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Investigation of the Fermentation Mode of Rice Husk for the Stabilization of Earth Plaster

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Abstract

Despite its low resistance to humidity, adobe remains the most widely used material for housing construction, particularly in developing countries. The present study aims to assess different modes of use of fermented RH and to evaluate their influence on the behavior of raw earth for application in plaster. The influences of two types of RH are evaluated: granular rice husk (RHg) and powdered RH (RHp). The clay mainly consists of clay (40%), silt (22%), and sand (38.4%), with a small proportion of gravel (0.24%). Its liquidity limit is 40% and the plasticity index is 26.5%. The mixtures were designed using earth and each of the two rice husks at the volumetric content of 10%, 15% and 20% of the total volume mixed with water 36.5%, 38.5% and 40.3% and fermented for three weeks. Each fermented mixture was added to the soil to form the paste, and $40 \times 40 \times 160$ mm^3 test speciments were made for characterization. The results generally show an improvement in the physico-mechanical properties and water resistance of the mortars containing fermented RH, with an optimal content between 10% and 15%. The powdered RH improved the performance of the mortar better than granular RH.

Keywords

Earth Plaster, Rice Husk, Clay, Fermentation, Adobe

1. Introduction

Globally, there is growing interest in the use of earth as a construction material due to its exceptional thermo-physical and mechanical properties. The material enables eco-friendly design and meets strength and serviceability requirements for thermal resistance. In Burkina Faso, adobe, commonly known as "banco" remains the most widely used material for the construction of habitats [1]. Indeed, more than 53.6% of households live in houses built using adobe. This is partly due to the large availability of clay raw material and its use which requires little energy, is affordable and easy to work [2]. In addition, its exploitation remains less expensive with a lower environmental impact than cement construction, whose production is energy-consuming and produces large quantities of greenhouse gases [3] [4] [5]. Furthermore, earth-based materials provide better thermal and acoustic comfort due to their high moisture absorption/desorption rates, and thermal and sound inertia [6].

However, adobes encounter problems in terms of mechanical resistance and water resistance. These problems are linked, among other things, to the poor cohesion, swelling/shrinkage of the clay matrix, and the appearance of pores during the production of adobes. Therefore, adobe walls must be protected with quality plasters, which remains a concern for low-income populations. An earth plaster of acceptable mechanical quality does not crack for water to penetrate the wall and must have adequate adhesion with the wall. To improve the above properties, plant fibers, organic binders, and small quantities of mineral binders (cement or lime) are commonly added to earth-based materials [7]. Cement or lime-based plasters are sometimes not suitable for plaster earthen walls and contribute to deteriorating their thermal parameters, on the one hand. On the other hand, raw earth plasters have a low weatherability resistance and require regular maintenance after each rainy season. The use of plant and animal by-products such as rice husk, rice straw, kenaf fiber, fonio fibers, animal dung allows to improve the quality of the plaster [3] [8] [9] [10] [11]. These fibers reduce the shrinkage cracking, improve the compressive strength and thermal properties, and most often reduce the water sensitivity of plasters.

Bamogo *et al.* [9] improved the physical, mechanical, hydric, and thermal properties of earth plaster amended by fermented cow dung at content of 2% to 6% by mass. They obtained an increase in compressive and flexural strength with 6% cow dung up to 0.7 MPa and 2.48 MPa, respectively, due to the formation of amine silicate; a very adhesive molecule and insoluble in water. The water sensitivity of the plaster as well as the thermal conductivity has also been improved.

The amendment of plaster using kenaf fibers showed comparable results. Indeed, Ouédraogo *et al.* [10] reported that the compressive strength increases from 2.5 to 3.45 MPa with an addition of 0.2% kenaf fibers of 3 cm long and from 2.5 to 2.7 MPa with 0.4% kenaf fibers of 1.5 cm long. They explained this increase by the presence of kenaf fibers, which prevents the propagation of cracks in the clay matrix due to the good adherence of their rough surfaces. However, higher content of the fiber (0.6%; 0.8%, and 1%) decreases the compressive strength. Similarly, studies on adobes stabilized with cow dung (1% to 3% by weight of the soil) have shown improved hydric and physical-mechanical properties [12] [13]. Cow dung was reported to interact with kaolinite and fine quartz to produce an insoluble amino silicate, which glues isolated soil particles together. In addition, the high fiber content of cow dung prevents crack propagation in adobes and makes the adobe microstructure homogeneous, with an apparent reduction in porosity.

Nafissatou *et al.* [11] used the bulk rice husk available in Burkina Faso [14] to stabilize the earth plaster. The result show that the apparent density, linear shrinkage, compressive strength, and abrasion resistance of the specimens decrease respectively from 1.88 g/cm^3 to 1.07 g/cm^3, 4.52% to 0.83%, 3.88 MPa to 0.82 MPa, and 0.21 cm^2/g to 2.84 cm^2/g with increasing RH content from 0% to 67%. The same applies to the thermal properties, where thermal conductivity decreases from 0.87 W/m·K to 0.05 W/m·K. Capillary absorption and water erosion show deficiencies for the contents of RH of 50% and 67%. These shortcomings may be linked to the coarse-grained appearance of rice husk or to the limited fermentation process.

The general objective of this study is to assess the optimal method for the fermentation of rice husk in the design of earthen plaster intended for coating adobe walls.

2. Materials and Methods

2.1. Raw Materials

The clay earthen material was collected in the locality of Kôdéni (11˚10'N and 04˚17'W) in the west of Burkina Faso. Local populations exploit this site mainly to produce construction earthen materials such as earth bricks and earth plasters. Bamogo *et al.* [9] have previously studied this clay to produce earthen plasters stabilized with cow dung. According to their study, the clay from Kôdéni is suitable to produce earthen plaster, because it contains a high proportion of kaolinite and clay, which acts as a binder for the particles. In addition, it does not contain swelling clay, such as montmorillonites and smectites [9].

In the present study, the rice husks (RH) was used in two forms: granular form (RHg) and powder form (RHp). The RHp and RHg were collected from Koupéla, a town in Burkina Faso, as that used by Nafissatou *et al.* [11]. **Figure 1** presents the materials used in the present study.

Figure 2 presents the results of the particle size analysis by sieving of the soil and RH. The earth contains sand (38.4%), silt (22%), clay (40%) and a small amount of gravel (0.24%). It mainly contains fine elements (>61% passing on 0.08 mm). According to the NF P11-300 diagram [15], this earth is type B6: clayey sand and gravel. The clay content is within the range recommended to produce plasters (20% and 40%) according to the XP P13-901 standard [16]. The powdered rice husk contains up to 96.32% of elements < 2 mm and only while 80% of the elements in bulk rice husks.

