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Influence of rice husk and cabuya fiber on the physical and mechanical properties of adobe

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Abstract

Adobe is one of the most widely used materials in housing construction around the world due to its low cost and ease of preparation. However, one of its main disadvantages is its low compressive and flexural strength. This research aims to study the influence of rice husk (RH) and cabuya fibers (CF) on the physical and mechanical properties of adobe. RH, a by-product available in rice-producing countries, offers environmental and economic benefits, while CF are natural fibers obtained from the leaves of plants of the Agave family. Their incorporation in adobe mixes helps prevent cracks and improves the durability of the final product. The methodology used considered proportions of 0.75%, 5%, 10% and 20% of RH and 0.5%, 1%, 1.5% and 2% of CF per weight of dry soil. The results indicated that the optimum content was 0.75% RH combined with 2% CF, where properties such as absorption and unit weight were reduced, while compressive, flexural, stacking and tensile strength increased by 52.31%, 22.49%, 52.64% and 50.48%, respectively, compared to the standard adobe. Concluding that RH and CF are viable as reinforcements in adobe production, supporting the feasibility of using these combinations as an effective strategy to strengthen adobe structures.

Keywords: Adobe, Rice husk, Cabuya fibers, Civil engineering, Sustainability

1. Introduction

Historically, adobe bricks were produced manually in various dimensions, with or without the use of molds, combining clay, sand, water and vegetable fibers [1]. Various civilizations have used adobe to create reliable and comfortable housing solutions [2]. This material is preferred due to its availability for large-scale production, which significantly reduces costs and maintains consistent quality [3]. However, environmental factors can affect the structural behavior of adobe, reducing its mechanical performance [4]. The density and quality of the final product depended on human factors and the composition of the mix [5].

Currently, adobes are produced using random materials and empirical techniques, resulting in non-homogeneous products with variable physical-mechanical properties [6, 7]. This has generated a generalized distrust towards adobe due to its rapid deterioration [8]. However, approximately 30% of the world's population lives in adobe houses, a figure that increases to 50% in developing countries [9]. Therefore, researchers have paid special attention to improving the standardization and reliability of adobe in modern construction [10].

World rice production generates more than 750 million tons of grain annually, of which 150 million tons are husk [11]. China is the largest producer with 28.5%, followed by India with 22% [12]. Rice husk is mainly composed of 50% cellulose, 25-30% lignin, 15-20% silica and 10-15% moisture [13]. Due to its low bulk density, ranging from 90-150 kg/m³, current methods of rice husk disposal pose safety concerns and waste resources [14]. In Peru, a South American country, according to the National Institute of Statistics and Informatics (NISI), paddy rice production in January 2023 amounted to 220,101 tons, and in May 2024, paddy rice production reached 524,56 tons, a higher volume than in 2023 [15, 16].

Also known as sisal, cabuya fibers are rapidly replacing synthetic fibers in composite materials [17]. Annually, 378,000 tons are produced, with Brazil, Tanzania and Kenya as the main producers [18]. These fibers consist mainly of 73.11% cellulose, 13.33% hemicellulose, 11% lignin, 1.33% pectin and 0.33% ash by weight [19]. With an average density of 1475 kg/m³, natural fibers are popular in the construction industry due to their sustainability, biodegradability, lower density and reduced energy consumption [20]. However, these organic materials have not yet been used together in the preparation of artisanal adobe. But there are studies where they have been used in the preparation of concrete [21-25], morter [26], soil stabilization [27, 28], concrete blocks [29, 30], etc., for a sustainable construction industry [31, 32].

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The incorporation of rice husk in adobe has been shown to be suitable in civil engineering [33, 34]. Ige and Danso [35], found that the incorporation of 1% RH increased the water absorption of adobe by 48%. However, Ouedraogo et al. [36], found that water absorption decreased with the addition of 8% RH to 11.11%. This decrease is due to the low porosity of the RH and the homogeneous microstructure of the RH-reinforced adobe [37]. The incorporation of agricultural residues has also been shown to reduce the unit weight of adobe. Huy et al. [38], recorded a 32.05% reduction with the addition of 9% RH.

The addition of rice husks (RH) influences the mechanical properties of adobe, though results vary depending on the proportion used. Ige and Danso [35], reported a 62% increase in compressive strength with 0.75% RH, while Modjonda et al. [39], observed a 12% improvement with 6% RH. In contrast, Huy et al. [38], found a 56.6% decrease using the same RH proportion, highlighting the importance of proper adhesion and dispersion of residues in the soil matrix [40]. Regarding flexural strength, Hany et al. [41], noted an 8% reduction with 0.25% RH, and Heniegal et al. [42] reported an 11% decrease with over 5% RH. For compressive strength in piles, Adazabra et al. [43], observed a 71.97% reduction with 16% RH, while Muñoz et al. [44], documented a 36.6% increase with 18% RH. Diagonal compressive strength also improved by 41.24% with 18% RH [44], and Ige and Danso [35], found a 95% increase with 0.75% RH. Additionally, Araya-Letelier et al. [45], noted a 134% improvement in flexural strength with 1% natural fibers (NF).

This study explores the novel combination of rice husk and cabuya fibers in adobe, addressing a gap in sustainable construction research. By analyzing their physical and mechanical properties, it provides a theoretical foundation for future advancements. Previous studies validated the feasibility of incorporating these materials, with proposed ranges: 0.75%, 5%, 10%, and 20% for rice husk, and 0.5%, 1%, 1.5%, and 2% for cabuya fibers. Highlighting potential in Latin America, particularly Peru, this research advances knowledge and offers practical solutions for sustainable, earth-based construction.

2. Materials and methods

2.1 Materials

2.1.1 Soil

The adobe bricks used in constructing the masonry specimens were manufactured using traditional techniques and considering the specifications of the Peruvian Standard [NTP] E.80 [46]. The brick dimensions were (80 × 160 × 320) mm. The soil was extracted from Ferreñafe, Lambayeque, Peru, in a specific area with geographical coordinates S 6°38'03" and W 79°48'11", at a depth of 50 cm, natural clay quarry material suitable for quarrying. According to ASTM D2487 [47], it is considered a clayey soil (CL). The Atterberg tests were conducted following ASTM D4318 [48]; and the results are shown in Table 1. The water content test was also performed according to ASTM D4959-16 [49], resulting in a 9% water content.

