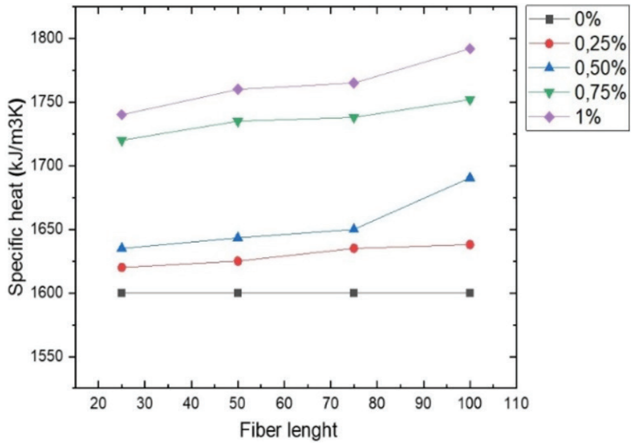

Figure 13. specific heat.

reinforcement not only increases mechanical strength, but also delays the appearance and propagation of cracks in the material.

It is essential to stress that the homogeneity and uniform distribution of the fibers guarantees a consistent improvement in mechanical properties throughout the material.

In our study, palm fiber–reinforced adobe achieved a flexural strength of up to 1.7 MPa, positioning it favorably among both natural and synthetic fiber reinforcements reported in the literature. For comparison, lower strengths have been reported for red millet fiber (0.17 MPa) [22], barley straw (0.28 MPa) [28], waste tire textile fiber (0.285 MPa) [59],, wool fiber (0.139 MPa) [60], eucalyptus pulp (0.45 MPa) [29], alfa fiber (0.488 MPa) [29], polypropylene fiber (0.83 MPa) [61], banana fiber (0.95 MPa) [61], sawdust fibers (0.4 MPa) [57], lavender straws (0.28 MPa) [56], neem straw at 2% (0.65 MPa) [58], doum fiber (0.412 MPa) [55], and crushed wheat straw (0.78 MPa) [54]. Palm fibers also compare closely with wheat long straw (1.42 MPa) [54], although they fall below alfa fiber in some cases (2.01 MPa) [38] and hemp fiber (3.11 MPa) [62]. These findings highlight palm fibers as a highly promising natural reinforcement for adobe, particularly in hot and arid regions, offering an effective and sustainable means of improving mechanical properties while supporting local resource use.

Thermal Properties

Figure 12 presents the results of the thermal conductivity tests conducted on adobe samples reinforced with varying percentages and lengths of palm fibers. An apparent decrease in thermal conductivity was observed, demonstrating the positive effect of palm fiber addition in enhancing the thermal insulation performance of adobe. The thermal conductivity dropped from 1.15 W/m·K (reference sample without fibers) to 0.65 W/m·K in the best-performing mix, which included 1% palm fiber with a length of 100 mm. Specifically, a reduction of 0.07 W/m·K was recorded for a fiber content of 0.25%, 0.15 W/m·K for 0.5%, and the reduction further increased to 0.2 W/m·K and 0.45 W/m·K for fiber contents of 0.75% and 1%, respectively.

Compared to values reported in the literature for other natural fiber reinforcements, palm fibers show competitive thermal performance. For example, wheat long straw at a 2% dosage yielded a thermal conductivity of 0.411 W/m·K [54], and hemp shiv at a 6% dosage reached a much lower value of 0.2 W/m·K [63]. While hemp-based materials exhibit superior insulation, the use of palm fibers remains a sustainable and effective solution, especially in arid regions where such resources are abundant and locally available.

These results clearly demonstrate that reinforcing adobe with palm fibers significantly enhances its thermal characteristics by effectively reducing its thermal conductivity.

Figure 13 shows the variation in the specific heat capacity of the samples as a function of fiber content and length. Improvements of 1.56%, 5%, 7.81%, and 12.5% were recorded for fiber dosages of 0.25%, 0.50%, 0.75%, and 1%, respectively.

These results demonstrate the positive effect of palm fibers on improving the specific heat capacity of adobe, a key parameter that plays an important role in thermal insulation and heat storage.

Adobe with a higher specific heat can absorb more heat during the day without significantly raising their temperature. As a result, the indoor temperature increases more gradually during peak heat periods, effectively delaying or reducing the intensity of heat reaching the interior. This delay in temperature changes, known as thermal lag, leads to a more stable indoor temperature throughout the day.