Table 1 presents the density and total porosity of the materials. The apparent density is 110 kg/m^3 and 329 kg/m^3 respectively for the RHg and RHp; which are lighter than the earth (1195 kg/m^3) which is related to their bio source and high

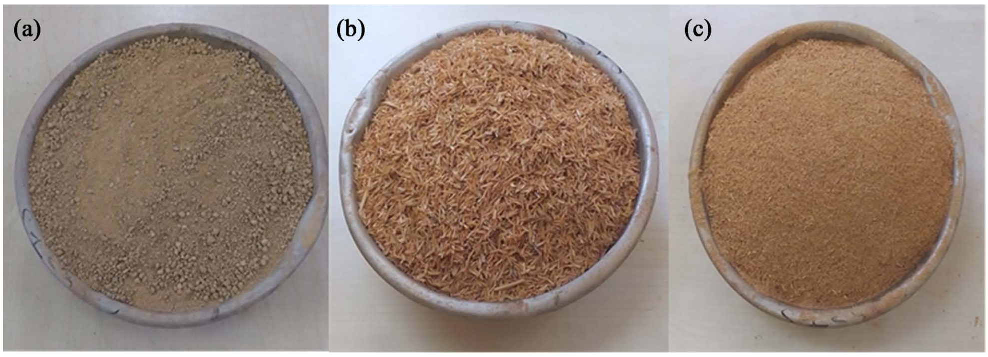

Figure 1. Materials used in the present study: (a) clay < 5 mm; (b) granular rice husk (RHg); (c) powdered rice husk (RHp).

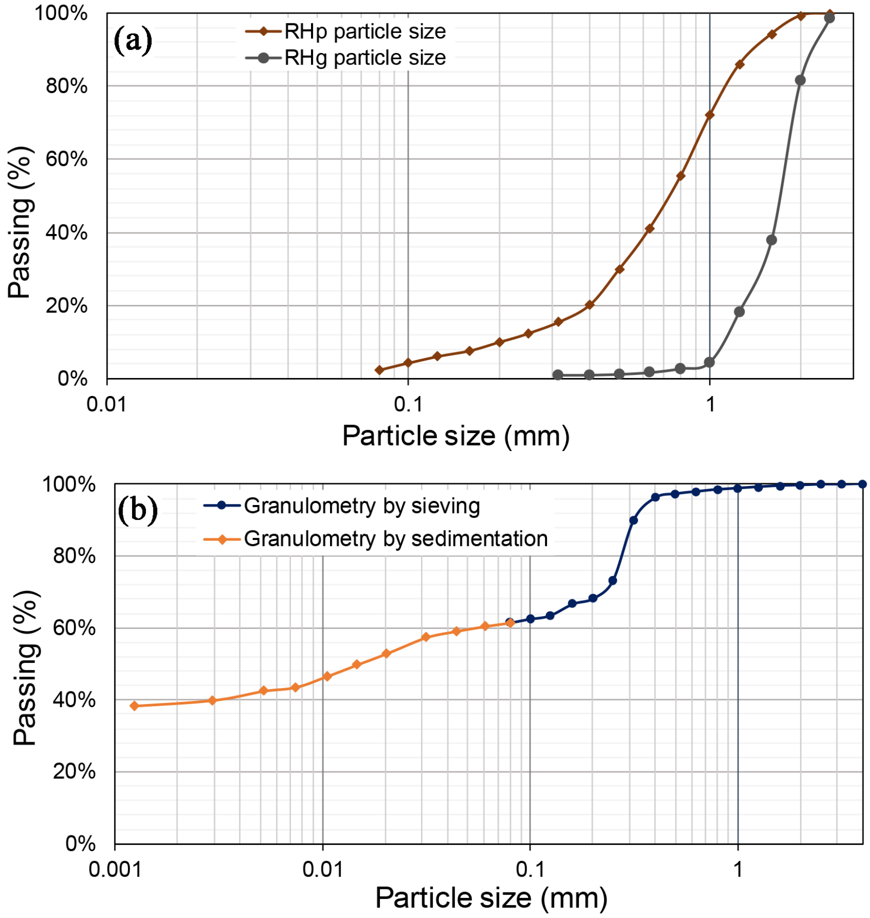

Figure 2. Particle size distribution of (a) clay and (b) rice husk: granular (RHg) and powdered (RHp).

Table 1. Bulk and specific density of materials.

	Apparent density, ρ_{Vap} (kg/m^3)	Specific density, γ_s (kg/m^3)
Clay earthen material	1195	2300
Granular rice husk	110	1400
Powdered rice husk	329	1800

porosity. The apparent density as well as the specific density of RHp is higher than those of RHg, related to the loss behavior of RHg.

Earth has a plasticity index, IP of 26.5% and a liquidity limit of 40%. It can be classified as plastic materials (IP > 20). It has a soft consistency with a consistency index Ic of 0.5. The Atterberg limits of this material fit in the recommended boundary on the Casagrande diagram [17] to produce plasters and adobes, as that used by Nafissatou *et al.* [11]. The cohesion and activity show that this material is strongly cohesive and inactive; according to the quantity of clays and the plasticity indices (**Figure 3**). This is confirmed by its activity coefficient which is less than 0.75. The methylene blue value (VBS) of 2.67 g/100g shows that the soil is silty-clay with medium plasticity (2.5 < VBS < 6). These results are summarized in **Table 2**.

2.2. Production of Test Specimens

The preparation of the earthen plaster was carried out according to the protocol described by [9]. A volumetric design was proposed according to the current use of RH to facilitate the popularization of the technic. The earth is crushed and sieved under 5 mm, the RHg is screened under 2 mm; the RHp is screened under 1 mm. The three materials are dried at 105˚ to constant masses, for about 48 hours, to control the consistency of the mortar when water would be added.

