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**Effect of Musa Paradisiaca fibers and coffee mucilage on the physical and
mechanical behavior of earth units**

**TRABAJO DE INVESTIGACIÓN PARA OPTAR EL GRADO ACADÉMICO DE
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Resumen

Este estudio tiene como objetivo evaluar cual es el comportamiento físico mecánico en unidades de tierra reforzadas con residuos naturales como las fibras de pseudotallo de Musa Paradisiaca con valores de 0.5%, 3.5% y 7% en relación con el peso de cada unidad y mucílago de café al 25% en sustitución del agua. Dándole así una nueva oportunidad de aprovechamiento a los residuos mencionados.

Los resultados indican que se ha observado un significativo aumento en la resistencia a la compresión, llegando hasta un 237%. Además, la resistencia a la tracción ha mejorado, con valores que han aumentado del 1.44 kg/cm² en las muestras estándar a 1.95 kg/cm² en las muestras reforzadas, representando un incremento del 135%.

En el ensayo absorción se verificó que las muestras reforzadas absorben agua presentando menos desintegración que las muestras patrón. Además, se ha notado que a medida que se aumenta el porcentaje de adición de fibras, la absorción también se incrementa. Esto se debe a la naturaleza hidrófila de las fibras, lo que disminuye la densidad y crea una mezcla con más espacio entre partículas.

Se ha llegado a la conclusión de que la incorporación de residuos naturales, como la fibra de pseudotallo de Musa Paradisiaca y el mucílago de café, en las unidades de adobe permite mejorar sus propiedades mecánicas. Además, el uso de estas fibras en la construcción contribuye a reducir el impacto ambiental, lo que hace de esta una opción viable para abordar los problemas de vivienda en áreas con recursos limitados.

Palabras clave: Unidades de tierra, fibra de Musa paradisiaca, mucílago de café, compresión, tracción.

Abstract

This study aims to evaluate the physical-mechanical behavior in soil units reinforced with natural waste such as *Musa Paradisiaca* pseudo stem fibers with values of 0.5%, 3.5%, and 7% about the weight of each unit and mucilage of 25% coffee instead of water. Thus, giving a new opportunity to use the aforementioned waste.

The results indicate a significant increase in compressive strength, reaching up to 237% additionally, tensile strength has improved, with values increasing from 1.44 kg/cm² in the standard samples to 1.95 kg/cm² in the reinforced samples, representing an increase of 135%.

In the absorption test, it was verified that the reinforced samples absorb water, presenting less disintegration than the standard samples. Furthermore, it has been noticed that as the percentage of fiber addition increases, absorption also increases. This is due to the hydrophilic nature of the fibers, which decreases density and creates a mixture with more space between particles.

It has been concluded that the coalescence of natural waste, such as *Musa Paradisiaca* pseudostem fiber and coffee mucilage, in adobe units allows their mechanical properties to be improved. Furthermore, the use of these fibers in construction contributes to reducing environmental impact, making this a viable option to address housing problems in areas with limited resources.

Keywords: Earth units, *Musa paradisiaca* fiber, coffee mucilage, compression, traction.

Introduction

Construction with adobe is an ancient practice that has been fundamental in the history of architecture. For more than 10 thousand years, it has been used in the construction of homes, tombs, and buildings around the world. In Egypt, the architect Hassan Fathy was one of the pioneers in using this material [1].

In Peru, adobe has been essential in the construction of historical places such as Caral, Chan Chan and the Huacas del sol y de la luna. Despite the age of this material, it remains relevant due to its thermal properties, its economy, and its accessibility, especially for vulnerable families.

However, it faces challenges, such as the deterioration caused by the El Niño Phenomenon in coastal areas of Peru. Despite these challenges, statistics from the National Institute of Statistics and Informatics show that, in 2019, 31.4% of private homes in Peru were built with adobe, which is more common in rural areas (71.8%) than in urban areas [2]

The use of adobe has also been present in the Lambayeque region, as is the Huaca Rajada, a well-known pyramid built from this material that housed the tomb of the Lord of Sipan [3] But in this culture, not only funeral tombs were made, but also houses based on adobe walls where its population lived. Currently, these constructions are deteriorated as a result of the El Niño Phenomenon that suddenly attacks the coastal areas of Peru [4].

