# UNIVERSIDAD CATÓLICA SANTO TORIBIO DE MOGROVEJO
## FACULTAD DE INGENIERÍA
## ESCUELA DE INGENIERÍA CIVIL AMBIENTAL

# A sustainable solution of adobe bricks improved in strength and permeability, manufactured using Equus asinus manure and calcium stearate

**TRABAJO DE INVESTIGACIÓN PARA OPTAR EL GRADO ACADÉMICO DE BACHILLER EN INGENIERÍA CIVIL AMBIENTAL**

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# Índice

# Resumen

La Tierra es uno de los materiales de construcción más utilizados en todo el mundo. Sin embargo, su uso en áreas sísmicas y su acelerada erosión hídrica son preocupaciones importantes para la comunidad ingenieril. Este estudio se centró en la incorporación de estiércol de Equus asinus en la elaboración de unidades de tierra reforzada, con el objetivo de mejorar su resistencia a la compresión y tracción. Además, se investigó el efecto del recubrimiento de estearato de calcio sobre su superficie para reducir su permeabilidad. Se llevaron a cabo pruebas in situ y en laboratorio para seleccionar la cantera de suelo y el agua. Las propiedades mecánicas se evaluaron mediante pruebas de compresión y tracción, siguiendo las normas ASTM E2392. Además, se propusieron pruebas simuladas de inundación y absorción para evaluar la hidrofobicidad de las unidades de tierra reforzada. Los resultados revelaron mejoras en la resistencia a la compresión y a la tracción de las unidades de tierra reforzada, con aumentos del 24% y el 50% respectivamente, a nivel de unidad, y del 20% y el 18% a nivel de murete. Asimismo, el recubrimiento con estearato de calcio permitió que las muestras absorbieran agua sin colapsar y retrasó su desintegración. En resumen, la incorporación de estiércol de Equus asinus en un 6% y el recubrimiento con estearato de calcio presentan mejoras significativas en las propiedades mecánicas e hidrofóbicas del material tierra utilizado en la construcción, lo cual es de gran interés para las comunidades que construyen en áreas sísmicas y propensas a inundaciones.

**Palabras clave:** Adobe, eco-construcción, ladrillo de tierra sin cocer, estiércol, estearato de calcio

# Abstract

Earth is one of the oldest building materials used worldwide, but its use in seismic-prone areas and its high sensi-tivity to water erosion are causes of concern for the engineering community. This study focused on incorporating of Equus asinus manure in the production of adobe bricks to improve their compressive and tensile strength, as well as the effect of dusting calcium stearate on their surface to reduce their permeability. First, in-situ and labora-tory tests were conducted to select the soil quarry and water. The mechanical properties of the adobe bricks were evaluated using compression and tensile tests, following ASTM E2392 standards. Also, simulated flooding and absorption tests were proposed by the author to evaluate the hydrophobicity. Finally, the results showed that the in-corporation of Equus asinus manure improved the compressive and tensile strength of the adobe bricks, with increases of 24% and 50%, respectively, at the unit level and 20% and 18% at the wall level. Additionally, the coat-ing with calcium stearate allowed the experimental samples to absorb water in a period without collapsing and de-layed their disintegration. To sum up, incorporating Equus asinus manure at 6% and coating with calcium stearate improve the mechanical and hydrophobic properties of earth material used in construction, which is interest to communities building in seismic and flood-prone areas.

**Keywords:** Adobe bricks, eco-building, unfired clay bricks, manure, calcium stearate

## Introduction

Adobe bricks are the oldest and most widely used building material globally because of their thermal and acoustic comfort, tolerable compressive strength, and low production cost [1]. Due to these qualities, many families around the world still use this material in their constructions, and there are multiple research projects to improve this building material to enhance its efficiency.

Widder [2] notes that the common factor in buildings made of adobe bricks is the search for thermal comfort, particularly in cold areas where other materials such as reinforced concrete, steel, or fired clay bricks are less favorable. His experiments found that adobe bricks have a heat transfer rate of 0.07 BTU/hr°F, while reinforced concrete has a rate of 0.81 BTU/hr°F. Other studies have shown that adobe bricks have a thermal conductivity of approximately 0.02 BTU/hr°F, making them an effective thermal insulator [3], [4].