Three volume contents of rice husks (10%, 15% and 20%) were fermented in appropriate quantity of water for the optimal time of three (03) weeks [9]. Each content was intended to be mixed with 6 liters of earth material (**Table 3**). The optimal quantity of water would allow to obtain a plastic mortar suitable to produce earth plaster. This quantity was estimated by Equation (1); where Wl and Wp are the liquid limit and the plastic limit, respectively. The pH of the

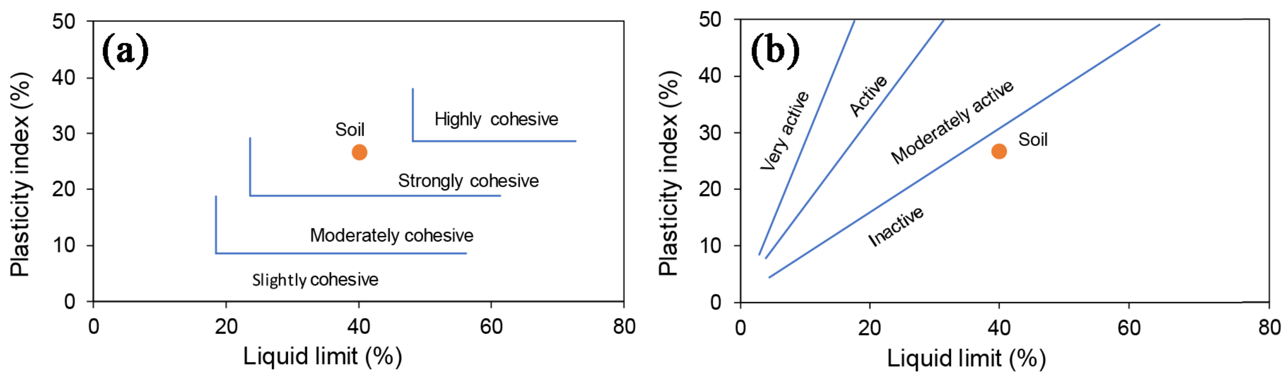

Figure 3. (a) Cohesion; (b) Activity of earthen material.

Table 2. Geotechnical properties of raw earth.

Granulometry				Atterberg limits			Methylene blue value (VBS) (g/100 g)
Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Liquid limit Wl (%)	Plastic limit Wp (%)	Plasticity index IP (%)	
40	22	38.4	0.24	40	13.5	26.5	2.67

Table 3. Design and fermentation of rice husk.

Design	Description of the fermentation mode	Earth (l)	Rice husk (vol. %)	Water content (vol. %)
0RH	Control mixture of 100% earth	6	0	24
10RHs	Mixture of 90% earth and 10% fermented rice husk in form of solution	6	10	24
15RHs	Mixture of 85% earth and 15% fermented rice husk in form of solution	6	15	33
20RHs	Mixture of 80% earth and 20% fermented rice husk in form of solution	6	20	27
10RHp	Mixture of 90% earth and 10% fermented powder rice husk	6	10	24
15RHp	Mixture of 85% earth and 15% fermented powder rice husk	6	15	33
20RHp	Mixture of 80% earth and 20% fermented powder rice husk	6	20	27
10RHg	Mixture of 90% earth and 10% fermented granular rice husk	6	10	23
15RHg	Mixture of 85% earth and 15% fermented granular rice husk	6	15	27
20RHg	Mixture of 80% earth and 20% fermented granular rice husk	6	20	24

Each mix was design to produce 3 specimens of 40 × 40 × 160 mm^3; firstly, the RH were fermented alone in water, before mixing with the earthen material to produce plaster.

solution was measured through the fermentation period to assess the maturity of the fermentation. Slight adjustments were made to produce plaster when the mixtures were a little too dry, due to the water absorption of RH of 250% over 24 hours [11].

$$W(\%) = \frac{WL + WP}{2} \quad (1)$$

Three (03) methods were used to make the mortar. After the fermentation of RH, the mortars were made by mixing earth with the solution extracted from the fermented RH without the fibers (RHs), or by mixing earth with the entire fermented RH (solution plus fibers) for the RHg and RHp. The mixtures were homogenized for 15 min and stored in a tightly closed plastic container in lab at room temperature (30˚C ± 5˚C) for 24 h to allow maceration. After 24 hours, they were mixed again and then poured into molds (40 × 40 × 160 mm^3) to cast test specimens in two layers. Each layer was manually compacted by 15 shocks. The molds were kept in the shade for 48 hours and then the specimens were removed from the mold and stored to dry for about 21 days at room temperature (30˚C ± 5˚C) with an average relative humidity of 32% ± 5% until constant mass, to avoid cracking (**Figure 4**).

2.3. Production of Test Specimens

The linear shrinkage α (%) of earth plaster was determined from the difference between the initial length (l_0) and final lengths (l) measured before and after drying (equation 4); on prismatic test pieces 40 × 40 × 160 mm^3 (**Figure 5**), according to [9] [17]. The apparent density ρ (g/cm^3) was determined according to DIN 18947 [18] using equation 3; where m (g) is the dry mass of the test piece and v (cm^3) is its volume. The thermal conductivity was tested using CT meter device (**Figure 6**) using a ring probe. The flexible printed circuit board (thickness 0.2 mm-dimension 60 × 90 mm), designed to be inserted between two flat pieces of the sample to be measured (whose surfaces have been ground beforehand). The diameter of the heating element (30 mm) is of type ϕ 30R. The operating principle consists in measuring the rise in temperature underwent by the sensor during a heating period chosen by the user and depending on the material to be tested and the probe to be used.

$$\rho = \frac{m}{v} \tag{3}$$

$$\alpha = \frac{l_0 - l}{l_0} \times 100 \tag{4}$$

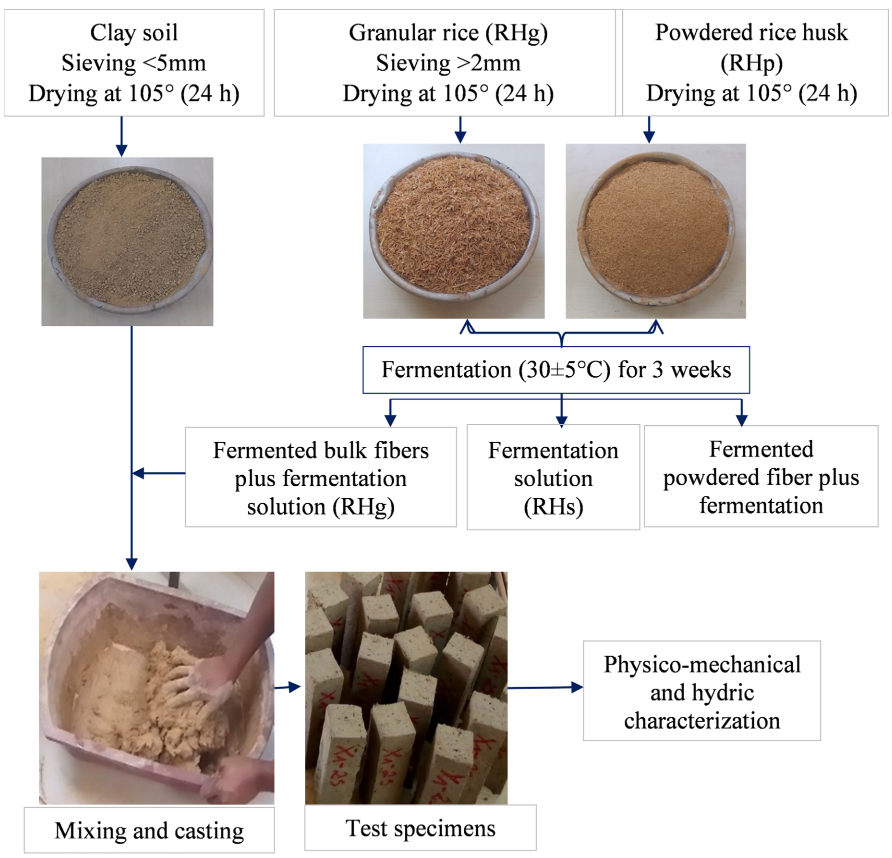

Figure 4. Experimental procedure.