In many countries, the economy demands the use of innovative technologies that facilitate the incorporation of renewable materials in the construction industry [8]. Therefore, it is of great importance to investigate effective approaches to produce high-quality materials, to change the misperception that exists about soil as an inadequate construction material [5].

On the other hand, I use *Musa paradisiaca* and coffee mucilage. The construction industry represents a recent innovation. These fibers are being used in the manufacture of bricks, panels, and composite materials with cement, thus contributing to the advancement of sustainable construction [9]. [10] However, it is important to highlight that the research and application of these fibers in earth-based construction materials is still in an incipient phase.

To address the deficiencies and improve the resistance of the adobe, it was proposed to implement and reinforce the earth masonry units with *Musa paradisiaca* fibers and coffee mucilage. According to what was developed in this research, the aforementioned makes the abodes more resistant and has more favorable results for the construction of the homes; the homes also become safer and more resistant to external agents and the climatic variability of Peru.

Materials and methods

Materials

In the place selected to carry out the investigation, the soil sample was extracted to determine if it was suitable according to the In Situ tests established in E.80: Adobe, 2017, where it met the conditions to make the adobes. Subsequently, the necessary soil sample was collected to carry out soil mechanics tests in the laboratory, such as granulometry, Atterberg limits, and moisture content.

For the experimental tests, standard samples were made, that is, conventional units as they are made by hand in the locality, and the samples with additions of *Musa Paradisiaca* pseudo stem fiber in percentages of 0.5%, 3.5%, and 7% in relation to the weight of units and coffee mucilage by 25% to replace water.

The pseudostem fibers of *Musa Paradisiaca* are obtained after carrying out the following procedure: The pseudostems were collected immediately after the fruits were harvested to avoid contamination with external agents. This stem is a waste for producers, as it is not provided. no use, then it is dried for 15 days and placed in a chopping machine to obtain the result of a fiber with measurements between 2 to 5 cm.

Coffee mucilage is also wasted without any use. The coffee beans are collected manually and then move on to the fermentation, pulping, and washing phase of the coffee and it is during this period that the mucilage is stored. In this way, the emitted waste will be reused.



Figure 1. *Musa Paradisiaca* pseudostem fiber



Figure 2. Coffee Mucilage

Sample preparation

Once the soil was selected, weight control tests were carried out in units to calculate the total amount to be added to the samples. With the fibers and mucilage already obtained, the earth masonry units were prepared: first, the soil was mixed with water, in this step the coffee mucilage was also added in the established quantity, the pseudostem fiber of *Musa Paradisiaca* in the indicated percentages, finally, a mold was used to give the exact measurements to the units. After this process, they were left to dry for a period of 28 days.

In each of the tests that were carried out, as indicated by the [6] standard, 6 samples were used, of these, the 4 best results were averaged and thus the final average was obtained. The samples used for the compressive strength test in earth units were made with 10 cm edge measurements, for the tensile strength test, cylindrical samples of 12" high and 6" in diameter were made and the Absorption had units of 40cm x 20cm x 10cm. Table 1 details the number of samples for the tests carried out.



Figure 3, Figure 4. Samples used.

Table 1. Number of samples for testing.

Test	Addition type	Standard dosage	Experimental dosage		
	Mucílago de café	0%	25%		
	Fibra de Musa Paradisiaca	0%	0.5%	3.5%	7.0%
Compression	quantity	6	6	6	6
Traction	quantity	6	6	6	6
Absorption	quantity	6	6	6	6
TOTAL			72		

Physical – mechanical tests

To perform the compressive strength test, a vertical load is continuously applied over the contact area (A) to each of the 10cm edge units. The load (P) will increase until the sample breaks, at which time the maximum value of the applied load is recorded. The resistance value is calculated with the following expresión (1):

$$f'b = \frac{P}{A} \left(\frac{\text{kgf}}{\text{cm}^2} \right) \quad (1)$$

**Figure 5.** Compression resistance test

The tensile strength test was applied by diametral compression (ASTM C 496-96) on cylindrical samples measuring 6'' in diameter (D) and 12'' in height (L). The crushing load (P) generates tensile stresses until failure, as shown in Figure 4. The ultimate resistance is calculated with the following expression (2):

$$F = \frac{2P}{\pi DL} \left(\frac{\text{kgf}}{\text{cm}^2} \right) \quad (2)$$



Figure 6. Diametral compression tensile strength test on cylindrical samples.

