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MANUFACTURE OF LIGHTENED MORTARS WITH PERLITE AND LIME APPLIED IN PANELS WITH A RICE STRAW RESIDUE MIX

FABRICACIÓN DE MORTEROS ALIGERADOS CON PERLITA Y CAL APLICADOS EN PANELES CON MATRIZ DE RESIDUOS DE PAJA DE ARROZ

FABRICAÇÃO DE ARGAMASSAS LEVES COM PERLITA E CAL APLICADAS EM PAINÉIS COM MATRIZ DE RESÍDUOS DE PALHA DE ARROZ

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RESUMEN

La presente investigación tiene como objetivo diseñar y caracterizar morteros de revoco a base de perlita y cal producida en Ecuador, con una resistencia mínima a compresión de 6.89 MPa, conforme lo establece el IRC 2018. Esto, con el fin de ser aplicado sobre paneles elaborados con paja de arroz. Para ello, se diseñan 2 mezclas patrón. En la primera se usa arena como árido fino, mientras que para la segunda se usa perlita. De cada una se obtienen 8 mezclas adicionales, en las que se sustituye el cemento por cal (en volumen) en diferentes porcentajes. Se realizan 270 probetas con la finalidad de evaluar la resistencia a compresión y la densidad de los morteros a 1, 3, 7, 28 y 50 días. El mortero elaborado con perlita y compuesto por 50% cal, 50% cemento y aditivo, alcanzó una resistencia de 7.22 MPa, con una densidad de 1.45 g/cm³. Al aplicar esta mezcla sobre los paneles elaborados con paja de arroz, dio como resultado el aumento de su resistencia a compresión hasta un 68%.

Palabras clave
revoco; mortero; paja

ABSTRACT

This research aims to design and characterize plaster mortars based on perlite and lime produced in Ecuador, with a minimum compressive strength of 6.89 MPa, as established by IRC 2018, to be applied on rice straw panels. For this purpose, two standard mixes are designed. In the first, sand is used as fine aggregate, while in the second, perlite is used. Eight additional mixes are obtained from each one, where cement is replaced by lime (in volume) in different percentages. A total of 270 test specimens were made to evaluate the compressive strength and density of the mortars at 1, 3, 7, 28, and 50 days. The mortar made with perlite, comprising 50% lime, 50% cement, and an additive, reached a resistance of 7.22 MPa, with a density of 1.45 g/cm³. When this mixture was applied to the rice straw panels, it resulted in an increase of up to 68% in their compressive strength.

Keywords
plaster, mortar, straw

RESUMO

O objetivo desta pesquisa é projetar e caracterizar argamassas de reboco à base de perlita e cal produzidas no Equador, com uma resistência à compressão mínima de 6,89 MPa, conforme estabelecido pelo IRC 2018. Isso, para ser aplicado em painéis feitos com palha de arroz. Para isso, foram projetadas duas misturas padrão. Na primeira, a areia é usada como agregado fino, enquanto na segunda, é usada perlita. A partir de cada uma delas, são obtidas 8 misturas adicionais, nas quais o cimento é substituído por cal (em volume) em diferentes porcentagens. Foram feitos 270 corpos de prova para avaliar a resistência à compressão e a densidade das argamassas em 1, 3, 7, 28 e 50 dias. A argamassa feita com perlita e composta por 50% de cal, 50% de cimento e aditivo, atingiu uma resistência de 7,22 MPa, com densidade de 1,45 g/cm³. Quando essa mistura foi aplicada aos painéis feitos com palha de arroz, ela resultou em um aumento de até 68% na resistência à compressão.

Palavras-chave:
reboco, argamassa, palha.

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INTRODUCTION

A study by Stephan and Athanssiadis (2018) concluded that, in the last 100 years, the world's population has increased fourfold, while the consumption of materials extracted from the Earth's crust has done so tenfold, the main driver being the construction industry. According to the same study, construction minerals saw a 42-fold increase to 2010 (Stephan & Athanssiadis, 2018). The relationship between these data is not random, as population growth results in a need for more housing and infrastructure, which, in turn, allows commerce and the economy to develop (Mendoza & Vanga, 2021).

In this sense, industrial development and population growth have also resulted in more construction waste, such as fly ash, silica fume, glass, concrete waste, and steel offcuts, among others (Sudharsan & Sivalingam, 2019). For this reason, it has become necessary to study materials where circular economy criteria prevail and the creation of new products is encouraged (Zhang et al., 2018) while being in tune with the need to minimize waste and reduce energy consumption (Fernández et al., 2020).

In this context, several research projects have pointed out that panels with straw, wood, and mortar are an alternative for sustainable construction. In these, straw, often burned and discarded by farmers, causing environmental pollution through CO_2 emissions (Teslík, 2021), is the primary material. When used in construction, this agro-industrial waste provides solutions that offer quality economic development, social welfare, and environmental respect (Cascone et al., 2019). According to statistical data, 1,132,267 tons of rice were produced in Ecuador in 2010, covering an area of 382,230 hectares (Ministry of Agriculture and Livestock of Ecuador, 2022), which generates a large amount of waste (straw) that could be used.

On the other hand, straw panels are manufactured by taking the straw bales directly from the agricultural producer or using a manual baler. Then, they are accommodated discontinuously inside a wooden frame, whose dimensions allow making a panel that fits the architectural design of a house. The plaster mortar consists of a mixture of aggregates (sand or perlite) and conglomerates (lime and cement) in proportions to protect the straw from external agents and improve the panel's structural properties.

The energy required to make the panels and build with them is negligible due to their easy assembly and disassembly. In addition, they provide a very high thermal resistance, adequate ventilation, greater comfort, and fire safety compared to traditional materials (Muntani et al., 2020). For this reason, buildings that use rice straw panels and coating mortars consume very little energy. They are also sustainable since, at the end of their useful life, the wood can be recovered or incinerated, the straw composted, and the lime used in the soil to improve agricultural fields (Martínez, 2019).