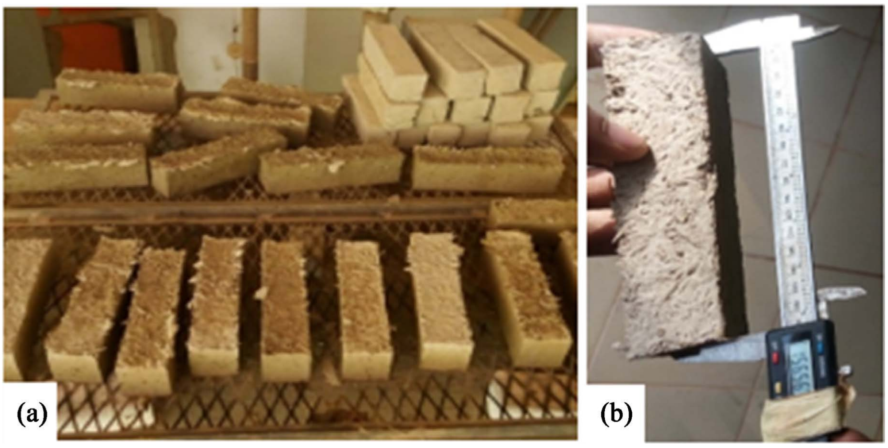

Figure 5. (a) Drying of samples at 30±5˚C, (b) Measurement of the drying shrinkage using Vernier caliper.

Figure 6. Device for thermal conductivity test.

The compressive strength R_c (MPa) was tested according to the German standard DIN 18947 [18]. The experimental set-up from the study by Nafissatou *et al* [11] was used to carry out the test. It was evaluated on the six half-prisms, obtained from the 3-point bending test, using a press. It is the ratio of the force F_c (N) to failure over the applied surface S (mm^2) and is estimated with Equation (5). The abrasion resistance was tested by subjecting the specimens to mechanical abrasion using a 3 kg wire brush [18]. The test consists of passing this brush along the length of the specimens for 60 cycles. The abrasion coefficient is expressed the ratio between the quantity of abrased material, $m_0 - m_1$ (g), over the abrased surface, S (cm^2) in Equation (6).

$$R_c = \frac{F_c}{S} \quad (5)$$

$$C_a = \frac{m_0 - m_1}{S} \quad (6)$$

Capillary absorption was tested according to NF XP 13-901 [16], measuring the increase in mass by capillary rise in the specimens (**Figure 7(a)**). The mass of water, $m_0 - m_1$ (g), absorbed by the sample is measured after 10 minutes and

Figure 7. Test setups for: (a) capillary water absorption; (b) water erosion.

allowed to determine the capillary absorption coefficient, C_b (g/cm^2·min$^{0.5}$), by dividing with the surface, S (cm^2) of the sample exposed to water and the square root of the time (t) in equation 7. To assess the behavior of raw earth plasters during the rainy season or for a humid climate, a water erosion test was carried out. The water erosion was tested by projecting water at a constant flow rate of 1.5 l/min for 10 min on specimens placed on an inclined plane at an angle of 30˚ (Figure 7(b)), referring to Bamogo *et al.* [9]. The mass loss, C (%), is estimated from equation 8; with m_0 is the dry mass before the test and m_1 is the dry mass after the test.

$$C_b = \frac{100(m_0 - m_1)}{S \times \sqrt{10}} \tag{7}$$

$$C = \left(\frac{m_0 - m_1}{m_0}\right) \times 100 \tag{8}$$

3. Results and Discussion

3.1. Variation of pH of Fermented RH

The evolution of the pH of the rice husk solution during the fermentation the of the rice husk is shown in Figure 8. The pH of the RHg solution changes very little (around 7.8 - 7) compared to that of RHp which becomes more acidic after three weeks of fermentation (6.1 to 4.6). The decrease in the pH of the solution over time would be due to the extraction of polysaccharide substances (cellulose, hemicelluloses, starches and pectins) which would be acids according Sakihito *et al.* [19]. It is also possible that these are the degradation products of rice cell walls, released and solubilized by microbial fermentation (cellulose, hemicellulose, or lignin). This extraction process was encouraged when the RH is in powder form. This may impact the workability of earthen materials as they can vary from a plastic state to a liquid state due to the high sensitivity of clay particles to variations in pH [20] [21]. Tannins are organic acids that mainly act as complex multivalent anions and can be adsorbed on the edges of clay particles and thus act as a dispersant of the clay network. Guihéneuf *et al.* [22] found similar results using tannin and citric acid on clay soils.

3.2. Thermo-Physical Properties of Plaster

3.2.1. Linear Shrinkage

Figure 9 presents the results of linear shrinkage on the specimens after 21 days of drying. There is a reduction in the shrinkage of the samples with the use of fermented RH. The decrease of the shrinkage with solution extracted from the RH indicates that fermentation allowed the formation of products which improve the resistance of the plasters. For the case of RHp and RHg, this reduction could be explained by good cohesion in the earthen matrix provided by the products of the fermentation and adhesion of the RH fibers due to their rough surface, in the clay matrix resulting in its reinforcement and physical stability. According to several authors, the formation of sticky gels is possible during the reaction between the extracted molecules (cellulose, hemicellulose, starch, lignin, …) and