Table 1 Results of Atterberg limits test

Test	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Plasticity Index (PI) (%)
Results	37	24	13

2.1.2 Rice husk

The rice husk (RH) is a product obtained from rice processing, shown in Figure 1, and is used in its raw state. It was collected in the district of Nueva Arica, Province of Chiclayo, Department of Lambayeque, Peru, and sieved through a 2 mm mesh to remove fine particles. The husks were dried for 24 hours until they reached constant masses to control consistency. The chemical analysis using the X-ray fluorescence test, following ASTM E1621-16 [50], presented the components shown in Table 2 and Figure 2. Mixes containing four (04) RH contents, namely 0.75, 5, 10, and 20% of the total volume of the mix, were studied to evaluate the optimal content.

Figure 1 Rice husk (a); sieved RH (b)

Table 2 Chemical composition of rice husk

Element	Mass (%)	Element	Mass (%)	Element	Mass (%)
Al_2O_3	0.338	K_2O	66.567	CuO	0.588
SiO_2	1.644	CaO	4.764	ZnO	0.378
P_2O_5	14.595	TiO_2	5.028	As_2O_3	0.024
SO_2	7.806	MnO	11.019	SeO_2	0.063
ClO_2	4.973	Fe_2O_3	3.891	BaO	0.101
				Total	121.842

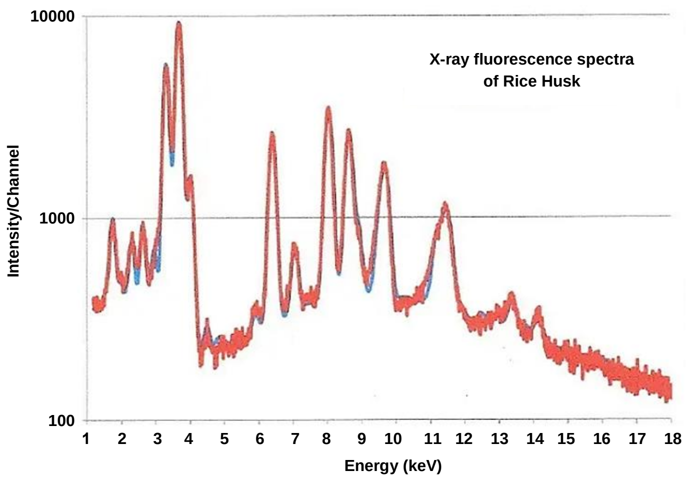

Figure 2 X-ray fluorescence analysis of rice husk

2.1.3 Cabuya fibers

Locally available untreated cabuya fiber (CF), with an average length of approximately 30 mm, was used at various stages and in four percentages: 0.5, 1, 1.5, and 2% of the total mix volume to evaluate the optimal content. The cabuya stalks were cut into fragments, scraped on the back, and soaked in water with sodium hydroxide for at least 24 hours. Subsequently, the stalks were hammered to separate them into strips. These fibers were then treated by soaking them in a water solution for 24 hours. Additionally, the soaking process reduces the fibers' ability to absorb water. Figure 3 illustrates the steps followed to extract and prepare the bamboo fibers. Various properties of cabuya fiber are detailed in Table 3. Based on the chemical analysis using the X-ray fluorescence test, following ASTM E1621-16 [50], the components are shown in Table 4 and Figure 4.

Figure 3 Cabuya extraction (a); branches (b); cleaning (c); fiber (d)

Table 3 Cabuya Fiber Properties

Description	Cabuya Fiber	ASTM Standard
Length (mm)	40	-
Diameter (mm)	0.10 - 2.0	-
Specific gravity	0.26	ASTM C188
Tensile strength (MPa)	320	-

Table 4 Chemical Composition of Cabuya Fiber

Element	Mass (%)	Element	Mass (%)	Element	Mass (%)
Al	0.676	Ca	0.920	Cu	0.189
Si	0.927	Ti	0.003	Zn	0.112
S	0.154	Mn	0.005	Sr	0.004
Cl	0.086	Fe	0.018	Subtotal	3.569
K	0.468	Ni	0.009	Others	96.431
				Total	100.00

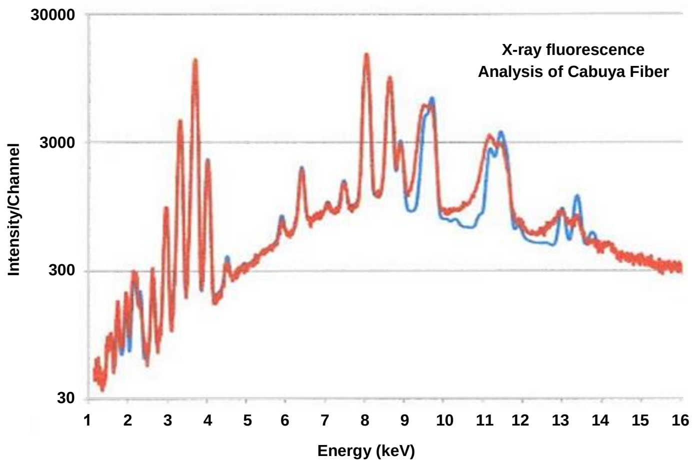

Figure 4 X-ray Fluorescence Analysis of Cabuya Fiber

The treatment ensures a uniform distribution of the fibers in the mixture, avoiding agglomerations and weak points. This results in a homogeneous reinforcement that improves tensile and flexural strength and increases the ductility of the material. By optimizing the characteristics of the fibers and their interaction with the matrix, the durability of the adobe is also increased. These benefits highlight the importance of appropriate treatment processes to develop sustainable, high-performance building materials.