The coating mortar or plaster on the panels has several important roles. One of these is to control the humidity inside it and thus prevent the straw from rotting (Walker et al., 2020). It also protects them from external agents such as rain, sun, and even insects or organisms that may alter their useful life (Martínez, 2019). Therefore, it is essential to study innovative materials as replacement alternatives to Portland cement for manufacturing these mortars in different proportions or their entirety (Aprianti, 2017).

One alternative is hydrated lime or calcium hydroxide ($Ca(OH)_2$). However, it has been studied very little for these purposes due to the emergence of cement in construction (Apostolopoulou et al., 2021). This material is considered sustainable, as it can generate 50% less pollution compared to the industrialization process of cement (Hermida, 2021).

Due to the reaction between this material and the gases in the atmosphere during the setting process, as lime traps CO_2, the mortar hardening times tend to be slower, unlike hydraulic binders (Pahlavan et al., 2018). However, over time, this chemical process allows the cracks in the hardened mortar to self-seal, providing greater durability and water vapor permeability thanks to the lime increasing the contact between the fine aggregate particles (Zhang et al., 2018).

The main objective of this research is the design and characterization of a lime and perlite-based mortar. This is to use it as plaster in straw-based panels obtained as waste from the rice harvest with ideal structural parameters for housing construction. Said plaster must also provide the panel with suitable strength, less weight, and sustainability conditions by permitting the highest amount of lime in its mixture to replace cement. It must be checked, therefore, that the use of lime instead of cement in the mortar maintains the required strength limits of 6.89 MPa, following

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the American standard for straw construction IRC 2018 (Table 1) and the Ecuadorian NTE INEN (Ecuadorian Institute of Standardization) and international ASTM standards (*American Society of Testing and Materials*) for mortar design.

Table 1: Minimum compressive strength of plasters for straw-made walls. Source: (IRC, 2018)

Type of plaster	Minimum compressive strength	
	(PSI)	(MPa)
Clay	100	0.69
Soil - Cement	1000	6.89
Lime	600	4.14
Cement - Lime	1000	6.89
Cement	1400	9.65

Straw, like wood, degrades over time in the presence of moisture (Yin et al., 2018). Therefore, researching materials such as lime to design plasters that control humidity and guarantee the harmony between wetting and drying ensures the durability and good behavior of buildings made with straw (ESBA, 2021). Those mortars that have a higher amount of lime in their composition have acceptable permeance and permeability (Pavia & Brennan, 2018) to prevent straw rot.

Consequently, mortars must not only meet the indicated strength but have a density that is as low as possible due to the large volume it occupies in the panel. For this reason, some mortars are designed with sand and others with perlite, a fine, low-density aggregate with a porous texture that can retain water on its surface (Artigas et al., 2022).

Currently, there are few studies on the use of lime and perlite in mortars for this purpose. However, one by Viera and Acero (2022) can be highlighted, which evaluates the compressive strength of mortars from lime produced and marketed in Ecuador for use as glue in masonry. The highest compressive strength, equal to 3.5 MPa after 28 days, is obtained with lime from the La Paz quarry. It also characterizes four additional limes (San Juan, San José, Incoreg, Indami) with lower strength.

In this sense, to promote materials such as perlite, lime, and straw, it is necessary to perform studies that determine their physical and mechanical characteristics, individually and jointly, such as with the panel. These also provide data that allow construction professionals to make the respective modeling and structural analysis of buildings with prefabricated straw. This research provides relevant data about the dosage and strength of low-density mortars with lime and perlite content, which can be an alternative in conventional and sustainable constructions when applied on the panel.

METHODOLOGY

The procedures established in the Ecuadorian NTE INEN and the ASTM international standards were followed in this research. These were used in the characterization of both the materials in the mortar, as well as the evaluation of its properties as a whole and to determine the compressive strength in the straw panels.

Figure 1 summarizes the methodology for the research, explained in detail in the following sections. The study starts by selecting the materials and their characterization to then design two standard mixtures, SM1 (cement + sand + water) and SM2 (cement + perlite + water), using the optimal density method. From each of these mixtures, eight additional variants are obtained where cement is replaced by lime in percentages of 30%, 50%, 70%, and 90%. Additives are also added to some of these.

A total of two hundred and seventy 50 mm cubic specimens were made with each study mixture to determine the density and compressive strength of the mortars at 1, 3, 7, 28, and 50 days. The mixture chosen will be the one that allows obtaining a low-density mortar with a higher lime content and an optimal strength that is equal to or greater than 6.89 MPa at 28 days, as established by the construction code for straw, IRC 2018 so that it can be used on walls.

Finally, the chosen mixture will be applied on the external faces of 3 prefabricated panels with wooden frames and previously baled rice straw. It will then be tested under compression to obtain its ultimate load, strength, and weight. The compression test is also performed on 3 additional panels where the coating has not been applied to determine the functionality and contribution of the mortar inside the panel against these load stresses.