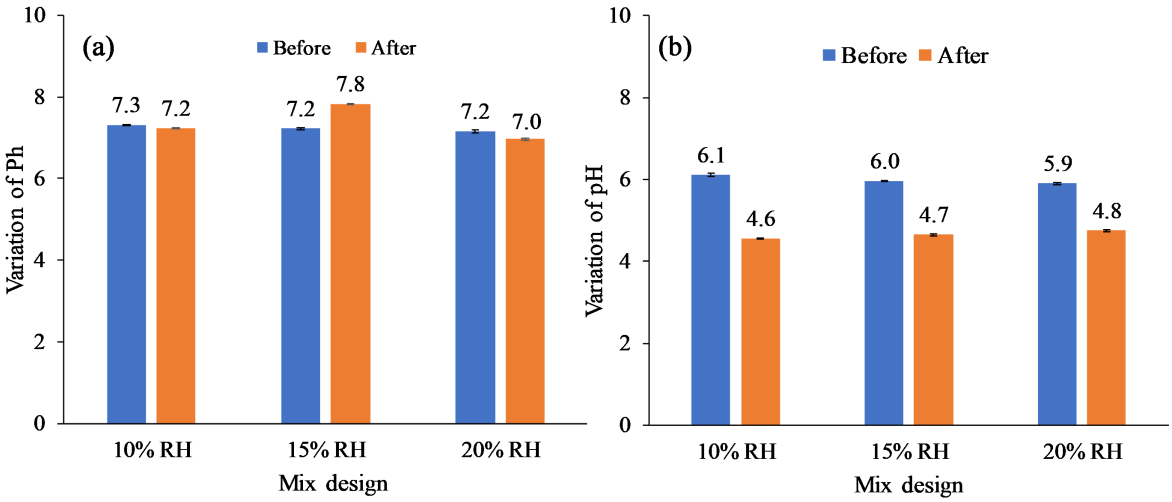

Figure 8. Variation of the PH of the solution of (a) granular rice husk, (b) powder rice husk before and after the fermentation.

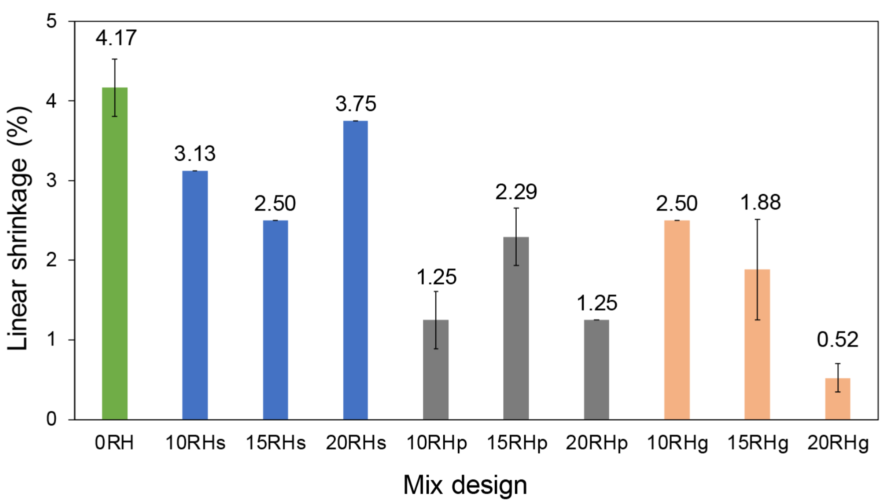

Figure 9. Variation of linear shrinkage.

crystalline clay minerals (kaolinite, quartz, …) [22] [23]. This gel would be amine silicate [$Si(OH)_4$-$4NH_3$], which connects isolated soil particles by limiting shrinkage through chemical bonds created with free electron of oxygen and nitrogen [9] [13]. This would explain the higher reduction observed with RHp and RHg compared to solution of RH due to the combined effect of the presence of fibers and amine silicate. This was similarly reported on raw earth plasters reinforced with plant fibers [24] [25] [26] [27].

The high value of shrinkage with 15RHp compared to 20RHp could be explained by the high quantity of water used in this mixture (33% of water, **Table 3**). The mixture 20RHg reaches the lowest shrinkage due to the presence of organic substances in the mixture which opposes the movement of shrinkage during maturation. The opposite effect for 20RHs is explained by the absence of these organic substances. According to DIN 18947 [18], the shrinkage of earth plasters stabilized with plant fibers must be less than 3%, which was achieved in the present study from 10% of RHg or RHp. This standard proposes that the linear shrinkage should not exceed 2% in the general case, but the maximum value could reach 3% in the case of fiber-reinforced plasters and 4% in the case of fiber-reinforced thin-layer plasters. The linear shrinkage of all the plasters designed in the present study is less than 4% and no cracking was observed on the samples during the experiments.

3.2.2. Apparent Density

Figure 10 shows that the apparent density of the dry specimens produced with the solution of RH (RHs) hardly varies compared to that of the reference plaster (0RH) around 1.76 g/cm^3. For RHp and RHg, the density slightly decreases with increasing content of RH from 1.76 g/cm^3 for 0RH to 1.64 g/cm^3 for 20RHp and 1.65 g/cm^3 for 20RHg. This decrease would be due to the large volume of rice husk fibers that are less dense than earthen minerals. The decrease in apparent density could also be explained by an increase in porosity created by the incorporation of fibers in the matrix [9] [28] [29]. Studies report a decrease in bulk density with the use of plant additives of lignin sulfonate and plant waste with algal fibers [24] [25]. According to DIN 18947 [18], these mixtures belong to the class of density of 1.80 g/cm^3 and could be suitable to produce earthen plaster.

3.2.3. Thermal Conductivity

Figure 11 presented the evolution of the thermal conductivity (λ) of the earth plaster with additions of fermented rice husk. The thermal conductivity of plasters generally decreases with the stabilization with fermented RH compared to the non-stabilized reference plaster. The three modes of use of fermented RH give approximately the same values of the thermal conductivity; with approximately a reduction of around 45% compared to the reference plaster. This reduction can be explained by two effects, namely the presence of plant fibers from the rice husk and the cellulose it contains; which is a good insulating molecule; contributing to reducing thermal conductivity, on the one hand. On the other

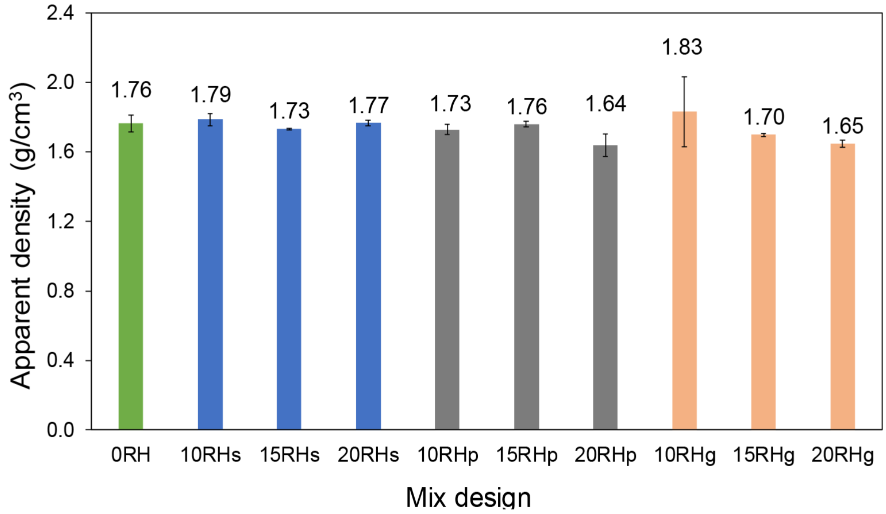

Figure 10. Variation of apparent density of dry specimens.