On the other hand, there is a growing trend of construction with sustainable materials to reduce environmental impact [5]. In consequence, earth has been reconsidered as a construction material. Certain studies have proposed more modern construction alternatives such as a 3D printing system prototype made with earth, starch gel, and fibers [6]. Some research aims to improve the construction process using earthen techniques, like cob [7]. Even non-destructive methods have been developed to evaluate the vulnerability of existing adobe brick buildings [8].

According to the National Institute of Statistics and Informatics (INEI) census, 30% of buildings in Peru are constructed with adobe bricks (INEI, 2017), which concerns for the engineering community. Most of these constructions are in seismic zones 3 and 4, which makes them particularly vulnerable to earthquakes, as described in the E.030 Standard for Seismic Design. Moreover, as well as known, adobe bricks are highly sensitive to erosion and disintegration caused by water and moderate precipitation is recorded from January to April, posing an imminent risk to these constructions.

As new building materials expanded, various construction techniques were developed, leading to the loss of "ancestral" construction techniques. Although some techniques are still preserved as a tradition in certain villages, insufficient scientific research has been conducted to demonstrate their effectiveness. One of these construction techniques involves incorporating fibrous manure into adobe bricks as reinforcement [2].

Research on the effect of incorporating straw, cow manure, and prickly pear sap on the compressive strength of adobe bricks [9] found that the incorporation of cow manure generated the highest compression results (as cited in Chicaiza & Mercedes, 2017). Although current construction standards for adobe bricks indicate that straw can be incorporated during their preparation [10] to reduce cracking, this incorporation could have more implications.

Recently, the effect of incorporating "fibrous" material as reinforcement in adobe bricks to improve their mechanical properties has been studied. One study demonstrated this improvement by incorporating rubber fibers from tire factory waste as reinforcement; however, a negative aspect was detecting a sudden failure type [11]. Another study showed a 38% improvement in compressive strength when 2% mijo fibers (Sorghum bicolor) were incorporated as reinforcement [3]. Similarly, it has been determined that incorporating 2% neem fibers (Azadirachta indica) globally improves mechanical properties with some negative effects on durability [4]. Furthermore, it was noted that organic fibrous reinforcement from eggshells, agricultural residues, sawdust, and coconut shells significantly improves the mechanical properties of unfired clay bricks [12]; however, there are research studies that demonstrate the opposite. Previous studies have shown that the use of chicken feather fibers (CFF) has a slight negative impact on the mechanical properties of adobe bricks and a positive impact on crack density and erosion [13]. Therefore, it is ideal that the reinforcement chosen in adobe brick production is optimal, meaning that it should improve mechanical properties without affecting durability.

Furthermore, the effect of incorporating "hydrophobic" material as a coating or reinforcement in adobe bricks to reduce their permeability has been studied. One study found that adobe bricks with 0.33% cationic amine (anionic fatty acid) and 3% emulsified asphalt incorporation reduce water absorption [14]. Another study found that coating adobe bricks with carrageenan, a biodegradable natural polymer, at 0.5% provided effective protection against water erosion [15]. Similarly, research suggests that incorporating biopolymers into adobe bricks positively binds their particles, thereby improving their hydrophobicity [16]. Additionally, another study demonstrated that tung oil improves the hydrophobicity of adobe bricks by providing high and persistent contact angles [17]. However, some reinforcements intended to improve adobe bricks hydrophobicity have simultaneously negatively impacted their mechanical properties [13]. On the other hand, some reinforcements aimed at improving the mechanical properties of adobe bricks have compromised their hydrophobicity, as indicated by a study on recycled sawdust fiber reinforcement [18]. In this sense, pursuing a hydrophobic coating rather than reinforcement is more convenient.

All these research efforts aim to find a sustainable solution to improve the mechanical properties of adobe bricks and reduce their permeability, as a significant population around the world involved in adobe brick constructions. In this regard, using manure as a reinforcement for adobe bricks and protecting them with calcium stearate offers a solution to the waste management problem in rural areas, reducing the carbon footprint and the amount of energy used in construction material production. Additionally, governments can implement adobe brick construction programs targeted at the most vulnerable populations to contribute to their economic and social development.

Given all the above, this study examines the effect of incorporating Equus asinus manure in adobe brick production to improve their compressive and tensile strength, as well as the effect of sprinkling calcium stearate on their surface to reduce their permeability.