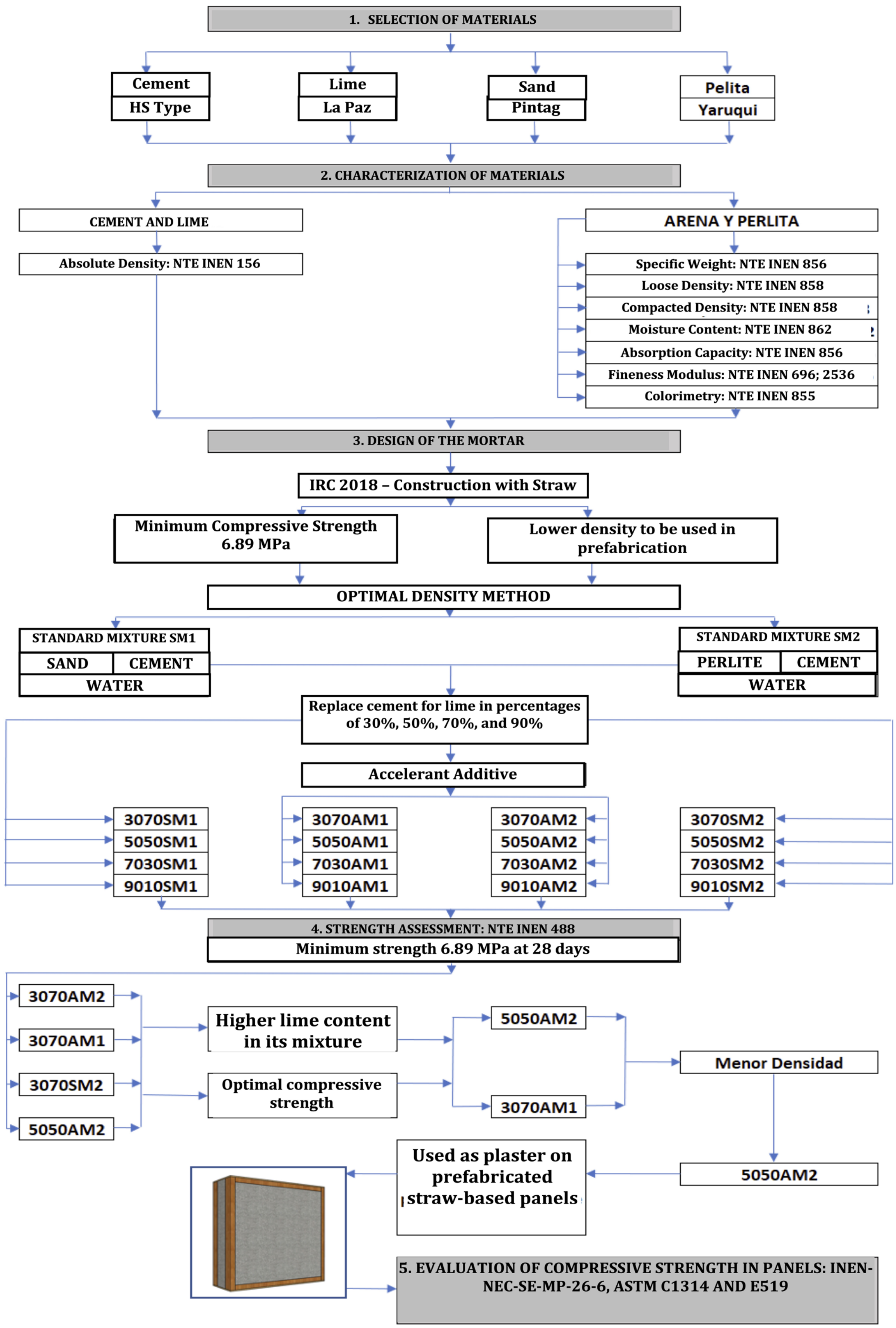

Figure 1: Research methodology. Source: Preparation by the authors.

MATERIALS

Sulfate-resistant hydraulic cement, whose absolute density is 2.80 g/cm³, was used to make the mixtures. The physical properties of the HS cement are indicated in Table 2 below, following what is indicated by NTE INEN 2380 and ASTM C1157.

Table 2: Physical properties of the cement. Source: (NTE INEN 2380, 2011)

Physical Properties	NTE INEN	ASTM	HS Type Cement
Change of length by autoclave (%)	200	C-490	0.80
Initial setting time (min)	158	C-191	≥45≤120
Compressive strength (MPa)	488	C-109	3rd day = 11 7th day = 18 28th day = 25
Mortar bar expansion 14 days (%)	2529	C-1038	0.020
Sulfate expansion / Sulfate resistance (%)	2503	C-1012	6 months = 0.05 1 year = 0.10

Nationally produced hydrated lime was used, extracted from the La Paz lime mill (Carchi – Ecuador), as a replacement for cement in different percentages (30%, 50%, 70%, and 90% by volume). According to its use and the NTE INEN 247 standard, this is classified as type N (Normal lime without incorporated air used in cement mortars and plasters). The physical-chemical properties of this lime are indicated below in Table 3.

Table 3: Physical-chemical properties of the lime. Source: Preparation by the authors.

Physical-Chemical Properties	NTE INEN	ASTM	Lime Type N
Absolute density (g/cm³)	156	C-144	2.20
Loose bulk density (g/cm3)	858	C-29	0.82
Compacted bulk density (g/cm3)	858	C-29	0.90
Residue sieve No. 30 (%)	244	C-110	23.20
Calcium oxides (%)	250	C-25-19	36.00
Magnesium oxides (%)	250	C-25-19	1.90

In the first design of mixtures to make the mortar, sand from the quarry located in the parish of Pintag (Quito – Ecuador) was used as a fine aggregate, while, for the second design, perlite from the Yaruquí parish (Quito – Ecuador) was used. Both materials comply with the granulometry to be used in mortars according to the NTE INEN 2536 standard. The granulometric curves of the aggregates are indicated below in Figure 2 and Figure 3.

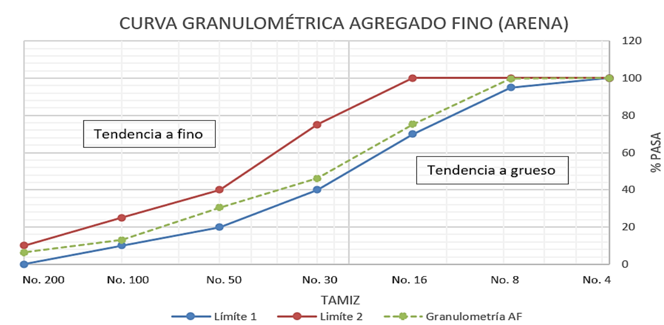

Figure 2: Granulometric curve of the sand. Source: Preparation by the authors.