The absorption test in units was carried out with an adaptation to the standard (NTP 339,613). The samples used were 40cm x 20cm x 10cm thick. The procedure was as follows: a container with water was used, where the dry units were completely submerged for a period of 1 min +- 1 sec, previously weighed (W_d = dry weight), when the time was up, the specimens were removed and the excess is gently removed with a flannel to weigh again (W_w = wet weight). The measurement of the percentage of absorption is given by the expression (3):

$$\%Abs = \frac{(W_w - W_d)}{W_d} \quad (3)$$



Figure 6. Absorption test, saturated sample

Experimental results and analysis

Soil characterization

The result of the Atterberg Limits test shows us that the Liquid Limit has a percentage of 21.32, a Plastic Limit of 15.96%, and a Plasticity Index of 5.36%, thus determining the soil as a low plasticity silty Clay with sand, as shown. shown in Table 2. In Figure 61, the granulometric curve of the data obtained from the sieving process of the soil sample from the chosen place is recorded, determining that the soil has a fineness modulus of 0.483, also, 1.1 and 1.1 for the coefficient of uni-formity and curvature respectively. In addition, the absence of large or fine gravel particles is noted and it is reflected that more than 90% of these are sands and clays.

Table 2. Classification of the soil sample.

Atterberg Limit Test	
liquid limit (LL)	21.32 (%)
Plastic Limit (LP)	15.96 (%)
Plastic Limit (IP)	5.36 (%)
Classification (S.U.C.S.)	CL-ML
Soil description	
Low plasticity silty clay with sand	
Classification	
(AASHTO)	A-4 (9)
Description	
SUELO ARCILLOSO	

GRANULOMETRIC CURVE					
Gravel		Sand			Clay and Silt
Gross	Fine	Gross	Medium	Fine	

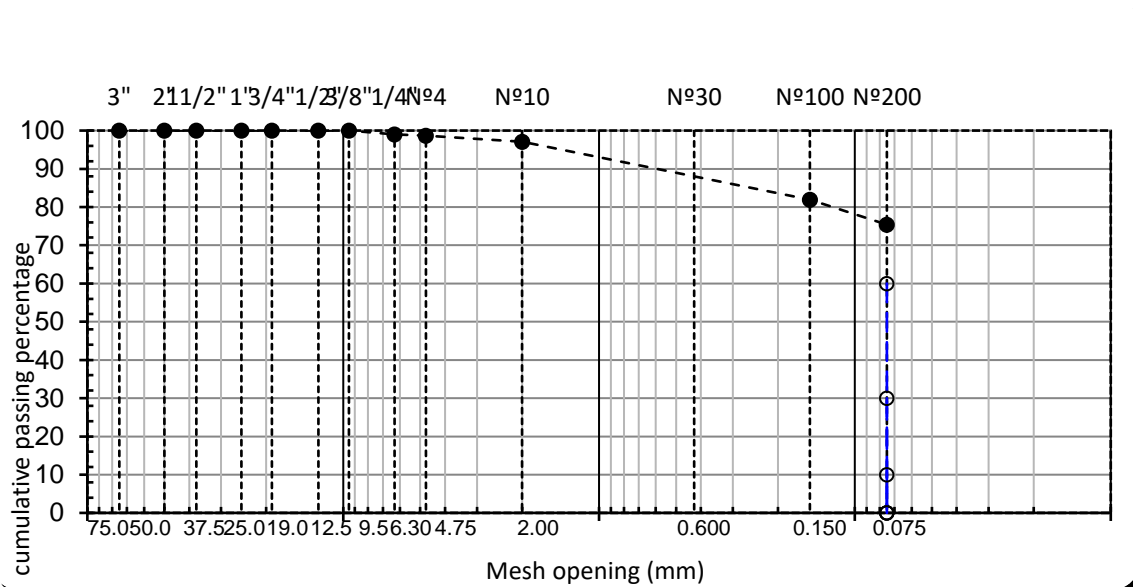


Figure 7. Granulometric distribution of the soil sample

Physical – mechanical properties

Each experimental group was assigned a name to simplify understanding in the graphs:

The assignment: MP indicates to be the standard sample.