2.2 Methods

The process of producing adobe with rice husks and cabuya fibers includes sifting the soil and acquiring the materials. The sifted soil is then mixed with water until a mud consistency is obtained. The appropriate proportions of rice husk (0.75%, 5%, 10% and 20%) and cabuya fibers (0.5%, 1%, 1.5% and 2%) are added and the mixture is homogenized. Descriptions of the experimental ratios are shown in Table 5. The mixture is poured into adobe molds and compacted to eliminate air pockets and ensure good cohesion. The adobes are air-dried for several weeks and can be cured with water to improve their strength. They are stored in a dry place until use. Physical and mechanical properties, such as absorption, unit weight, compressive, flexural and tensile strength, are evaluated to ensure quality and durability. This process follows the Peruvian methodology under the E.080 standard. [46]. Figure 5 shows the process flow from obtaining the materials, testing, and interpreting the information obtained for the scientific study.

Table 5 Mix Design Proportions

Mix code	Description
M-0	Standard adobe
M-01RH	Standard adobe + 0.75% rice husk (RH)
M-05RH	Standard adobe + 5% rice husk (RH)
M-10RH	Standard adobe + 10% rice husk (RH)
M-20RH	Standard adobe + 20% rice husk (RH)
M-05	Standard adobe + Optimum% RH + 0.5% CF
M-10	Standard adobe + Optimum% RH + 1.0% CF
M-15	Standard adobe + Optimum% RH + 1.5% CF
M-20	Standard adobe + Optimum% RH + 2.0% CF

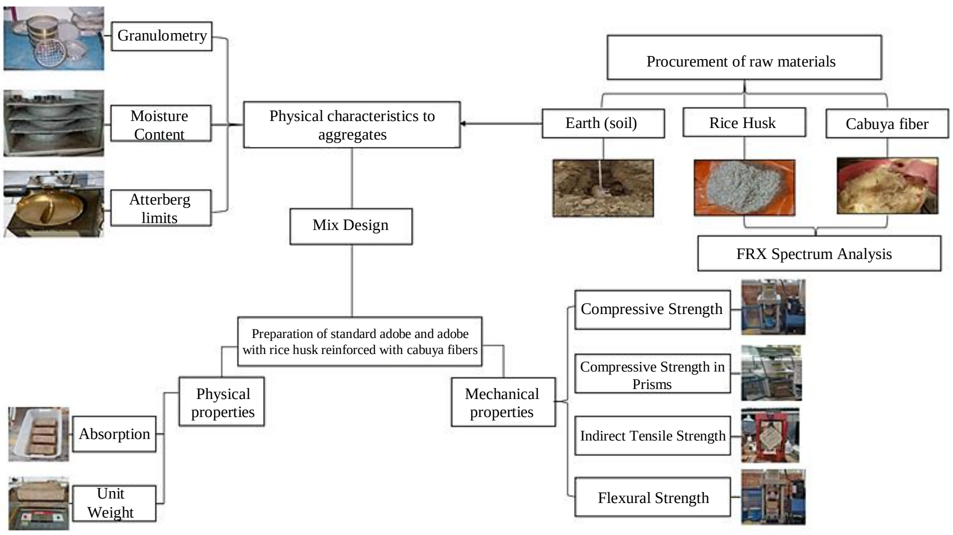

Figure 5 Flowchart of Research

3. Results and discussions

3.1 Absorption of adobe

In Figure 6, it is observed that traditional adobe exhibited an average absorption of 15.17%. However, the mixes with 0.75, 5, 10, and 20% RH showed increases of 50, 30.9, 15.8, and 5.9%, respectively, compared to the initial sample. This behavior suggests there is an optimal concentration of RH that minimizes water absorption, crucial for enhancing the durability and moisture resistance of the material. These findings align with research by Ige and Danso [35], who reported a 48% increase in absorption with 1% incorporation of RH. Similarly, Huy et al. [38], found that ratios above 6% led to a 33.33% increase in absorption compared to the initial sample. In contrast, Ouedraogo et al. [36], demonstrated an 11.11% reduction in adobe absorption when 8% RH was added in their study. This study shows results in adobe absorption at 24 hrs, similar, in addition, the matrix is not structurally altered during the short test period (≤24 h) [51].

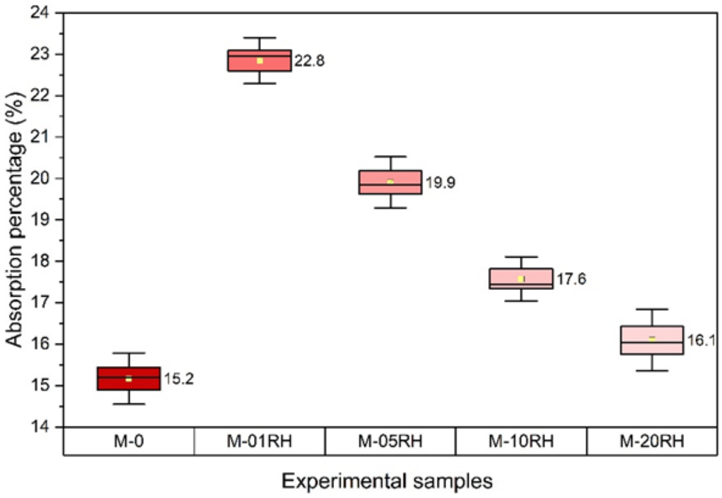

Figure 6 Variation in absorption depending on different proportions of RH

In Figure 7, the standard adobe exhibited an average absorption of 15.17%. However, the mixes with 0.75% RH combined with 0.5, 1, 1.5, and 2% CF showed a reduction in absorption levels of 7.71, 13.77, 17.26, and 20.21% respectively, compared to the initial sample. These values serve as a reference to compare the effectiveness of the different materials that have been incorporated, aiming to reduce water absorption in adobe. This reduction is crucial for enhancing its durability and moisture resistance.