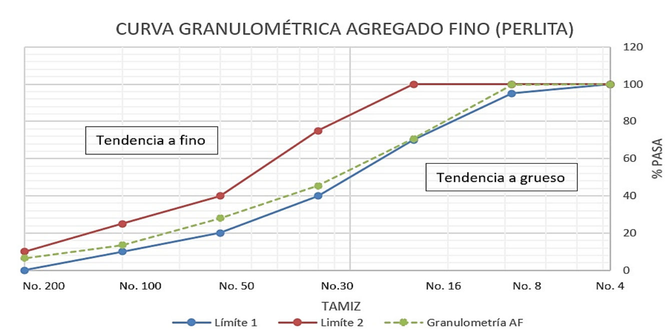

Figure 3: Granulometric curve of the perlite. Source: Preparation by the authors.

The appearance of perlite is similar to polystyrene beads (as shown in Figure 4). It is used in construction when it is necessary to improve the thermal and acoustic properties and obtain greater lightness (El Mir et al., 2020). Incorporating perlite in the mixtures allows comparing the mortar's densities to find one that is as light as possible in balance with its compressive strength.

Tests are run for sand, perlite, cement, and lime to identify their specific weight, loose and compacted density, moisture content, absorption capacity, granulometry, fineness modulus, and colorimetry. This is shown in Figure 5.

Figure 4: Perlite. Source: Preparation by the authors.

Figure 5: Laboratory tests: a) cement and lime, b) perlite, c) sand. Source: Preparation by the authors.

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The results of the tests run on the sand and perlite are shown below in Table 4.

Table 4: Physical properties of the sand and perlite. Source: Preparation by the authors.

Physical Properties Test	NTE INEN	ASTM	Sand	Perlite
Specific Weight (g/cm3)	856	C-127	2.41	1.44
Loose Density (g/cm3)	858	C-29	1.41	0.60
Compacted Density (g/cm3)	858	C-29	1.60	0.68
Moisture content (%)	862	C-127	1.04	3.39
Absorption capacity (%)	856	C-127	2.26	9.55
Fineness Modulus	2536	C-136	2.44	2.43
Colorimetry	855	C-40	WOM	WOM

WOM: Without organic matter

Using lime in mortar mixtures delays setting times and decreases its strength at early ages. For this reason, using an accelerator additive (Plastocrete 161 HE) with a density of 1.10 kg/dm^3 has been necessary. Its dosage can vary between 0.2% and 2.5% of the cement's weight and is manually added to the kneading water.

On the other hand, the rice straw used to make the panels was previously baled, and its physical properties are indicated in Table 5.

Table 5: Physical properties of straw bales. Source: Preparation by the authors.

Physical Properties	Bale
Dimensions (cm)	35x45x120
Absolute density (kg/m3)	84.00
Moisture content (%)	13.00
Weight (kg)	12.90

DESIGN OF THE MIXTURES

Two standard mix designs, SM1 and SM2 here, were made using the optimal density method. Both had a design strength of 12.40 MPa, corresponding to type S cement and lime mortars (which have better adhesion and use in coatings) according to the NTE INEN 2518 standard. Variants were generated from these base mixtures where the cement was replaced by lime in different proportions to find the optimal percentage that guarantees a minimum mechanical strength of 6.89 MPa, according to the parameters of the IRC 2018 code.

In the SM1 design, water, cement, and sand were used. In contrast, in the SM2 design, perlite was used as a fine aggregate since it has a low density, is easily accessible in the local environment, and has a cost similar to that of sand. Eight variants were obtained from each of these mixtures, where an additive was added to 4 mixtures (strength accelerator additive at 2.5% of the weight of the cement), and no additive was added to the remaining 4. In addition, cement was replaced by lime in proportions of 30%, 50%, 70%, and 90% in each group of mixtures. The methodology used to obtain the mixtures is summarized in Figure 6.

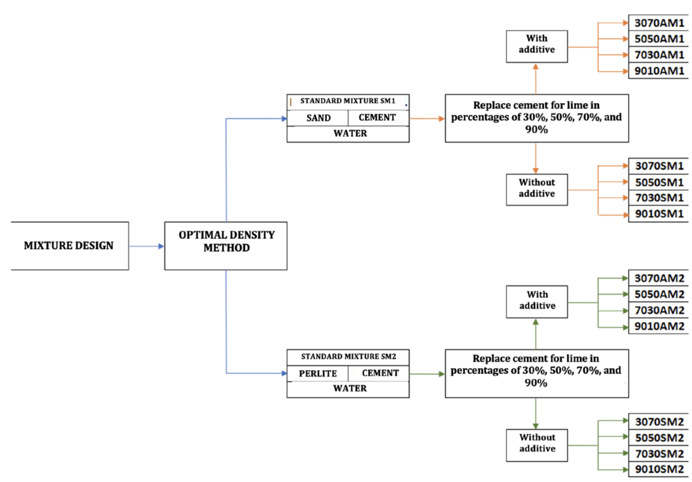

Figure 6: Methodology to obtain the mixtures. Source: Preparation by the authors. Source: Preparation by the authors.

The coding indicated in Figure 7 was used for the mixtures obtained, for example, the mixture 9010AM1.

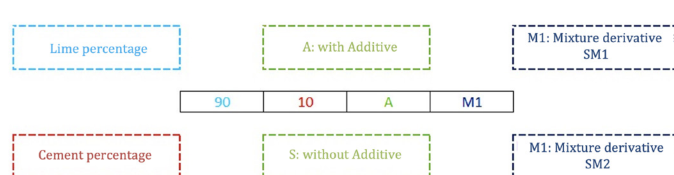

Figure 7: Coding for the study mixtures. Source: Preparation by the authors.

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Table 6: Dosage in kilograms for one cubic meter of mortar. Source: Preparation by the authors.