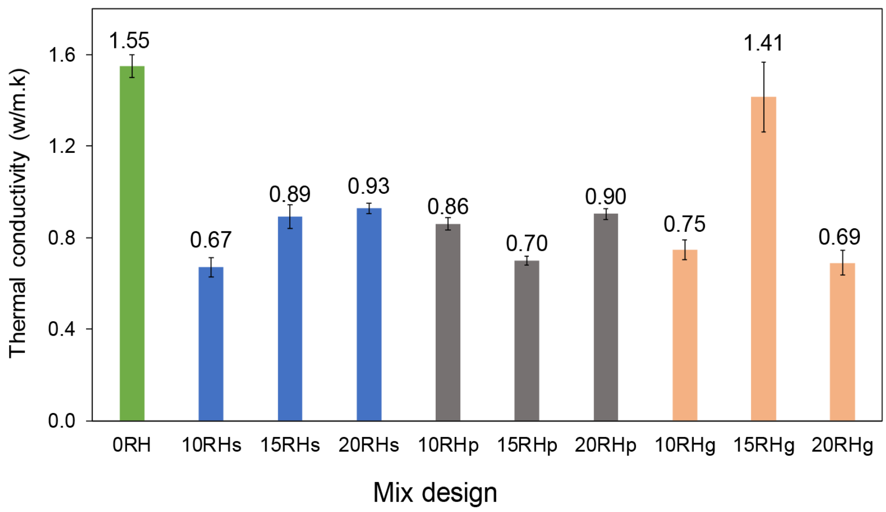

Figure 11. Thermal conductivity of the plaster.

hand, the increased porosity characterized by the decrease of density of the stabilized plasters compared to the reference plaster [9] [22] [23] [30] [31].

Depending on how RH is used, the optimal content is 10% for RHs, 15% for RHp and 20% for RHg.

These values of the thermal conductivity of earth plasters reinforced with rice husk are comparable to the values reported in the literature for raw earth materials (plasters/adobes) reinforced with plant fibers [22] [23] [30] [32] [33]. Losini *et al.* [5] reported a significant reduction of 60% to 78% in thermal conductivity in samples incorporating 1% and 2% by weight of corn pith, respectively. Similar results, 36% and 60% reduction with 1% and 2% by weight when barley was added were reported by Palumbo *et al.* [34]. This difference with the results of the present study can be explained by the biochemical nature of the fibers, the quantity of fibers as well as the particle size of the soils and the instruments of used for the measurement.

3.3. Mechanical Properties of Plaster

3.3.1. Compressive Strength

The compressive strength of earth plaster with additions of fermented rice husk is shown in Figure 12. There is an improvement in the compressive strength of the plasters with the use of fermented RH compared to the reference plaster without RH. There is a gradual increase in compressive strength with the increase in the content of RHs, up to 3.6 MPa from 2.7 MPa without RH. However, the RHp and RHg show that 10% is the optimal content to reach the maximum compressive strength of 3.7 MPa and 3.3 MPa, respectively; beyond 10%, there is a decrease on the strength. This corresponds to the increases of around 35%, 37% and 24% respectively for 20RHs, 10RHp and 10RHg compared to 0RH. Several phenomena can explain the increase in the mechanical resistance of plasters. On the one hand, the formation of insoluble amine silicate, binds the isolated particles of the raw materials and maintain their cohesion. On the other hand, the presence of fibers of rice husk reinforces and prevents the propagation of cracks in the clay matrix thanks to the good adhesion of their rough surfaces with this matrix [13] [34] [35].

Other studies have shown the creation of hydrogen bonds or chemical reactions between clay particles and bio-polymers, which form stable particle clusters, and would explain the increased mechanical strength [13] [36]. However, Abbas *et al.* [37] obtained des results lower than those in this study using rice husk to improve the mechanical properties of adobes. This difference can be explained by the particle size of the soil or the biochemical nature of the RH or the fermentation method as well as the fermentation conditions (humidity, ambient temperature).

The reduction observed beyond 10% with RHp and RHg can be related to the unfavorable effects of the addition of high amount of fibers on the mechanical resistance. In fact, the effectiveness of fibers depends on the type, quantity, and length of the fibers [13] [22]. The addition of optimum quantity of fibers would

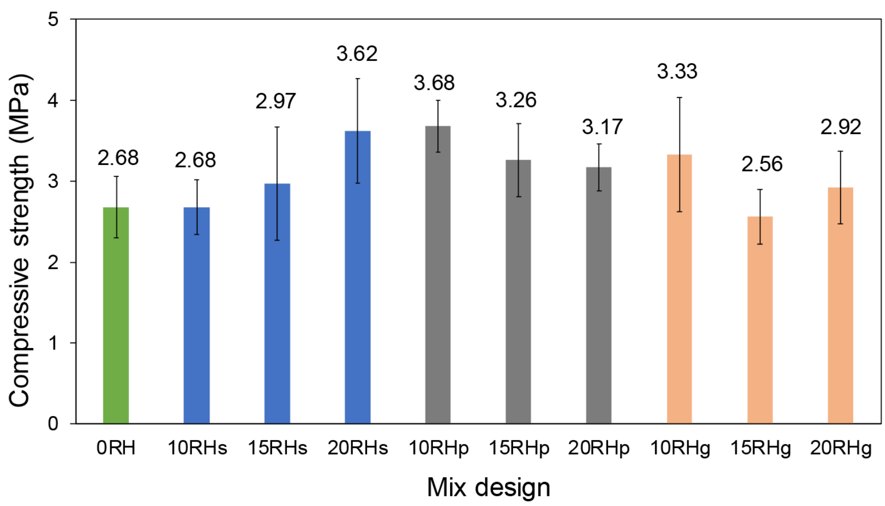

Figure 12. Compressive strength.

results in the improvement of the strength due to their ductility and ability to stabilize the matrix and reduce the shrinkage and initial cracking on drying and the propagation of the crack during the test. It turns out that the rice husk in powder form is more suitable at an optimal content of 10% by volume of the total mixture to reach the value of the strength of 3.68 MPa. The values of the strength reached in the present study are beyond the minimum threshold for the second category (SII ≥ 1.5 MPa) defined in the DIN 18947 standard [18].