Nevertheless, these results contrast with those obtained by Labiad et al. [52], who reported an 81% increase with the addition of NF, showing a significant difference. Similarly, Subramanian et al. [53], noted a 15% improvement in absorption with NF at the same proportions compared to the standard sample. Conversely, Araya-Letelier et al. [54], indicated in their study that incorporating 2% NF caused a 79% increase in the adobe's absorption level. On the other hand, in the case of the porous stones studied, no liquid penetrated into the porous substrate due to inertia effects at the moment of impact and the liquid in the porous substrate is only due to capillary absorption by the porous substrate [55].

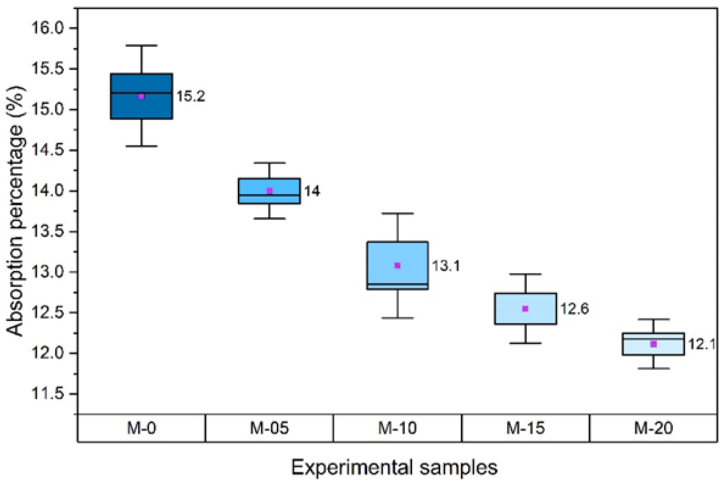

Figure 7 Variation in absorption based on 0.75% RH and CF proportions

3.2 Unit weight

As shown in Figure 8, adding RH in proportions of 0.75, 5, 10, and 20%, respectively, results in a reduction of 1.29, 2.57, 4.05, and 5.47%, respectively, in the unit weight of adobe compared to the initial sample. This indicates that denser adobe tends to have better capability to withstand vertical and lateral loads, which can be beneficial for the stability and durability of constructed structures.

Similar results were presented by Ouedraogo et al. [56], who demonstrated increases in adobe unit weight when 0.2% RH was incorporated. In the same vein, Morsy et al. [33], showed that a 5% RH proportion led to a 1.77% reduction in unit weight compared to the standard adobe; meanwhile, Huy et al. [38], recorded that adding 9% RH resulted in a 32.05% reduction in adobe unit weight compared to the standard adobe.

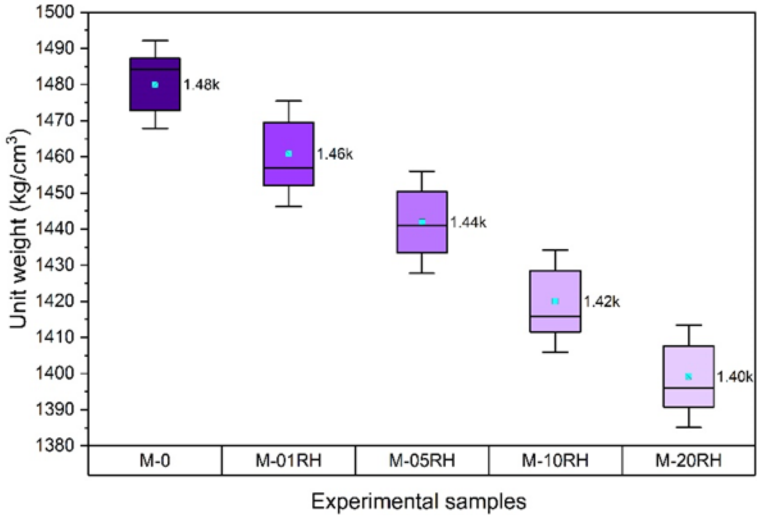

Figure 8 Variation in unit weight depending on different proportions of RH

In Figure 9, adding 0.75% RH along with varying concentrations of CF to adobe results in a decrease in unit weight after 28 days of curing compared to the standard adobe, which initially has a unit weight of 1480.0. With 0.50% CF, the unit weight decreases by approximately 3.41%; with 1% CF, by 2.70%; with 1.5% CF, by 2.85%; and with 2% CF, by 3.55%. This indicates that higher concentrations of CF result in a slight reduction in the adobe's unit weight.

Similarly, these results align with those obtained by Araya-Letelier et al. [45], who reported a significant reduction of 99% in adobe when 1% NF was added. However, Ige and Danso [57], demonstrated that the same fiber proportion resulted in a 4.04% increase in unit weight compared to the standard adobe. On the other hand, Olacia et al. [58], indicated that 5% NF caused a 1.28% reduction in adobe unit weight.

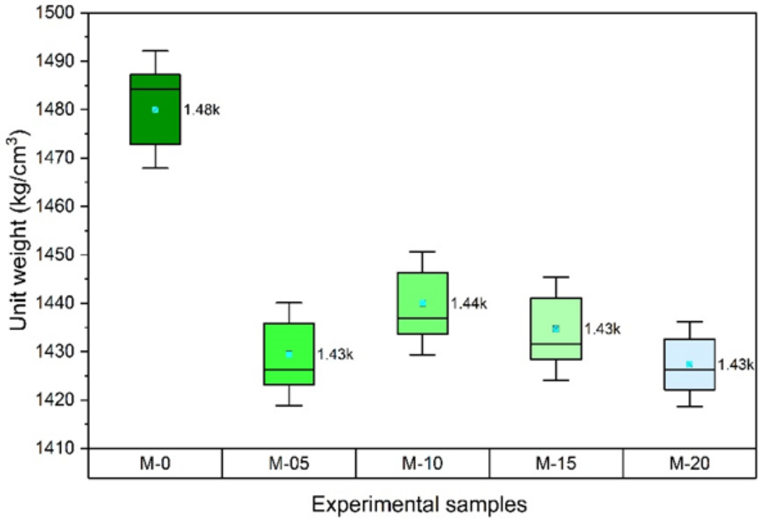

Figure 9 Variation in unit weight based on 0.75% RH and CF proportions

3.3 Compression strength

In Figure 10, the compression strength at 28 days reveals that adding only 0.75% RH shows an increase of 2.15% compared to the standard adobe; however, at proportions of 5, 10, and 20% RH, the strength shows reductions of 1.99, 2.91, and 4.69%, respectively, indicating an optimal content of 0.75% RH. These variations suggest that incorporating RH affects the adobe's strength, providing useful guidance for selecting and applying these materials in construction. Additionally, an ANOVA analysis and Tukey's multiple comparison tests yielded a p-value of $0.268 > 0.05$, indicating that the strength variations are not statistically significant for the evaluated mixes. This supports the feasibility of using RH in masonry unit production.