Id.	Lime (kg)	Cement (kg)	Fine Aggregate (kg)	Water (kg)	Additive (kg)
MP1	0.00	339.63	1446.50	392.29	0.00
9010AM1	240.17	33.96	1446.50	390.29	8.49
9010SM1	240.17	33.96	1446.50	390.29	0.00
7030AM1	186.80	101.89	1446.50	370.75	8.49
7030SM1	186.80	101.89	1446.50	370.75	0.00
5050AM1	133.43	169.82	1446.50	370.29	8.49
5050SM1	133.43	169.82	1446.50	370.29	0.00
3070AM1	80.06	237.74	1446.50	342.86	8.49
3070SM1	80.06	237.74	1446.50	342.86	0.00
MP2	0.00	523.63	552.40	404.88	0.00
9010AM2	370.28	52.36	552.40	408.31	13.09
9010SM2	370.28	52.36	552.40	408.31	0.00
7030AM2	288.00	157.09	552.40	383.05	13.09
7030SM2	288.00	157.09	552.40	383.05	0.00
5050AM2	205.71	261.82	552.40	371.62	13.09
5050SM2	205.71	261.82	552.40	371.62	0.00
3070AM2	123.43	366.54	552.40	360.20	13.09
3070SM2	123.43	366.54	552.40	360.20	0.00

The quantities in kilograms of water, cement, lime, sand, perlite, and additive for one cubic meter of mortar made with the standard mixtures SM1, SM2, and their derivatives are indicated below in Table 6.

DESCRIPTION OF THE TESTS

Mortars

All the mortars produced have a flow of 110% ± 5%, as indicated by the NTE INEN 488 standard. This property guarantees the manageability of the mixtures without generating segregation problems. Inspired by the technique used by Echeverría et al. (2022) in a similar study regarding the elaboration of sustainable panels for residential interiors through the use of banana fiber and peanut shells, 15 cubic specimens (Figure 8) of 50x50x50 mm were manufactured for each of the 18 mixtures, including the standard samples (Echeverría et al., 2022).

For this work, 270 compression tests were carried out on mortar cubes to evaluate their strength, following the guidelines established by the NTE INEN 488 standard.

Figure 8: Elaboration of cubic mortar specimens. Source: Preparation by the authors.

For each mixture, 3 test specimens were made at 1, 3, 7, 28, and 50 days. The specimens were stored in a curing chamber until they reached the specified age, following the requirements indicated in the ASTM C511 standard. Due to the presence of hydrated lime in the mortar mixtures, the test specimens were not immersed in water, but were exposed to the open air to interact with the CO_2 and then set.

The compression test of the specimens was carried out using a 200-ton universal machine (Figure 9) equipped with metal discs for an effective distribution of the load over the application area of the cube. The loading speed was 0.25 MPa/s and was controlled by an automated system.

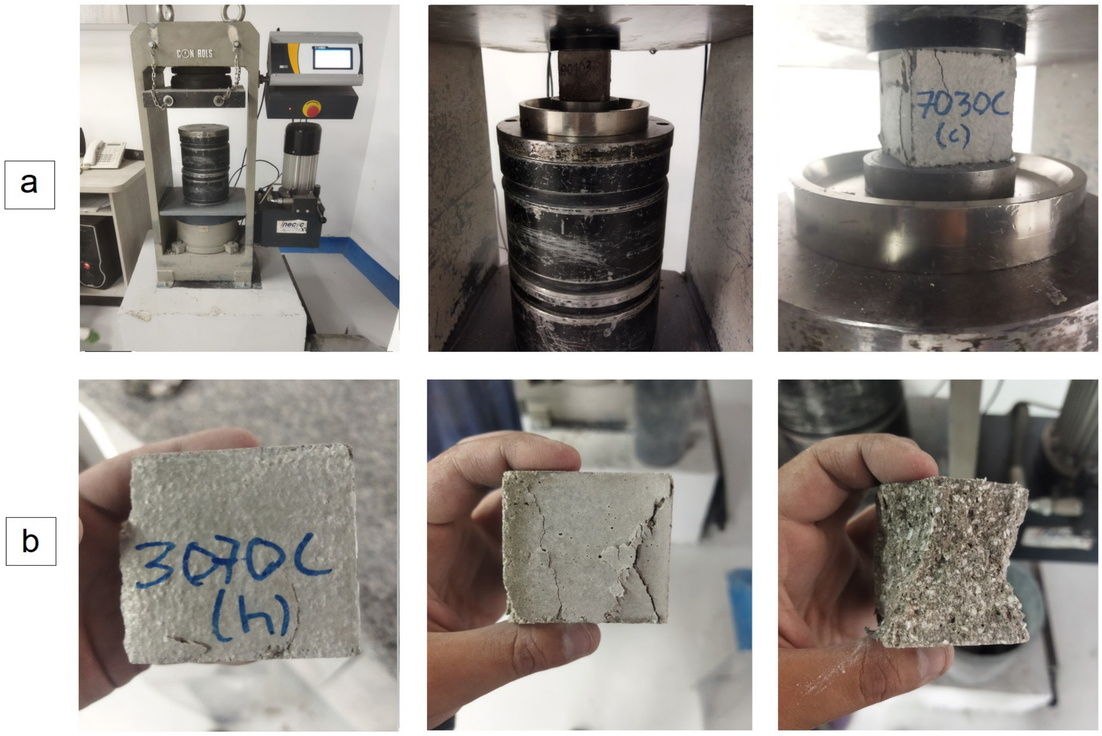

Figure 9: Compression test: a) equipment, b) cubic specimens. Source: Preparation by the authors.

Figure 10. Construction of panels Source: Preparation by the authors.

Panels

Regarding the elaboration of panels, 6 samples were built based on 1.20 m long, 1.20 m high, and 0.35 m thick straw and wooden frames. As in the previous test, the samples were divided in half, adding mortar to 3 and no mortar to the other 3 (Figure 10).

In the panels that include mortar, a 2.5 cm thick layer was applied on both sides (Figure 11), made with the 5050AM2 mixture (50% lime, 50% cement, perlite, with additive). This mixture meets the objective of this research by providing sustainability conditions and the required properties, such as strength and density.