3.3.2. Abrasion Resistance

The results of the abrasion tests are expressed by the coefficient of resistance to abrasion which is the loss of mass per unit area of the tested surface of the samples, as presented in **Figure 13**. In general, the coefficient of abrasion of the plasters stabilized with fermented RH improves, more with RHp than RHg. While RHp allowed to reach a gradual decrease in the coefficient of abrasion; the RHs and RHg did not reach a significant evolution of the coefficient of abrasion. The contents giving the best resistance to abrasion are 20% (0.11 g/cm^3) for RHp, 20% (0.26 g/cm^3) for RHs and 10% (0.32 g/cm^3) for RHg respectively corresponding to a reduction of 73%, 37% and 22% compared to the reference plaster (0.41 g/cm^3). The decrease of the coefficient of abrasion can be explained by the good cohesion between the soil particles and the plant fibers of rice husk which limit the particle loss. The abrasion resistances obtained in this study are similar to those reported by Millogo *et al.* [9] [13] on adobes and earth plasters stabilized with cow dung. According to the German standard [18], these results allow to classify the studied earth plasters in the SI category (<1.5 g/cm^2).

3.4. Durability Properties of Plaster

3.4.1. Capillary Absorption

The evolution of the water absorption coefficient (Cb) by capillarity of the coatings with the square root of time and the nature of the fermentations is shown in **Figure 14**. The control mixture (0RH) shows slightly lower absorption kinetics

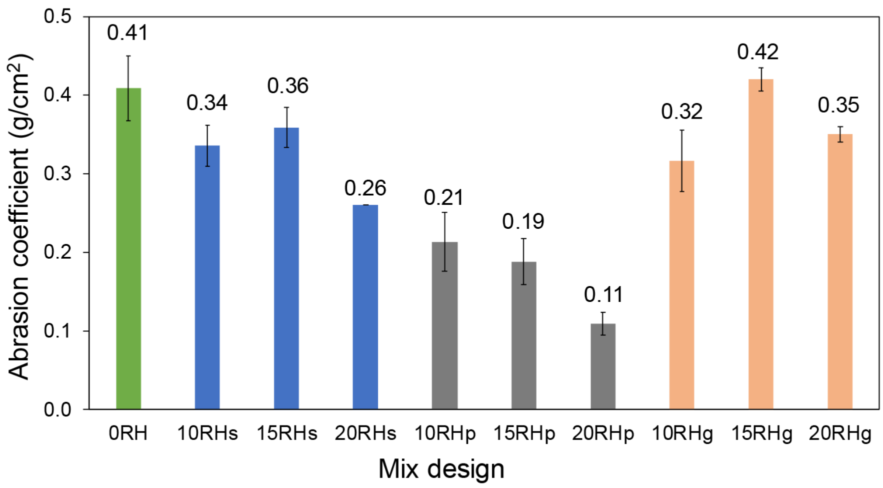

Figure 13. Coefficient of abrasion of plaster.

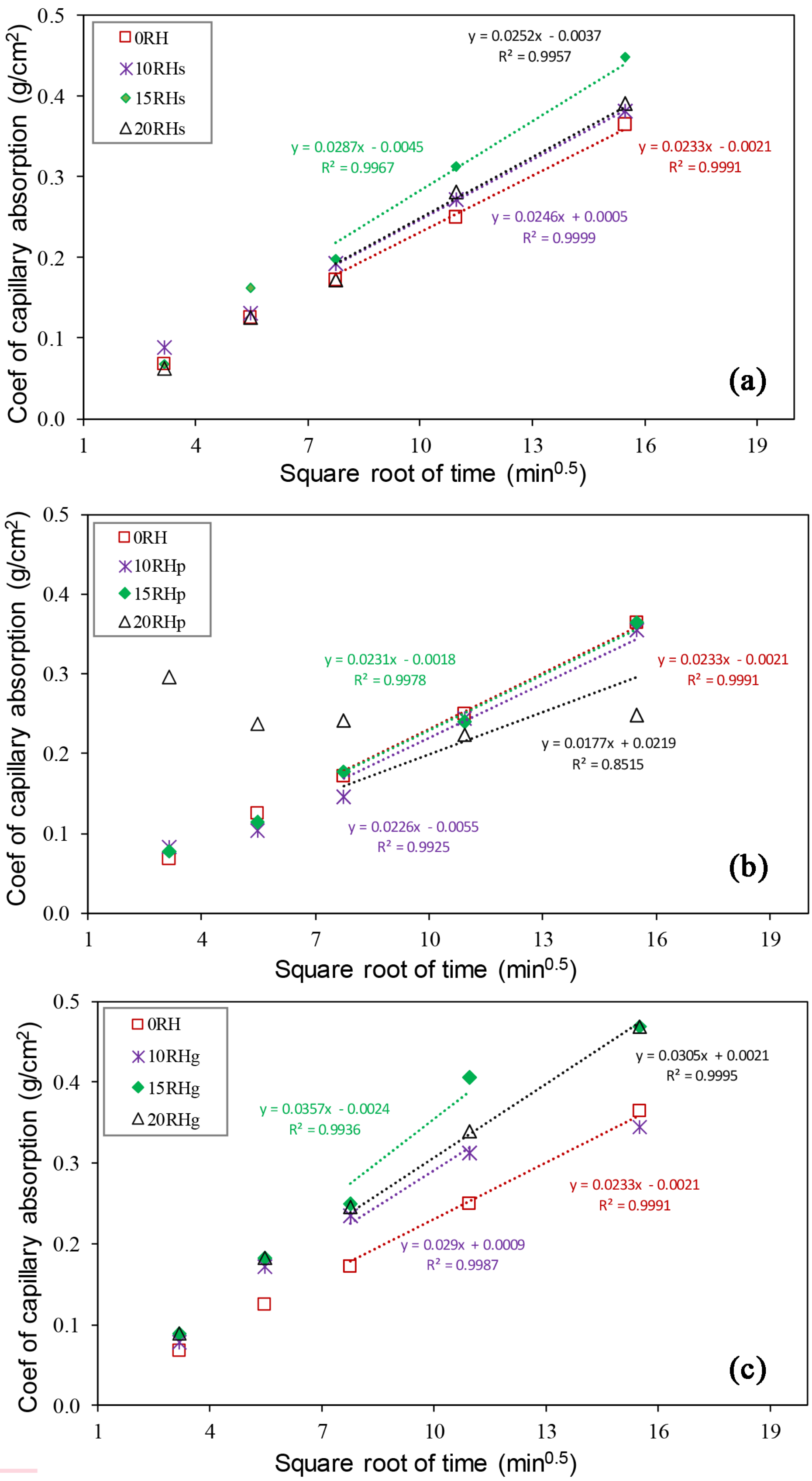

Figure 14. Capillary absorption coefficient: (a) RHs; (b) RHv; (c) RHp.