These findings are similar to those presented by Ige and Danso [35], who demonstrated that incorporating 0.75% RH improved adobe strength by 62%; however, Modjonda et al. [39], showed that adding 6% RH resulted in a 12% increase in compression strength compared to the traditional sample. Similarly, Huy et al. [38], reported that the same proportion of RH led to a significant 56.6% reduction in compression strength compared to the standard adobe.

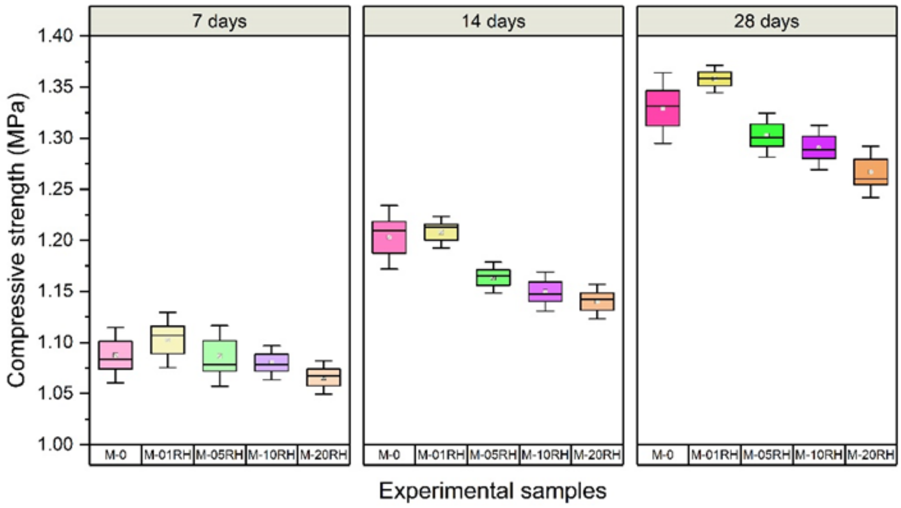

Figure 10 Variation in compression strength of units based on different proportions of RH

In Figure 11, the compression strength at 28 days reveals that adding 0.75% RH along with different concentrations of CF to adobe shows a significant increase compared to the standard adobe. Specifically, the average increases in strength are 13.34% with 0.5% CF, 38.17% with 1% CF, 45.19% with 1.5% CF, and 52.31% with 2% CF, compared to the standard adobe. This progressive increase suggests that the addition of RH and CF notably enhances the mechanical properties of adobe, demonstrating the effectiveness of these materials in increasing compression strength. Additionally, an ANOVA analysis and Tukey's multiple comparison tests yielded a p-value of 0.386 > 0.05, indicating that the variations in strength are not statistically significant for the evaluated mixes. This supports the feasibility of using these combinations in masonry unit production.

Similar results were presented by López et al. [59], who showed a 40% increase in strength with 1.75% CF compared to the standard adobe. Similarly, Eslami et al. [60], reported a 33% increase in strength with the addition of 0.25% NF. However, Bouchefra et al. [61], demonstrated that additions greater than 2% of fibers resulted in a 35% reduction in compression strength compared to the control adobe.

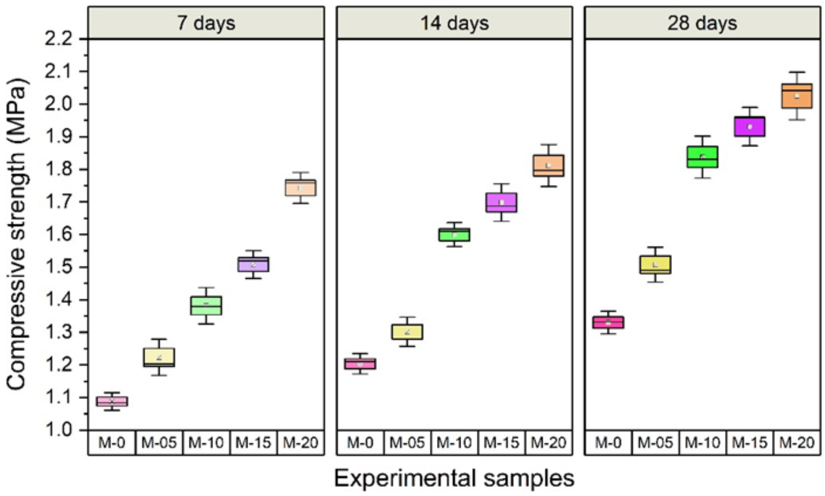

Figure 11 Variation in compression strength of units based on 0.75% RH and CF proportions

3.4 Flexural strength

In Figure 12, the flexural strength at 28 days indicates that adding 0.75% RH results in a 10.25% increase in strength compared to the initial sample. However, proportions of 5, 10, and 20% RH caused reductions of 5.19, 0.67, and 10.79%, respectively, relative to the standard adobe, highlighting an optimal content of 0.75% RH. These variations illustrate how each addition of RH affects the adobe's flexural strength compared to the standard adobe, providing insight into how the material responds to compositional changes. Additionally, an ANOVA analysis and Tukey's multiple comparison tests confirmed that the strength variations are not statistically significant for the different evaluated mixes (p-value of 0.057 > 0.05). This supports the notion that all adobe mixes with RH could be equally suitable in terms of strength.