## Materials and methods

### Sample preparation

The first step involves selecting the soil quarry and water. "In situ" tests are then performed to choose the suitable soil quarry, followed by a granulometric analysis [10], [19]. For selecting the water, a physicochemical analysis is conducted in the laboratory.

The "in situ" tests comprise two types: the "mud ribbon" test and the "presence of clay" test [10]. In the mud ribbon test, mud cylinders with a diameter of 12mm are made (with minimal water added to the soil) and crushed until they reach a diameter of 4mm. The soil is deemed suitable if the mud ribbon breaks in the 20-25cm range. In the presence of clay test, four mud spheres with a diameter of 3cm are made and crushed after 48 hours of drying. The soil is suitable if none of the four spheres crack when crushed.

After confirming the soil's suitability, a granulometric analysis is conducted on a 15kg sample from the same quarry [10], [20], [21]. Additionally, a 1L water sample is collected and tested to ensure it is suitable for sample preparation [22], [23].

### Compression and tension strength testing at unit level

Compression (10cm cubic units) and tensile (cylindrical units with 15.24cm diameter and 30.48cm length) tests will be performed on adobe brick "units" to compare results between the control and experimental groups [10]. The control group involves making conventional adobe bricks, while the experimental group is divided into five subgroups according to the incorporation percentage of Equus asinus manure (relative to its weight): 3%, 6%, 9%, 12%, and 15%. The following table shows the number of samples to be prepared:

**Table 1.** Number of samples for mechanical testing of unit

| Test | Control Group (Unit) | Experimental Group (with Equus asinus manure) | | | | |
|---|---|---|---|---|---|---|
| | | 3 % (Unit) | 6 % (Unit) | 9 % (Unit) | 12 % (Unit) | 15 % (Unit) |
| Compressive strength | 6 | 6 | 6 | 6 | 6 | 6 |
| Tensile strength | 6 | 6 | 6 | 6 | 6 | 6 |

The unit-level compression test involves applying a crushing force to the cubic samples until they fail. The ultimate strength is calculated using the following expression:

$$f_0 = \frac{P}{A} \qquad (1)$$

Where: $P =$ Maximum load reached; $A =$ Compression area.

**Figure 1.** Compression testing on units

The unit-level tensile test involves applying a crushing force to the cylindrical samples made until they fail. The ultimate strength is calculated using the following expression:

$$f_0 = \frac{2F}{\pi \emptyset l} \qquad (2)$$

Where: $F =$ Maximum load reached; $\emptyset =$ Sample diameter; $l =$ Sample height.

**Figure 2.** Tensile testing on units

**Testing of compressive and tensile strength at the level of low walls (masonry units)**

The control and experimental groups will be evaluated to compare the results of compression and tensile strength tests on adobe brick walls [10]. The control group will consist of adobe brick walls (0.65mx0.65m) made with conventional bricks. The experimental group, on the other hand, will be composed of walls (0.65mx0.65m) made with adobe bricks that performed the best in unit-level compression and tensile strength tests. These bricks were determined by the percentage of Equus asinus manure incorporated, which resulted in the highest performance in the previous tests. The number of samples to be produced is listed below:

**Table 2.** Number of samples for mechanical testing of low walls

| Test | Control Group (Low wall) | Experimental Group (optimal % of manure) (Low wall) |
|---|---|---|
| Compressive strength | 6 | 6 |
| Tensile strength | 6 | 6 |

The compression strength test at the wall level involves applying a crushing force to the wall until it fails. The allowable compression stress is calculated using the following expression:

$$f'_m = \frac{P}{ab} \quad (3)$$

Where: $P =$ Maximum load reached; $a =$ wall thickness; $b =$ Length of the wall.

**Figure 3.** Compression testing on Low wall

The indirect tensile strength test at the wall level involves applying a crushing force to the wall in an inclined position until it fails. The allowable shear stress is calculated using the following expression:

$$f'_t = \frac{p}{2ae_m} \ (4)$$

Where: $p =$ Maximum load reached; $a =$ Length of the wall; $e_m =$ wall thickness.

**Figure 4.** Tensile testing on Low wall

## Test of absorption and simulated flooding

For the unit-level absorption test, the results of the control group and experimental group will be compared. The control group will consist of conventional adobe bricks, while the experimental group will consist of conventional adobe bricks with a dusting of calcium stearate. The number of samples to be produced is shown below:

**Table 3.** Number of samples for absorption testing on units

| Test | Control Group (Unit) | Experimental Group (coated with calcium stearate) (Unit) |
|---|---|---|
| Absorption | 6 | 6 |

The author proposed a unit-level absorption test that measures the amount of water absorbed by the samples.