The assignment: M + 0.5F + 25M indicates the dosage of the sample with 0.5% fiber and 25% mucilage.

The assignment: M + 3.5F + 25M indicates the dosage of the sample with 3.5% fiber and 25% mucilage.

The assignment: M + 7F + 25M indicates the dosage of the sample with 7% fiber and 25% mucilage.

Compression resistance

For this test, the 4 best results of the 6 tests were taken, for each experimental percentage, as well as for the standard sam-ples. The results are expressed in Figure 8.

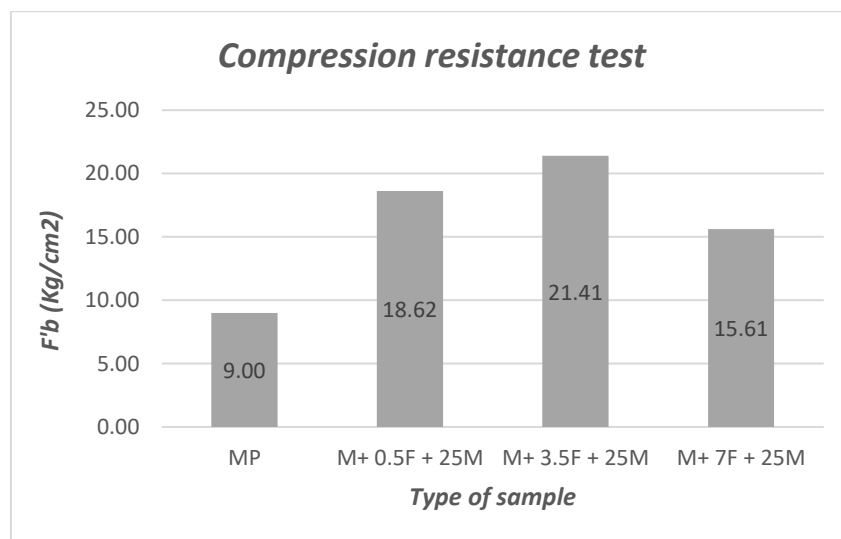


Figure 8. Results for the compressive strength test at 28 days.

Samples with additional doses of fiber and mucilage performed significantly better in the compression test than the standard MP sample, with an average strength of 9 kg/cm² for their top four results. The sample with the highest resistance in this test was M+ 3.5F + 25M with 21.41kg/cm², meaning an improvement of up to 230%.

The MP standard sample does not meet the requirements, while the three samples with additives meet the minimum breaking stress of 10.2 kg/cm² required by the E0.80 standard.

The increase is supported by the research of [11] for the study he conducted where he examined the physical, mechanical, and thermal characteristics of adobe blocks fortified with banana pseudostem fibers. Experiments were carried out using different proportions of fibers (0%, 0.25%, 0.5%, 0.75%, and 1% by weight) mixed with the soil to make these adobe blocks.

Subsequently, the properties of these fortified blocks were evaluated. The results showed that the fiber-reinforced sam-ples experienced significant improvements, with a 53% increase

in tensile strength and a 33% increase in compressive strength compared to the unfortified samples. The results indicated that the inclusion of fibers in the blocks slightly reduced their density but increased their ability to absorb and retain water through capillary action.

Although the compressive and tensile strength of the fiber-reinforced blocks was lower than that of the unreinforced blocks, the presence of fiber improved the blocks' ability to deform without breaking and their ability to withstand stresses. Although both types of fiber-reinforced blocks showed similar compressive toughness, the coconut fiber blocks exhibited higher flexural toughness[10].

What was observed in the research is that the incorporation of fibers and the amount of water in the mixture have a significant impact on the mechanical performance of adobe bricks and, consequently, on masonry in general. The study quantifies and analyzes how these factors influence the dynamic behavior of the material, especially in high-speed situations, using data obtained through Hopkinson bar testing.