These findings contrast with those of Hany et al. [41], who found that incorporating 0.25% RH resulted in an 8% reduction in adobe strength. However, Khoudja et al. [62], confirmed in their research that additions greater than 10% RH led to a 73% reduction in strength compared to the standard adobe, consistent with the study by Liu et al. [63], which showed that additions of 35% RH resulted in a 16.56% reduction in strength compared to the standard adobe. These reductions in strength align with the findings of this research.

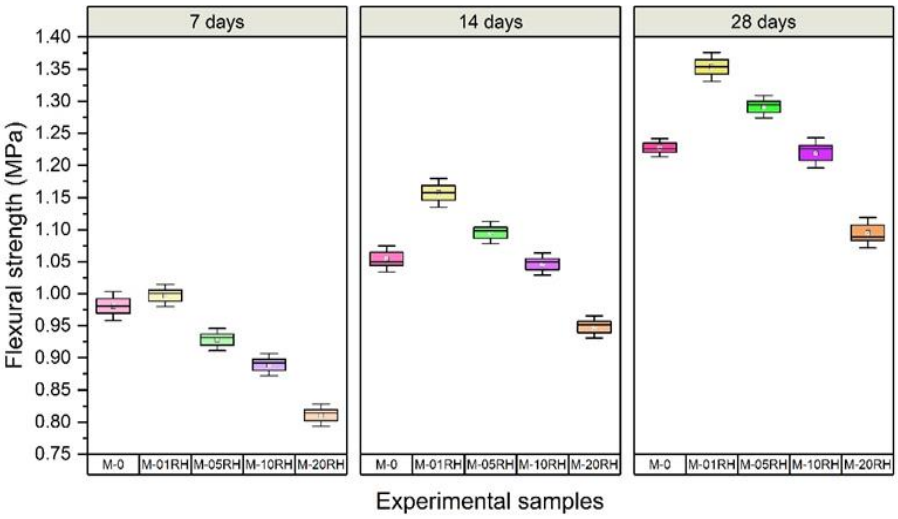

Figure 12 Variation in flexural strength based on different proportions of RH

In Figure 13, the flexural strength at 28 days indicates that adding 0.75% RH along with different concentrations of CF to adobe shows a significant increase compared to the standard adobe. Specifically, the average increases in flexural strength are 18.20% with 0.5% CF, 19.96% with 1% CF, 20.51% with 1.5% CF, and 22.49% with 2% CF, relative to the standard adobe. This progressive increase suggests that the combination of RH and CF is an effective technique for reinforcing adobe constructions, notably improving both the wall's flexural strength and its ductility. Additionally, an ANOVA analysis and Tukey's multiple comparison tests confirmed that the strength variations are not statistically significant for the different evaluated mixes (p-value of 0.067 > 0.05). This supports the feasibility of using these combinations in various construction applications.

This finding aligns with the research of Araya et al. [45], who demonstrated a 134% increase with the addition of 1% NF, although this variation was not statistically significant. Similarly, López et al. [59], reflected increases of up to 12% in strength with the incorporation of 1.75% CF. However, Babé et al. [64], presented studies were adding 2% NF resulted in a 9% increase in strength compared to the initial sample. Likewise, Muñoz et al. [3], demonstrated that adding 0.5% NF led to a 22.6% increase in strength. These results indicate that adobe strength can be enhanced with the addition of NF, considering proportions not exceeding 15% [65].

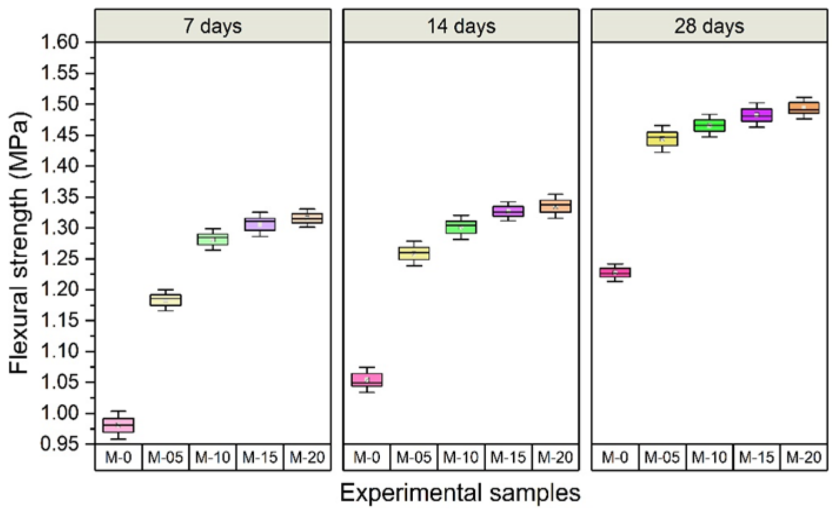

Figure 13 Variation in flexural strength based on 0.75% RH and CF proportions

3.5 Compression strength of piles

In Figure 14, the compression strength in pillars at 28 days indicates that adding 0.75, 5, 10, and 20% RH resulted in a significant increase compared to the standard adobe. Specifically, the average increases in compression strength in pillars are 10.29, 10.23, 8.80, and 5.85%, respectively, compared to the initial sample. This progressive increase suggests that this technique can be an effective strategy to enhance adobe properties, providing a solid foundation for its application in various construction conditions. Additionally, the results of the one-way ANOVA and Tukey's multiple comparison tests yielded a p-value of 0.152, which is greater than 0.05, indicating that no significant differences were found between the compared groups. This supports the feasibility of using RH in adobe constructions, promoting the strength and durability of the material.

These findings are compared with studies by Adazabra et al. [43], who reported a 71.97% reduction in strength when using 16% RH compared to the standard adobe. On the other hand, Muñoz et al. [44], found a 36.6% increase in strength by adding 18% of residues compared to traditional adobe. In a similar context, Yang and Wang [66], demonstrated that the use of 10% and 12.5% siliceous material resulted in a 10.32% increase in strength, respectively, compared to the standard adobe.