The absorption percentage is calculated using the following expression:

$$\%Abs = \frac{W_w - W_d}{W_d} \qquad (5)$$

Where: $W_w$ = Wet weight; $W_d$ = Dry weight.

Additionally, the time (in minutes) the units completely dissolve after being submerged in water is recorded.

**Figure 5.** Absorption testing on units

The results of the control and experimental groups will be compared for the flood test on the adobe brick walls. The control group will consist of adobe brick walls made with conventional bricks. The experimental group will consist of walls made with adobe bricks incorporating the ideal percentage of Equus asinus manure and the sprinkling of calcium stearate.

The number of samples to be produced is shown below:

**Table 4.** Number of samples for simulated flood testing of low walls

| Test | Control Group (Low wall) | Experimental Group (with ideal % of calcium stearate and coated with calcium stearate) (Low wall) |
|---|---|---|
| Simulated flood testing | 1 | 1 |

**Figure 6.** Samples for simulated flood testing of low walls

The flooding test on walls, proposed by the author, involves measuring the capillarity of water in the samples. The walls are constructed in a pool and flooded with water. Additionally, the time (in minutes) the samples fall due to water erosion is recorded.

## Results and analysis

### Soil analysis was conducted on the selected sample.

Table 5 displays the particle size distribution analysis of a soil sample collected from the previously selected quarry site using in-situ tests. The analysis determined that the soil has a fineness modulus of 0.638, a uniformity coefficient of 6, and a curvature coefficient of 0.9. The fineness modulus was obtained from the analysis of the particle size distribution. The granulometric curve is presented in Diagram 1.

**Table 5.** Granulometric analysis

| **N°Sieve** | **Opening diameter** | **% Cumulative** | |
|---|---|---|---|
| | | **Retained** | **Passing** |
| 3” | 75.000 | 0.00 | 100.00 |
| 1 1/2” | 38.100 | 0.00 | 100.00 |
| 3/4” | 19.000 | 0.00 | 100.00 |
| 3/8” | 9.500 | 0.00 | 100.00 |
| N° 4 | 4.760 | 1.40 | 98.60 |
| N°8 | 2.360 | 7.90 | 92.10 |
| N°16 | 1.100 | 17.60 | 82.40 |
| N°30 | 0.590 | 36.90 | 63.10 |
| N°50 | 0.297 | 54.80 | 45.20 |
| N°100 | 0.149 | 82.10 | 17.90 |
| N°200 | 0.075 | 92.40 | 7.60 |
| Bottom | - | 100.00 | 0.00 |
| Fineness modulus | | 0.638 | |
| Uniformity coefficient | | 6.0 | |
| Coefficient of curvature | | 0.9 | |

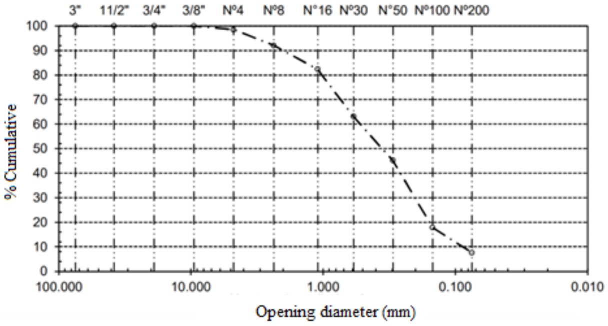

**Diagram 1.** Granulometric curve of the studied soil sample.

Table 6 shows the Atterberg limits calculated for the soil sample studied, where the liquid limit was determined to be 24, the plastic limit was 14, and the plasticity index was 10. According to Table 5, the coefficient of curvature is less than 1. The Atterberg limits determine the soil has a SUCS classification: poorly graded sand with clay (SP-SC).