than the rice husk mixtures (RHs, RHg). Capillary absorption with the square root of time (sorptivity) for the control mix, in the 10 min - 4 h immersion range, is equal to 0.02 g/cm^2·min$^{0.5}$. An increase in sorptivity can be seen in the mixtures with rice husk solution (RHs) (**Figure 14(a)**) and those with RHg (**Figure 14(c)**). Sorptivity values summarized in **Table 4** ranged from 0.03 g/cm^2·min$^{0.5}$ for RHs blends to 0.04 g/cm^2·min$^{0.5}$ for RHg mixtures. For mixtures with RHp, a decrease in sorptivity is observed compared to 0RH, where the sorptivity value is 0.017 g/cm^2·min$^{0.5}$ for 20RHp (**Figure 14(b)**).

This improvement in sorptivity with RHp mixtures is thought to be linked to the presence of small RHp particles which block the porosity with the probable formation of insoluble amine silicate (hydrophobic molecule), making earth plasters less permeable to water [22]. Such an evolution of the capillary water absorption coefficient has been reported by Faria *et al.* [26]. The absence of fibers with the use of RHs would explain the slight increase in Cb compared to RHp blends. In the case of RHg, the increase in Cb could be due to the presence of larger fibers in greater quantities, which themselves absorb water when the specimen is brought into contact with water. Indeed, a measurement of the absorption coefficient of RHg shows that they can absorb up to 250% of their weight in water [11].

3.4.2. Water Erosion

Figure 15 presents the results after the erosion test. A decrease in the mass loss of plasters stabilized with fermented RH is observed compared to the reference plaster without stabilization. This results mainly from the presence of insoluble amine silicate, which ensure the cohesion of earthen particles by creating chemical bonds (hydrogen bridge bonds) with the kaolinite or quartz sheets in the earth plasters reinforced with fermentable biopolymers, making them weather resistant [13] [22] [23].

The high decrease of the mass loss was obtained with the RHs, then RHp and

Table 4. Summary Cb 10 min, coefficient of sorptivity.

Design	Cb10 min (g/cm^2·min$^{1/2}$)	Sorptivity (g/cm^2·min$^{1/2}$)
0RH	2.1	0.023
10RHs	2.8	0.024
15RHs	2.5	0.029
20RHs	2	0.025
10RHp	2.6	0.023
15RHp	2.5	0.023
20RHp	2.8	0.018
10RHg	2.5	0.029
15RHg	2.8	0.036
20RHg	2.8	0.031

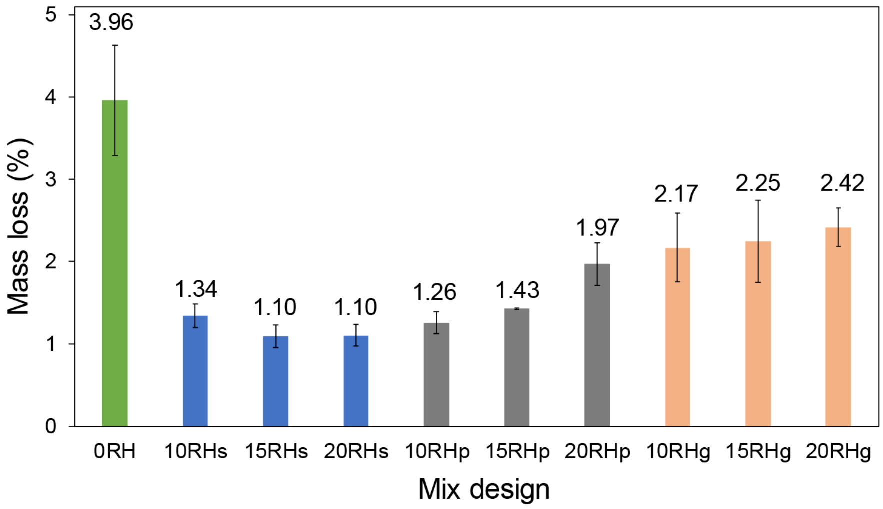

Figure 15. Water erosion.

RHg. While the lowest value of mass loss (1.1%) was reached with 20% for RHs; it was reached with 10% for RHp and RHg and increased beyond; but remaining lower than 3.96% with % RH. The presence and size of the fibers would impact the water resistance of earth plasters; the higher the content and the larger the fiber size, the lower the water resistance. The decrease of the mass loss corresponding to 72%, 68% and 45% was recorded for 20RHs, 10RHp and 10RHg with respect to 0RH. The bonds created by the amine silicate would be stronger than those linked to the presence of fibers, which create weak spots (pores) in the matrix for water erosion. In addition, the absorption of water by the RH fibers would facilitate the detachment of clay particles during water erosion. According to CRATERRE [38] the mass loss should not exceed 10% on the initial mass of the sample. Therefore, all the plaster designs are useful.

4. Conclusions

This study assessed the most appropriate mode of stabilization of earthen plasters intended for coating adobe walls using fermented rice husk. The study consisted of characterizing the earth and the RH, then designing plasters using clay earthen materials and previously fermented and finally characterizing the plasters on a physico-mechanical, thermal and durability properties.

The grain size of the clay is dominated by silts, clay and sand with a low gravel content. The liquid limit and the plasticity index are respectively WL = 40% and IP = 26.5% and the methylene blue value is 2.65. The stabilization of the earth plaster by the fermented rice husk made it possible to improve the shrinkage, resistance to compression, abrasion, water erosion and thermal conductivity of the plasters regardless of the fermentation method:

1) RHp allowed to reach the highest improvements in shrinkage and resistance to compression, abrasion, and water erosion. The optimal content of RHp is 10% considering the parameters resistance to compression and capillary absorption. It can be brought to 20% to consider the abrasion resistance.

2) RHg allowed to reach the lowest thermal conductivity.

3) RHs allowed to reach the lowest water erosion at content of 20%.

4) Regarding capillary absorption, only the use of RHp allows an improvement compared to the reference plaster.

The consideration of all the parameters shows that M-10%RHp is the optimal mix design for earth plaster stabilized with fermented rice husk.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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