Thermal Insulation of The Building

The variation in the internal temperature of the building for the two variants, compared to the external temperature

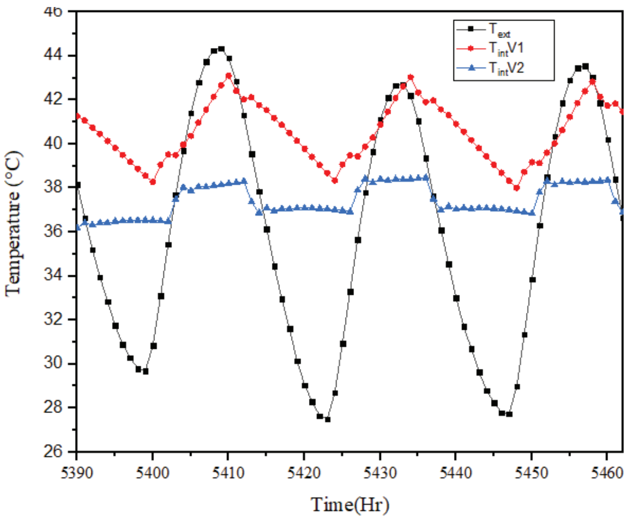

Figure 14. internal temperature of the building.

during a summer period, is illustrated in **Figure 14**. A significant daily temperature difference between day and night was observed, reaching up to 17°C, with a maximum temperature of 45°C, highlighting the severity of the climate. For Variant 1, with the Saharan sand-based waterproofing, the temperature difference between the exterior and interior does not exceed 3°C. In contrast, for Variant 2, with a floor waterproofing system incorporating fiber-reinforced adobe, the temperature difference reaches 7°C, representing an improvement of 133%.

Figure 15 shows the variation in temperature on both sides of the floor, external and internal, for the two variants. In Figure 15.a, we observed a difference between the temperatures on the two sides, with a notable daily variation. However, in Figure.15b, we recorded that the temperature on the internal side remains relatively independent of the temperature on the external side.

The variation in the internal and external surface temperatures of the floor for the two variants during the period starting in August is presented in Figure 16. It was observed that the temperature on the internal side for Variant N°2(with adobe) figure 16a remains nearly stable, while for Variant N°1(Fig. 16.b), it fluctuates between 47°C and 38°C. In contrast, the temperature on the external side reaches up to 62°C, with a significant daily temperature difference of 33°C. This highlights the highly aggressive effect of the climate in arid and hot regions on construction materials, particularly cement-based products. Therefore, adobe presents an ideal solution for floor insulation in buildings, protecting against the effects of external temperatures.

Energy Balance

Figure 17 presents the energy needs for cooling (Fig. 17.a) and heating (Fig. 17.b) for two construction variants: V1, which uses sand, and V2, which incorporates fiber-reinforced adobe as the terrace sealing material.

Regarding cooling needs, Figure 14. a shows that the summer period extends approximately six months, from May to October. However, the winter lasts around five months, from November to March. It shows the significant