**Table 6.** Atterberg limits

| **Consistency tests** | **Liquid limit** | | | **Plastic limit** | | |
|---|---|---|---|---|---|---|
| Container code | 30 | 204 | 93 | LP-02 | LP-11 | Average |
| Number of blows | 10 | 25 | 35 | - | - | - |
| Container + moist soil | 48.1 | 45.9 | 48.6 | 55.1 | 56.8 | 55.18 |
| Container + dry soil | 42.8 | 41.4 | 43.5 | 52 | 53.1 | 51.58 |
| Water | 5.3 | 4.5 | 5.1 | 3.1 | 3.7 | 3.4 |
| Container weight | 22.2 | 22.2 | 22.2 | 27.5 | 28 | 27.75 |
| Dry soil weight | 20.6 | 19.2 | 21.3 | 24.5 | 25.1 | 24.8 |
| Moisture content percentage | 25.95 | 23.32 | 23.79 | 12.65 | 14.74 | 13.7 |
| Liquid Limit | 24 | | | | | |
| Plastic Limit | 14 | | | | | |
| Plasticity index | 10 | | | | | |

Table 7 shows the moisture content of the soil sample, which was 2.61%. This value is important to consider in the production of adobe bricks because it influences their quality and strength.

**Table 7**. Moisture content

| | |
|---|---|
| Container code (gr) | S-03 |
| Container + wet soil (gr) | 162.9 |
| Container + dry soil (gr) | 161.4 |
| Water (gr) | 1.5 |
| Container weight (gr) | 104 |
| Dry soil weight (gr) | 57.4 |
| Moisture content (%) | 2.61 |

### Physical-chemical analysis of water.

Table 8 shows the results of the physicochemical analysis of the water sample studied. These results indicate that the water is suitable for construction because its parameters do not threaten the integrity of the soil or reinforcement.

**Table 8.** Physicochemical analysis of water

| | |
|---|---|
| pH | 7.79 |
| Conductivity (µS/cm$^2$) | 528 |
| Salinity (%) | 1.0 |
| Chlorides (mg/L) | 14.4 |
| Sulfates (mg/L) | 345.6 |
| TDS (mg/L) | 264.0 |
| Turbidity (NTU) | 10.1 |

### Compressive strength

### Compressive strength in units

Table 9 displays the average results of compression strength at the unit level for both the control and experimental groups. All samples exceeded the standard strength requirement of 10.2 kgf/cm$^2$ [10], demonstrating the high quality of the soil selected for making adobe bricks and the importance of conducting in-situ tests to detect the presence of clay in the soil. Moreover, the maximum value was obtained from the experimental group incorporating 6% Equus asinus manure. Overall, a 24% increase in compression strength was achieved compared to the control group, and a 135% increase compared to the minimum standard value.

**Table 9.** Compression strength in units

| Sample Group | Average ultimate strength (kgf/cm$^2$) |
|---|---|
| Control | 19.2745 |
| Experimental – 3% | 21.4612 |
| Experimental – 6% | 23.9320 |
| Experimental – 9% | 20.9850 |
| Experimental – 12% | 19.4769 |
| Experimental – 15% | 15.3919 |

According to Diagram 2, compressive strength results obtained through the uniaxial compression test, increased as the percentage of Equus asinus manure incorporation increased, reaching maximum values with a dosage of 6%. However, these values progressively decreased, falling below the control group. Therefore, the incorporation of fibrous material in the production of adobe bricks should not be uncontrolled to obtain favorable results. Some studies achieved a maximum compressive strength of 16.09 kgf/cm$^2$ [1], 18.96 kgf/cm$^2$ [9], 22.88 kgf/cm$^2$ [13], 23.45 kgf/cm$^2$ [24], and 25.4 kgf/cm$^2$ [5], which are similar to the values obtained in the present study. However, other research achieved much higher values, such as 71.19 kgf/cm$^2$ [3], 64.29 kgf/cm$^2$ [4], and 60.38 kgf/cm$^2$ [25], due to the use of different soil and a new technique for making adobe bricks, compressed earth blocks (CEB). This highlights the crucial need to improve techniques for making adobe bricks.

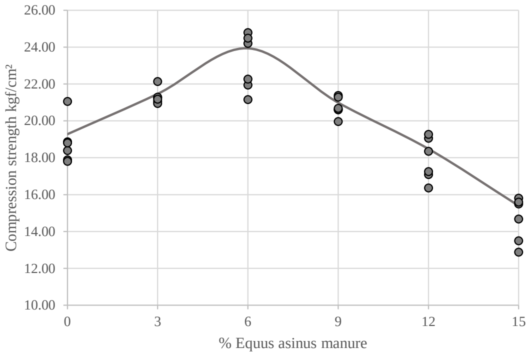

**Diagram 2**. Compression strength results

### Compressive strength in masonry walls

Table 10 shows the average compression strength results of both the control and experimental groups. Both samples achieved a higher strength than the standard (6.12 kgf/cm$^2$) (ASTM, 2016), demonstrating the good quality of the adobe brick units. Furthermore, it was found that the maximum value was achieved with the experimental group incorporating 6% Equus asinus manure. Overall, there was a 20% increase in the compression strength of the wall compared to the control group and a 27% increase compared to the minimum standard value.