The panels were subjected to compression tests, as shown in Figure 12, following the procedures established in the INEN-NEC-SE-MP 26-6 and ASTM C1314 standards. For the tests, a loading system consisting of a 20-ton cell and a 100-ton hydraulic cylinder controlled by a 10000Psi hydraulic pump was used. 2 LVDTs (displacement meters) were placed on the panel, connected to an 80-channel HBM UPM

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Figure 11. Application on mortar panels made with 5050AM2 mixture. Source: Preparation by the authors.

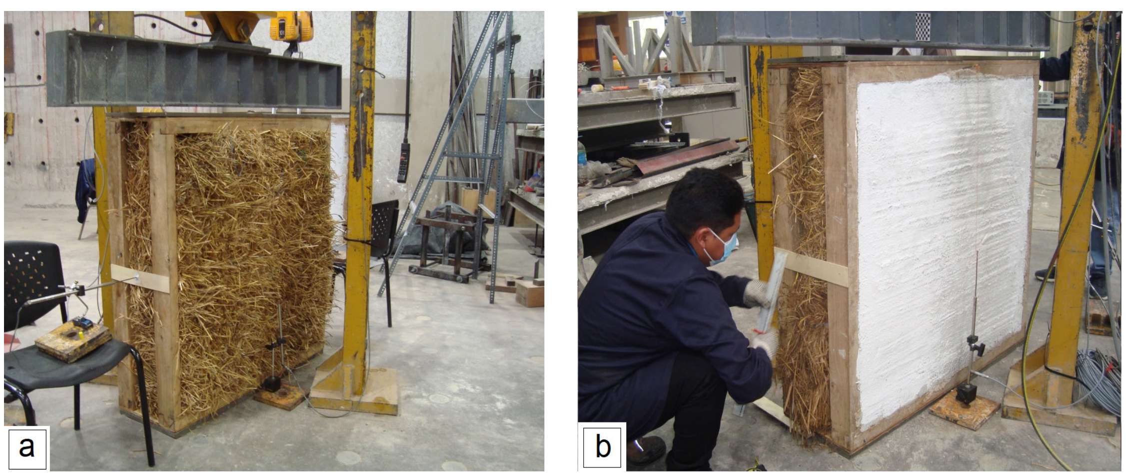

Figure 12. Compression test of panels: a) without mortar, b) with mortar. Source: Preparation by the authors.

box that records the load and displacement data. The test speed was 0.03 mm/s, as indicated in the standards.

The compression test of the panels was carried out to determine the structural capacity of the set of materials that they comprise (wooden frame, straw, and plaster), just as used in buildings. In addition, it was sought to determine whether the previously designed mortar provides strength to the panel. The axial loads applied during the test represented the dead and live loads that govern the structures. The resulting value of the panel's compressive strength will allow looking closer at the structural modeling of the constructions where this type of prefabrication is used.

RESULTS AND DISCUSSION

Figure 13 shows the compressive strength results of the mortars made from the SM1 standard mix design at different ages (1, 3, 7, 28, and 50 days). It is observed that SM1 exhibits higher compressive strength values than the other mixtures, as it contains a binder comprising 100% cement, calculated using the optimal density method. Including an additive at 2.5% of the weight of the cement in the mixtures derived from SM1 leads to an increase in its strength that varies between 20.13% and 51.52%. These findings suggest the desirability of including additives in lime mortars to reduce the setting time and achieve greater strength at an early age. In particular, the 3070AM1 mixture complies with the minimum required compressive strength of 6.89 MPa at 28 days of age, with an average strength of 7.19 MPa, exceeding the target by 0.30 MPa. This indicates its suitability to be used as plaster in buildings made with straw panels.

In addition, Figure 14 presents the compressive strength results at different ages (1, 3, 7, 28, and 50 days) of the mortars made from the SM2 standard mix design. As with SM1, the compressive strength of this mortar is superior to other mixtures due to its composition with a binder comprising 100% cement. It is important to note that this mixture contains 54% more cement than SM1, as perlite, whose density is 0.68 g/cm^3, is used as a fine aggregate. Compared to sand, whose density is 1.60 g/cm^3, a reduction of 57.5% is observed, resulting in a greater amount of paste in the mixture.

The replacement of cement by lime in SM2, in percentages of 30%, 50%, 70%, and 90%, leads to a decrease in compressive strength. As the percentage of lime in the mixture increases, and the percentage of cement decreases, the compressive strength also decreases, a behavior similar to that observed in mixtures generated from SM1. Incorporating an additive to 2.5% of the weight of the cement results in an increase in its strength that varies between 33.33% and 72.28%. In this case, the mixture that meets the minimum required compressive strength of 6.89 MPa at 28 days of age is 5050AM2, with a strength of 7.22 MPa, exceeding the target strength by 0.33 MPa. This indicates that it can also be used as plaster in buildings made with straw panels.

The results of the compressive strength at 28 days of the mortars studied in this investigation are presented in Figure 15. It is noted that there are 6 mixtures (SM1, SM2, 3070AM1, 3070AM2, 3070SM2, 5050AM2) that show a compressive strength above the required value of 6.89 MPa. The other mixtures obtained values below this threshold, so they would be discarded for use. However, of the 6 selected mixtures, two are the standard mixtures SM1 and SM2, which do not contain lime in their composition and do not meet the research objective.

Of the remaining 4 mixtures, it is observed that the mixtures 3070AM2 (30% lime, 70% cement, perlite, with additive) and 3070SM2 (30% lime, 70% cement, perlite, without additive) generate mortars with compressive strengths of 13.09 MPa and 8.90 MPa respectively, exceeding the minimum required value by 89.99% and 29.17%. On the other hand, the mixtures 3070AM1 (30% lime, 70% cement, sand, with additive) and 5050AM2 (50% lime, 50% cement, perlite, with additive) generate mortars with compressive strength of 7.19 MPa and 7.22 MPa respectively, exceeding the minimum required value by 4.35% and 4.78%. Therefore, the mixtures 3070AM2 and 3070SM2 are discarded, as their strength is well above the required one, and the mixtures 3070AM1 and 5050AM2 are accepted as preselected optimal mixtures due to their lime content and strength presented.