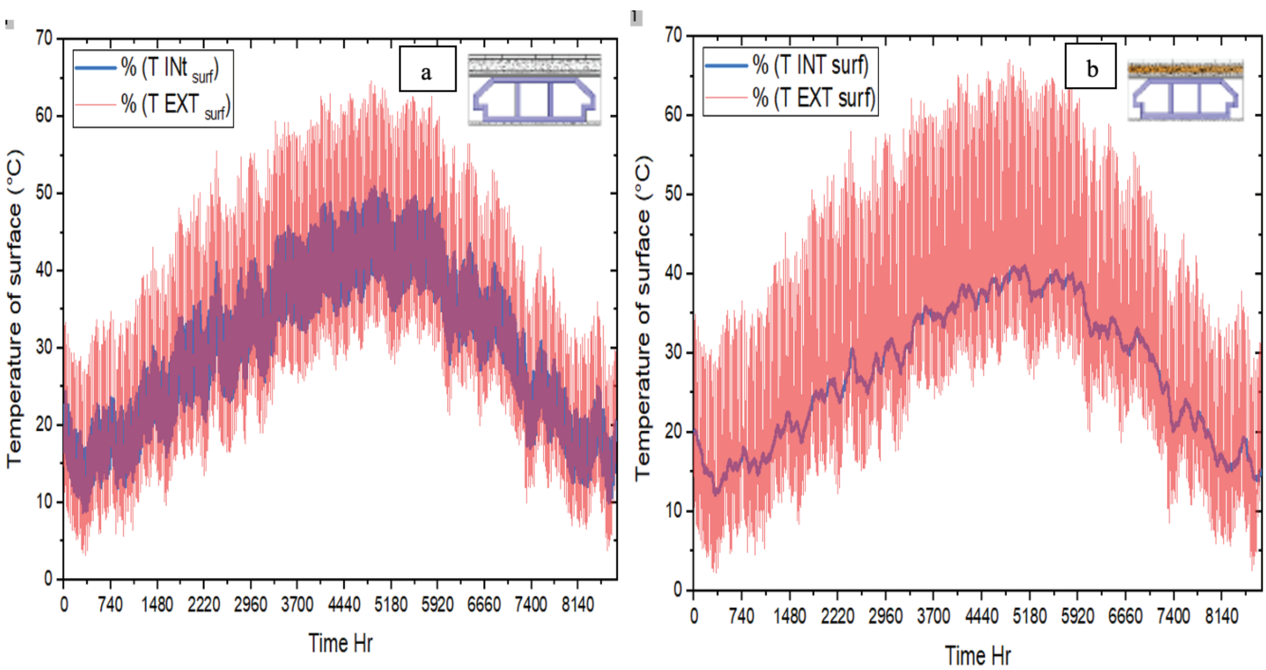

Figure 15. variation in temperature on both sides of the floor.

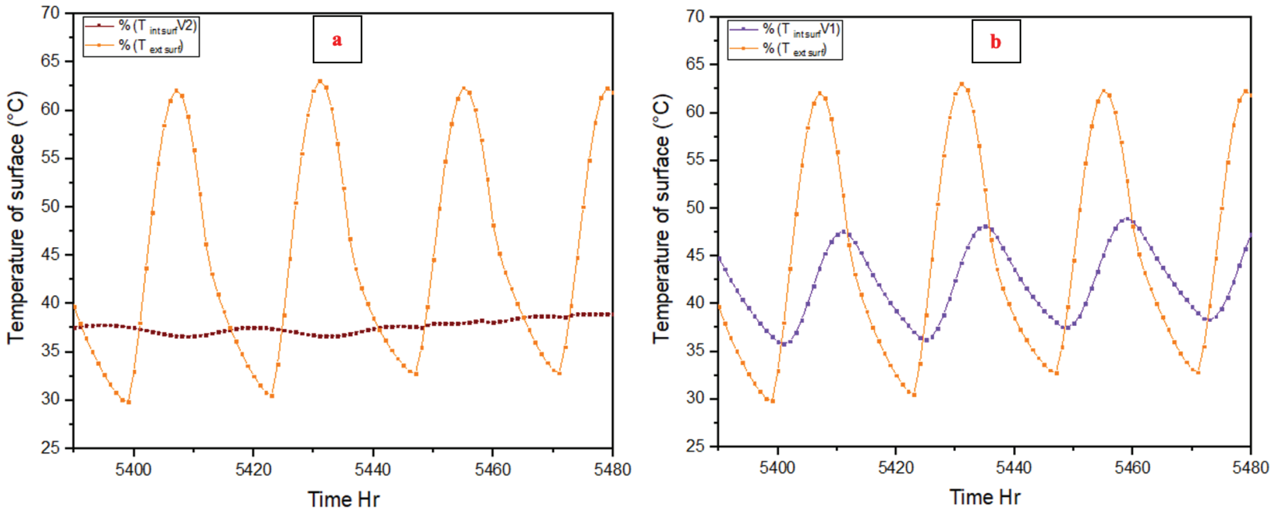

Figure 16. variation in temperature on both sides of the floor in summer period.