**Table 10.** Compression strength in masonry walls

| Sample Group | Average ultimate strength (kgf/cm$^2$) |
|---|---|
| Control | 6.50 |
| Experimental – 6% | 7.80 |

The study on the compressive strength of adobe bricks is generally conducted at the unit level due to the high sensitivity of the walls to breaking. A study on 3D printing with earth matrices produced samples through stacking, where a compressive strength of 9.18 kgf/cm$^2$ was achieved [6], with taller stacks proving to be stronger, reaching values of up to 22.94 kgf/cm$^2$. However, problems related to slenderness arose. The study encompasses a new construction technique using more modern methods such as 3D printing, which is more expensive, but yields similar results to those obtained in the present study.

## Tensile strength

### Tensile strength in units

Table 11 shows the average tensile strength results at the unit level for both the control and experimental group. All samples achieved a strength greater than the standard (0.81 kgf/cm$^2$) [10], demonstrating the good quality of the selected soil to produce adobe bricks and the importance of carrying out "in situ" tests to detect the presence of clay in the soil. Additionally, it was found that the maximum value was achieved with the experimental group that incorporates 6% of Equus asinus manure. In general terms, an increase of 50% in tensile strength was achieved compared to the control group and 206% compared to the minimum standard value.

**Table 11.** Tensile strength in units

| Sample Group | Average ultimate strength (kgf/cm$^2$) |
|---|---|
| Control | 1.6574 |
| Experimental – 3% | 2.3082 |
| Experimental – 6% | 2.4786 |
| Experimental – 9% | 2.1359 |
| Experimental – 12% | 1.9687 |
| Experimental – 15% | 1.7582 |

According to Diagram 3, the results of tensile strength using the Brazilian tensile test increased as the percentage of Equus asinus manure incorporation increased, reaching maximum values with a dosage of 6%. However, these values progressively decreased, even falling below the control group. Some studies achieved a maximum tensile strength of 4.59 kgf/cm$^2$ [1], 4.08 kgf/cm$^2$ [26]. However, other studies achieved much higher values: 6 kgf/cm$^2$ [15], 11.8 kgf/cm$^2$ [27], due to the use of different soil and methods for determining tensile strength than those used in the present study. Therefore, the incorporation of fibrous material in the production of adobe bricks should not be uncontrolled to obtain favorable results.

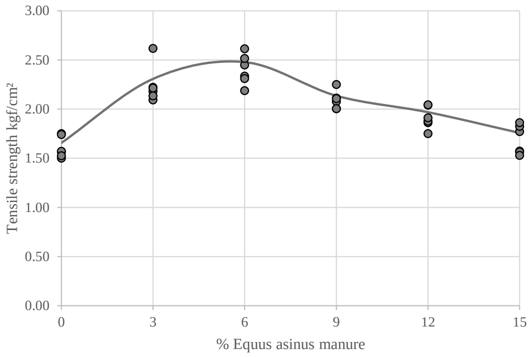

**Diagram 3.** Tensile strength results

## Tensile strength in masonry walls

Table 12 shows the average results of the indirect tensile strength of the masonry for both the control and experimental groups. Both samples achieved a strength greater than the standard (0.25 kgf/cm$^2$) [10], demonstrating the good quality of the adobe bricks. Additionally, it was found that the maximum value was obtained by the experimental group that incorporated 6% Equus asinus manure. In general terms, there was a 18% increase in the masonry's tensile strength compared to the control group and a 32% increase compared to the minimum standard value.

**Table 12.** Tensile strength in units

| Sample Group | Average ultimate strength (kgf/cm$^2$) |
|---|---|
| Control | 0.28 |
| Experimental – 6% | 0.33 |

Unlike other construction materials, adobe brick walls exhibit low tensile strength as their behavior is not entirely monolithic. As a result, it has been demonstrated that their performance under uniaxial compression [1], [28] is much better than under tension. These findings align with the nature of earth material and its mechanical characterization, emphasizing compression over tension [29].