In this study, the feasibility of using banana fibers as reinforcement in adobe mixtures was analyzed. They examined four combinations of adobe with different proportions of banana fibers (0%, 0.25%, 0.5% and 1% by weight of clay soil) to evaluate the compressive strength giving positive results to the samples with addition [12].

On the other hand, [13] focused on improving resistance and deformation capacity.

When using compressed earth blocks (CEB) with the addition of 0.4% polypropylene fibers, an improvement in compressive strength of 22.5% was observed compared to unreinforced compressed earth blocks (CEB).

Adobe units using a combination of mud and short tire fibers demonstrated maximum strength and rigidity against possible sudden failures. It was also observed that the mortar reinforced with soaked straw fibers improved its compressive strength by 87%, while the mortar reinforced with short tire fibers experienced a 115% increase in its maximum compressive strength, albeit with a sudden and spontaneous collapse [14].

Tensile strength

Figure 9 shows the results of the tensile test where cylindrical samples measuring 6" x 12" (ASTM C496-96) were used, respecting the [6] standard, which stipulates that the minimum resistance in this test is 0.81 kgf/cm².

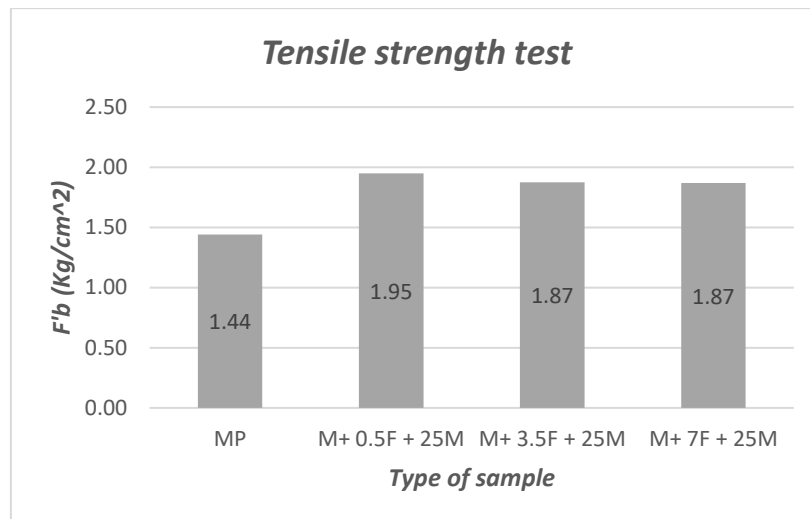


Figure 9. Results for the tensile strength test at 28 days

In this test, all samples met the minimum breaking stress specified in standard [6], which corresponds to 0.81 kg/cm². Although all tensile test results met the standards, the samples with additions of F and M achieved good results that differed from the standard samples. At the same time, it can be stated that M + 0.5F + 25M managed to reach 1.95 kg/cm². It is the most resistant in this test with an improvement of up to 135%.

The incorporation of fibers resulted in a significant increase in the tensile strength of the mortar, raising the figure from 28.2 N to 37 N, which translates into a 31% improvement in terms of strength. The addition of fibers generated an increase in the shear resistance of the adobe masonry. Initially, the average strength was 0.028 kPa, but with lateral confinement of 0.025 kPa, it increased to 0.035 kPa. Furthermore, when a higher lateral confinement of 0.1 kPa was applied along with the inclusion of fibers, the shear strength was raised from 0.085 kPa to 0.105 kPa. This increase in shear resistance was accompanied by an increase in the corresponding friction coefficient from 0.63 to 0.81, representing a 22% improvement in friction. These observations highlight the positive impact of fiber incorporation on the strength and mechanical behavior of adobe masonry [15].

The addition of fibers increased the tensile strength of the mortar from 28.2 N to 37 N, representing a 31% improvement in strength [16]. Furthermore, in the study by [17] it was shown that a higher content of palm fibers resulted in a significant increase in the modulus of rupture, which translated into a 104% increase in the tensile strength of units when 1% fiber was added compared to the control samples.