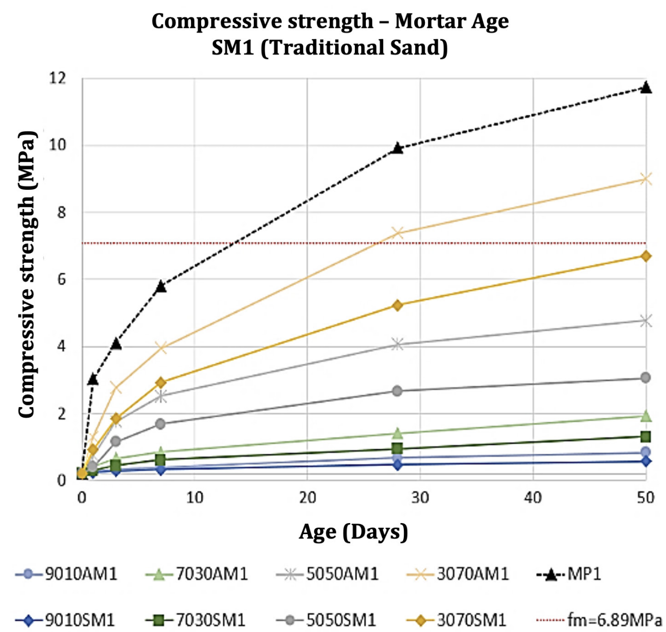

Figure 13. Compressive strength of sand-based mortars (M1). Source: Preparation by the authors.

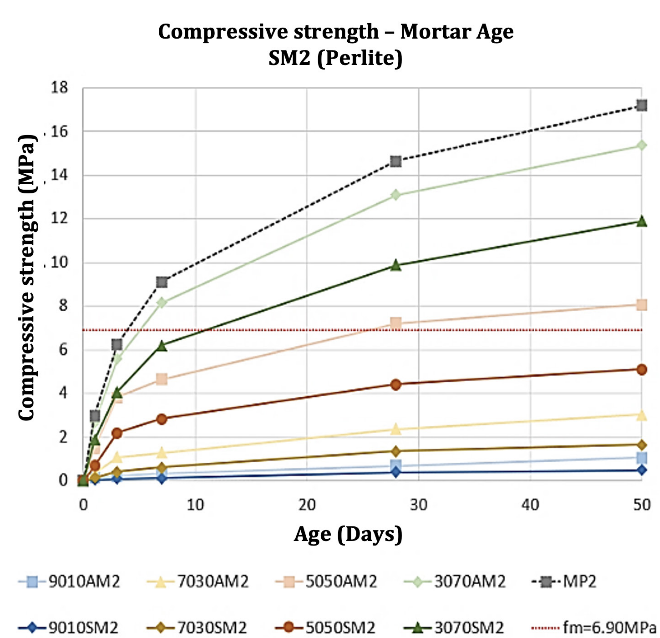

Figure 14. Compressive strength of mortars made with perlite (M2). Source: Preparation by the authors.

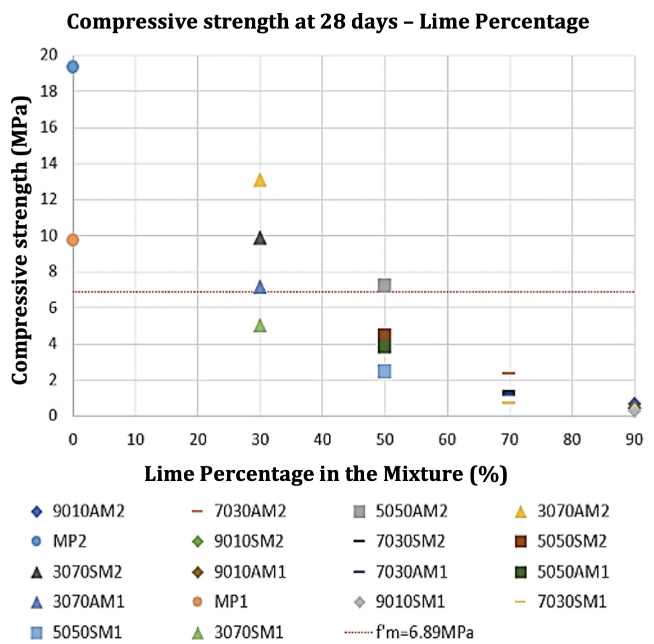

Figure 15. Compressive strength after 28 days of mortars made with sand (M1) and perlite (M2). Source: Preparation by the authors.

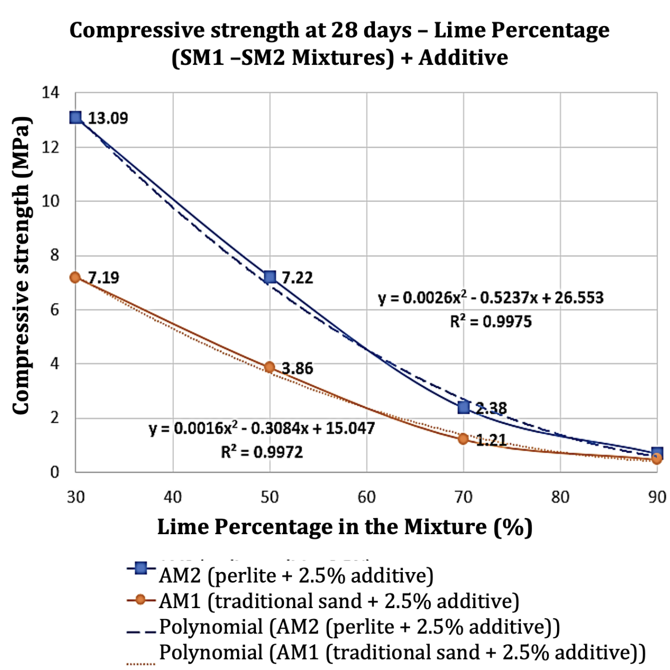

Figure 16. Polynomial adjustment compressive strength vs. percentage of lime, SM1 and SM2 mixtures with additive. Source: Preparation by the authors.