## Absorption and simulated flooding

### Absorption in units

Table 13 shows the average absorption results for the control and experimental groups. The control group exhibited negative absorption; an inconsistent data point that makes sense due to the crumbling of the samples because of water erosion. On the other hand, the samples from the experimental group were able to store the infiltrated water through small cracks and unlike the control group samples, did not crumble instantly. In this sense, the coating with calcium stearate radically changed the behavior of the adobe bricks in the presence of water.

**Table 13.** Average absorption on units

| Sample Group | Average absorption (%) |
|---|---|
| Control | -7.11 |
| Experimental – Calcium stearate coating | 4.17 |

Table 14 presents the disintegration time of samples from the control and experimental groups. It was observed that the coating with calcium stearate greatly protected the adobe bricks from erosion, significantly delaying their disintegration. This confirms the effectiveness of the hydrophobic coating. A study demonstrated that the incorporation of polymeric materials improved the erosion resistance of the earth material, achieving a similar absorption level as in the present study: 9% [14]. Another study qualitatively concluded that incorporating Carrageenan reduced adobe bricks' absorption, linking absorption to the total erosion of the samples [15].

**Table 14.** Total disintegration time on units

| Sample Group | Average total disintegration time (min) |
|---|---|
| Control | 54 |
| Experimental – Calcium stearate coating | 479 |

## Simulated flooding of the wall

Table 15 displays the results of capillarity measured in the masonry walls during the simulated flooding test. The control group achieved a capillarity of 640 mm, while the experimental group reached 320 mm. These results demonstrate the effectiveness of the calcium stearate coating as a permeability reducer.

**Table 15.** Capillarity in low wall

| Sample Group | Maximum Capillarity (mm) |
|---|---|
| Control | 540 |
| Experimental | 320 |

Research absorption through capillarity has demonstrated that construction techniques significantly influence this phenomenon. It is concluded that the higher the porosity of the adobe brick, the greater its capacity for water infiltration and erosion [6]. On the other hand, it has been shown that incorporating hydrophobic materials during the adobe brick manufacturing process allows it to repel water [17].

Table 16 presents the results of the drop time for the masonry walls. The control group yielded at 345 minutes, while the experimental group yielded at 1120 minutes under a pressure of 0.30 meters of water. This demonstrates the effect of calcium stearate in reducing permeability and, simultaneously, improving the strength of the adobe brick units due to the incorporation of 6% Equus asinus manure.

**Table 16.** Low wall drop time

| **Sample Group** | **Low wall drop time (min)** |
|---|---|
| Control | 345 |
| Experimental | 1120 |

## Conclusions

It was determined that the soil quarry and water source were suitable for making adobe bricks through "in situ" tests and the physicochemical analysis of the water, respectively.

The soil from the quarry obtained a SUCS SP-SC-poorly graded sand with clay classification and had a moisture content of 2.61%, which represents a good quality indicator. This can be evidenced in the high resistances achieved by all samples.

At the unit level, adobe bricks reinforced with 6% Equus asinus manure showed a 24% increase in compression strength and a 50% increase in tensile strength compared to conventional adobe bricks. Compared to the minimum standardized values, the improvement was 135% and 206%, respectively, for each type of strength.

At the wall level, walls made with adobe bricks reinforced with 6% Equus asinus manure showed a 20% increase in compression strength and a 18% increase in indirect tensile strength compared to conventional adobe bricks. Compared to the minimum standardized values, the improvement was 135% and 32%, respectively, for each type of strength.

At the unit level, adobe bricks coated with calcium stearate improved their resistance to erosion by water and were able to absorb water without disintegrating for a certain time. They also delayed the total disintegration time by up to 8 times compared to uncoated adobe bricks.

At the wall level, the simulated flooding test determined that capillarity was 3/4 times lower in the wall made with adobe bricks reinforced with 6% Equus asinus manure and coated with calcium stearate. On the other hand, the fall time in this wall was delayed up to 2 times compared to the wall made with conventional adobe bricks.

Adobe bricks reinforced with 6% Equus asinus manure and coated with calcium stearate provide a sustainable solution that improves of the mechanical and hydrophobic properties of the earth material used in building construction.

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