Absorption Test

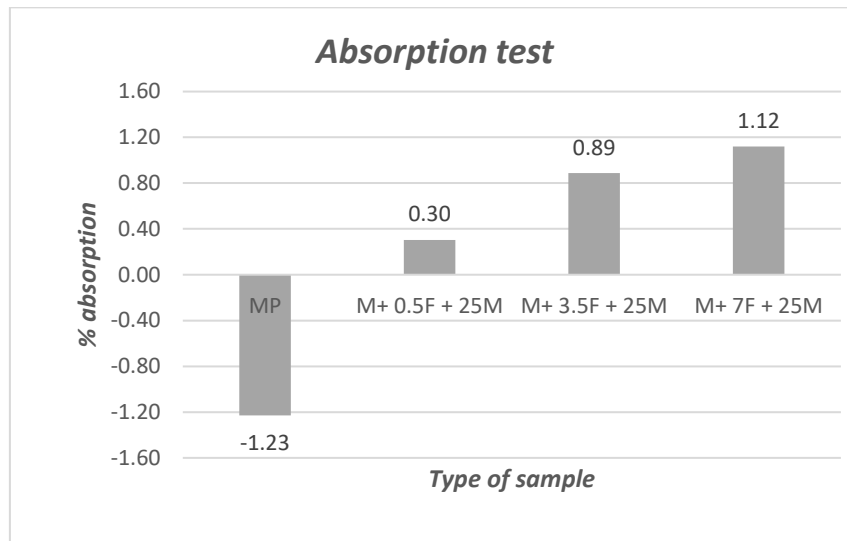


Figure 10. Results for the absorption test at 28 days.

It is not logical that the standard sample gives a negative result in the absorption calculation as shown in figure 9. The reason for this result is the reaction that occurs when it comes into contact with water. Due to water erosion, it begins to decompose, causing it to lose mass. Furthermore, the results show that the greater the addition of MP fibers, the greater the absorption [18]. The most optimal sample would be $M + 0.5F + 25M$, since it has fewer voids due to the presence of fiber and is a more compact block.

Supporting the use of fibers [7] in their research, they incorporated bamboo fibers into the soil blocks, and there was an increase in water absorption capacity as the fiber content increased, reaching a value of 27.6% when adding 1%. This is attributed to the porous and hydrophilic nature of the additional material.

On the other hand [19] studied the wastewater of cassava, giving favorable results for the reduction of water absorption and lower mass loss of the soil-cement units.

Conclusions and comments

In conclusion, the results obtained from this research by incorporating *Musa Paradisiaca* pseudostem fibers and coffee mucilage in soil units lead to a substantial improvement in their mechanical properties, allowing them to withstand higher loads compared to units that lack reinforcement, it is evident. that the proposed approach has considerable potential to establish a practical and sustainable means to strengthen adobe units.

1. Compressive strength increases up to 237% and tensile strength up to 240% compared to standard samples, this is achieved with an addition of 3.5% *Musa Paradisiaca* pseudostem fibers along with 25% of coffee mucilage and 0.5% of *Musa Paradisiaca* pseudostem along with 25% of coffee mucilage respectively.

2. The best result of the tensile strength test was the sample M+0.5F + 25M, resulting in an improvement of 135% compared to the MP standard sample. The inclusion of *Musa Paradisiaca* fibers in the mixture plays a crucial role in the behavior of the adobe since it enhances its ductility thanks to its notable flexibility. This demonstrates the ability of the specimens to resist significant deformations before reaching their breaking point.

3. On the other hand, it was demonstrated that the presence of coffee mucilage and *Musa Paradisiaca* fiber in the absorption test, that the reinforced samples are capable of absorbing water with a lower incidence of disintegration compared to the standard samples. It should be noted that as the percentage of fiber incorporation increases, the absorption capacity also increases. This is explained by the hydrophilic nature of the fibers, which reduces the density of the mixture and generates greater space between the particles.

Finally, the application of fibers from *Musa Paradisiaca* and coffee mucilage in the production of reinforced earth blocks can have important positive and significant impacts on sustainable construction, improving their mechanical properties, in addition to contributing considerably to the reduction of contamination with these wastes, representing a striking option for the construction of sustainable and environmentally friendly homes.

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