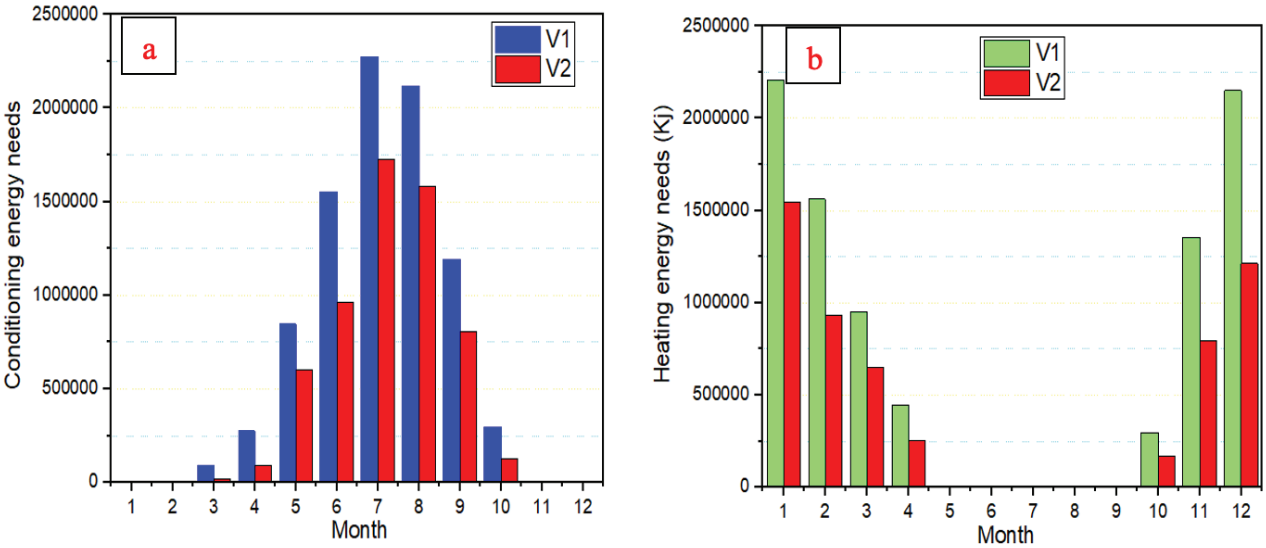

Figure 17. Energy needs. (a) Cooling, (b). Heating.

thermal demand of the examined location, defined by an extended hot season, emphasizing the necessity for efficient building insulation.

CONCLUSION

This study on the incorporation of palm fibers into Adobe reveals significant and promising results for improving the mechanical properties of this traditional building material.

The addition of palm fibers showed different effects on the compressive and flexural strength of Adobe. For compressive strength, the results were mixed, with a notable improvement for some combinations of fiber dosage and length, notably 0.5% of 50 mm fibers, while other combinations showed a decrease in strength. On the other hand, flexural strength was considerably improved for all dosages and fiber lengths tested, with increases of up to 45% for the highest dosages.

These results underline the importance of fiber dosage and length in optimizing the mechanical properties of reinforced Adobe. The optimum dosage appears to be around 0.5% to 1%, while the most effective fiber lengths vary between 50 and 75 mm, depending on the mechanical property under consideration.

The improvement in flexural strength is particularly significant, as it indicates a better ability of the material to resist tensile stresses and delay the onset and propagation of cracks.

The homogeneity of fiber distribution in the adobe matrix plays a role in achieving optimal and uniform mechanical properties.

Integrating palm fiber-reinforced adobe as a thermal insulation layer offers substantial benefits, notably reducing annual energy consumption by up to 53%. This underscores the material's strong potential as a sustainable and efficient solution for modern construction in hot and arid climates. Furthermore, the results highlight the vulnerability of conventional cement-based materials to harsh climatic conditions, reinforcing the suitability of Adobe for thermal insulation, particularly in thermal sealing on the roof. The improvement in Adobe's specific heat capacity due to palm fiber incorporation further enhances its ability to store and regulate heat, making it a promising material for energy-efficient and climate-resilient building design

This study shows the considerable potential of using palm fibers as a natural additive and reinforcement in Adobe. It opens up new prospects for the improvement and modernization of this traditional building material, offering a sustainable and environmentally-friendly solution to meet current performance requirements in the construction sector. However, further research may be required to optimize formulations further and explore other aspects such as long-term durability and behavior in the face of varied environmental conditions.

Perspectives

This study serves as an introduction to the exploration of new methods for construction in arid zones, focusing on improving the durability of adobe bricks. Additionally, future work may involve the development of insulating sheets made from earth-based materials, contributing to more sustainable and energy-efficient building solutions.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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