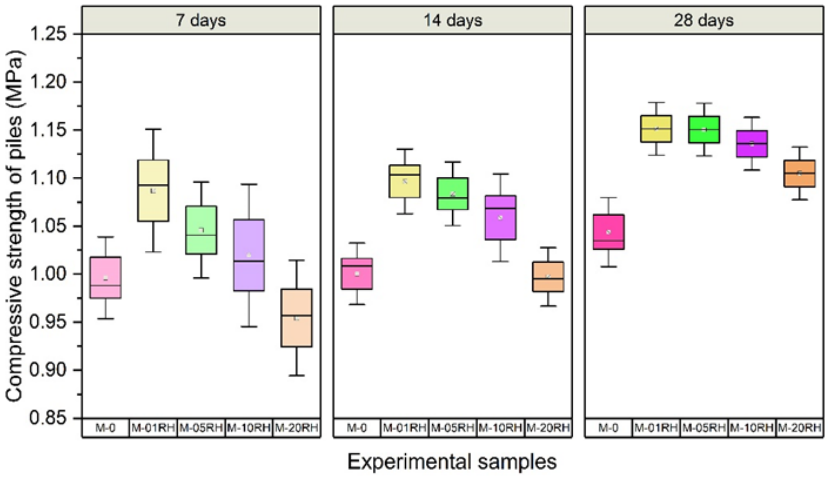

Figure 14 Variation in compression strength in pillars based on different proportions of RH

In Figure 15, the compression strength in pillars at 28 days indicates that adding 0.75% RH along with varying concentrations of CF to adobe shows a significant increase compared to the standard adobe. Specifically, the average increases in compression strength in pillars are 15.82% with 0.5% CF, 27.18% with 1% CF, 48.36% with 1.5% CF, and 52.64% with 2% CF, compared to the standard adobe. This progressive increase suggests that incorporating RH and CF is an effective strategy to enhance compression strength in adobe pillars, crucial for resilient and cost-effective structural systems. Additionally, the results of the one-way ANOVA and Tukey's multiple comparison tests yielded a p-value of 0.384, which is greater than 0.05, indicating that the variation in compression strength is not significant for any of the four evaluated percentages. This supports the feasibility of using these enhanced combinations in adobe constructions, promoting the strength and durability of the material.

These results are similar to those obtained by Ige and Danso [57] and Muñoz et al. [3], who reported that adding 0.5% NF resulted in an increase of 31% and 65.9% in strength compared to the standard adobe, respectively. Additionally, Khorasani and Kabir [67], reported that adding 1.5% NF showed a significant increase of 84% compared to traditional adobe. However, Araya-Letelier et al. [54], found significant differences in this property, as adding 2% NF resulted in a 40% reduction in strength.

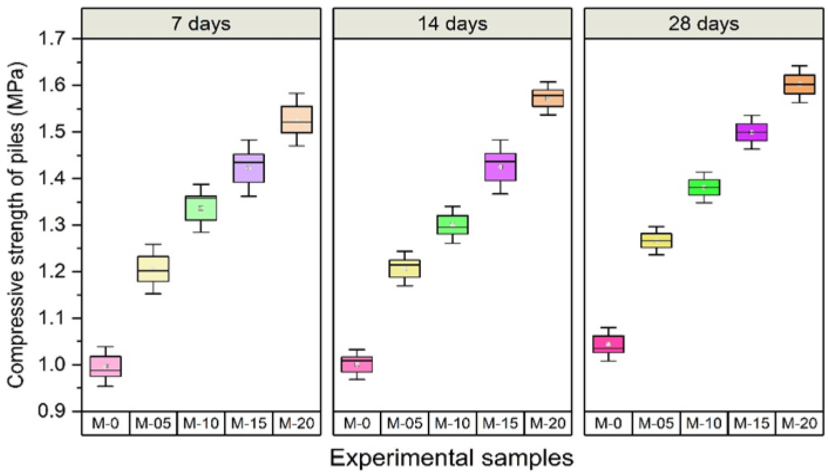

Figure 15 Variation in compression strength in pillars based on 0.75% RH and CF proportions

3.6 Diagonal compression strength in masonry walls

In Figure 16, the diagonal compression strength at 28 days indicates that adding 0.75, 5, 10, and 20% rice husk showed an increase of 17.73, 14.48, 11.88, and 9.56%, respectively, compared to the initial sample. This increase constitutes an effective strategy for structurally strengthening the material, which is crucial in applications where adobe needs to support higher loads or severe environmental conditions. Additionally, an ANOVA unification analysis and Tukey's multiple comparison tests were performed, obtaining a P-value of 0.287 > 0.05. This statistical support strengthens the viability of using rice husk, representing a significant improvement in the material's properties, offering advantages in terms of structural performance, durability, and sustainability in construction.

These findings are compared with research by Muñoz et al. [44], who observed that adding 18% of residues resulted in a 41.24% increase in diagonal compression strength of walls. On the other hand, Murthi et al. [68], showed that additions above 25% RH caused a 12.81% reduction in adobe strength compared to the traditional sample. Additionally, Ige and Danso [35], found a 95% improvement in the strength of the standard adobe with the addition of 0.75% RH. Similarly, Onyenokporo et al. [69], observed that adding 15% RH increased the diagonal strength by 9% compared to the initial sample.

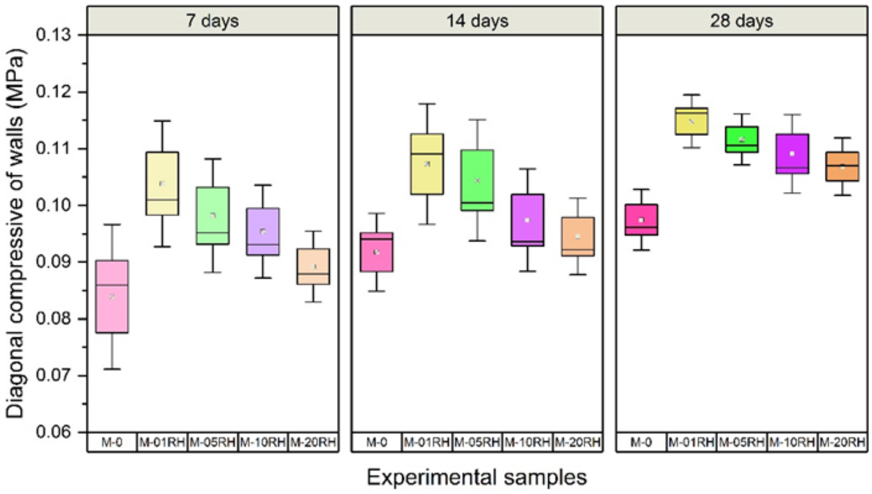

Figure 16 Variation in diagonal compression strength based on different proportions of RH

In Figure 17, the diagonal compression strength at 28 days indicates that adding 0.75% RH along with different concentrations of CF to adobe shows a significant increase compared to the standard adobe. Specifically, the average increases in the diagonal strength are 23.81% with 0.5% CF, 35.24% with 1% CF, 61.90% with 1.5% CF, and 50.48% with 2% CF, compared to the standard adobe. This increase constitutes an effective strategy to enhance the indirect tensile strength of adobe, crucial for structural systems. Additionally, an ANOVA analysis and Tukey's multiple comparison tests yielded a p-value of 0.647 > 0.05. This statistical support strengthens the feasibility of using RH and CF as improvements in adobe construction, contributing to the safety and robustness of buildings.

These findings are consistent with research by Ige and Danso [57], who showed that adding 0.75% NF resulted in a 33% increase in strength. However, studies like those of Muñoz et al. [3], have observed variations in the effects of NF addition, where 0.75% NF produced a 3.3% increase. On the other hand, other studies have reported significant improvements, such as a 55.56% and 83% increase with 0.5% and 7.5% NF [58, 67]; likewise, the addition of 2% NF has resulted in a 20% increase in strength compared to traditional adobe [70].

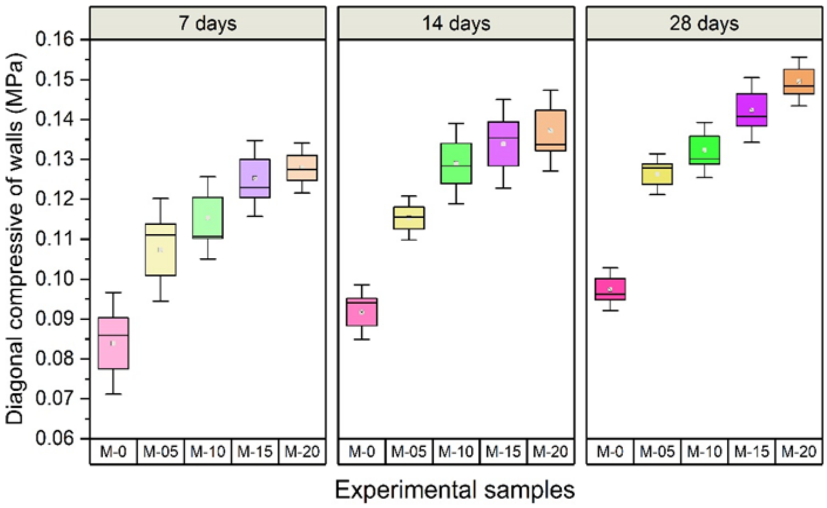

Figure 17 Variation of diagonal compression strength based on 0.75% RH and CF proportions

4. Conclusions

The incorporation of rice husk (RH) and cabuya fibers (CF) significantly influences the physical and mechanical properties of adobe. The findings indicate that the physical and chemical characteristics of natural materials such as RH and CF can vary due to the diversity of their sources, impacting adobe quality. The addition of RH reduces water absorption and optimizes the unit weight of adobe, enhancing its durability and structural strength.

Air drying over several weeks was sufficient to obtain preliminary results. However, it is acknowledged that controlled conditions of temperature and humidity could further optimize the mechanical properties of adobe. It is suggested that future studies explore controlled drying experiments to identify the optimal drying parameters.

The optimal proportion of rice husk was found to be 0.75%, which significantly increased the mechanical properties of adobe: compressive strength by 2.15%, flexural strength by 10.25%, prism compressive strength by 10.29%, and diagonal compressive strength by 17.73%.

A fiber length of 30 mm was selected to optimize the reinforcement of adobe without compromising its workability. Shorter fibers tend to be less effective in load transfer and crack control, while longer fibers may cause clumping and hinder uniform distribution. The choice of 30 mm allowed for a more homogeneous dispersion of stresses and greater resistance to crack propagation, resulting in a significant improvement in the material's tensile and flexural properties. It was concluded that combining 0.75% RH with 2% CF significantly enhances the mechanical properties of adobe. The evidence suggests that these natural materials are viable as reinforcements in the production of handmade adobe.

The synergy between RH and CF improves the physical and mechanical properties of adobe. Due to its porous, silica-rich structure, RH increases cohesion, fills voids, and reduces microcracks. CF, with its high tensile strength and flexibility, bridges cracks and distributes stresses, preventing fractures. This combination optimizes energy absorption, enhances compressive and flexural strength, reduces water absorption, and increases durability, making it a sustainable option for construction.

Improvements were observed in the matrix cohesion and the distribution of fibers within the material, which reduced the formation of microcracks and increased strength. However, additional testing is required to evaluate long-term durability (such as freeze-thaw cycles or biodegradation), thermal conductivity, and microstructural properties to determine the service life of reinforced adobe. It is recommended to assess behavior under cyclic or seismic loads through specific tests or numerical simulations. Additionally, the environmental impact of using RH and CF in adobe production has not yet been analyzed in this study. This limitation is acknowledged, and it is suggested that such analyses be included in future research.

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6. References

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