In Figure 16, the trend of the curves obtained from the results of the mixtures AM1 (cement + lime + sand + additive) and AM2 (cement + lime + perlite + additive) can be observed, which contain additives and are derived from the preselected optimal mixtures (5050AM2, 3070AM1).

Equation 1 is obtained by making the polynomial adjustment of the curves (compressive strength v/s percentage of lime). This equation allows determining the compressive strength after 28 days of mortars made from the AM1 mixture depending on the percentage of lime that is replaced by cement.

$$fm = 0{,}0016(\%limo)^2 - 0{,}3084(\%Cal) + 15{,}047$$

(Equation 1)

(Equation 2) is obtained for the AM2 mixture.

$$fm = 0{,}0026(\%limo)^2 - 0{,}5237(\%Cal) + 26{,}553$$

(Equation 2)

Where:

fm: Compressive strength in MPa.
%Lime: Percentage of lime in the mixtures replaced by cement.

The correlation coefficient (R^2), whose value for both models is 0.997, similar to 1, is determined to evaluate the validity of the equations. Therefore, both equations correctly fit the results achieved and provide very accurate estimates of compressive strength at 28 days of age to those obtained through experimentation.

Figure 17 shows the box and mustache diagrams made from the results of the densities of the mortars manufactured with the preselected optimal mixtures 5050AM2 and 3070AM1. The values of the densities were taken in cubic specimens of 50 mm at 1, 3, 7, 28, and 50 days. 6 specimens were made by age, obtaining density values for 60 mortar cubes, i.e., 30 values for each mixture.

The mortars manufactured with the 5050AM2 mixture have density values ranging between 1.34 g/cm³ as a minimum value and 1.55 g/cm³ as a maximum value, with an average density of 1.45 g/cm³. On the other hand, the mortars manufactured with the 3070AM1 mixture have densities ranging between 1.85 g/cm³ as a minimum value and 2.02 g/cm³ as a maximum value,

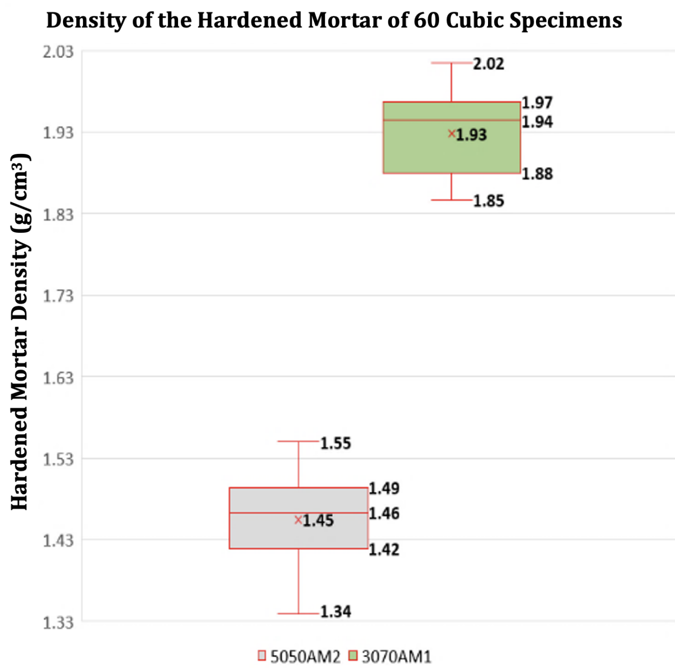

Figure 17. Densities of mortars made with the 5050AM2 and 3070AM. Source: Preparation by the authors.

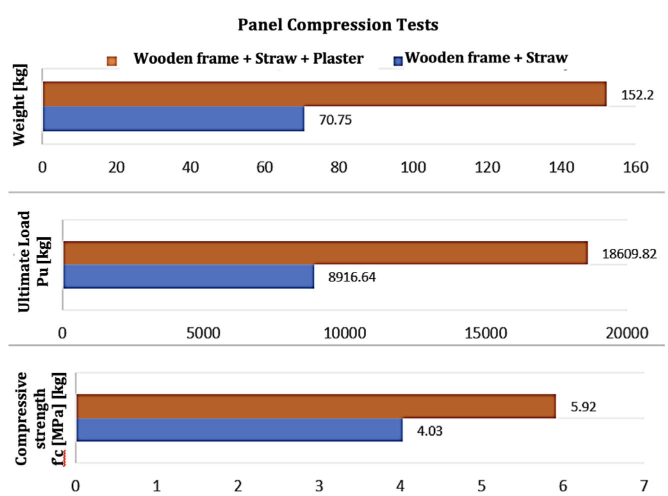

Figure 18. Results obtained from the compression test on panels with and without plaster. Source: Preparation by the authors.

higher than those obtained with the 5050AM2 mixture, as the average density is 1.93 g/cm^3. In this sense, the final mixture chosen as plaster in the panels with straw is the 5050AM2, which has a lower density.

The results of the weight, ultimate load, and compressive strength of the straw and wooden frame panels are shown in Figure 18. The weight of the panel with plaster is 152.20 kg, while without plaster, it is 70.75 kg, which indicates that the plaster adds more weight to the panel. As for the ultimate load, the panel with plaster has a value of 18609.82 kg, while without plaster, this value decreases to 8916.64 kg. Finally, a maximum compression strength of 5.93 MPa is obtained when the panel is plastered and a value of 4.03 MPa if it is not. Therefore, the plaster or coating mortar increases the ultimate load and provides greater strength to the panel.

CONCLUSIONS

After analyzing the results, it can be concluded that, on the one hand, using accelerator additives in lime-containing mixtures is beneficial, as a higher efficiency is demonstrated by using perlite as a fine aggregate. The low density of the perlite allows a greater amount of binder in the mixtures and, therefore, a greater amount of additive. In addition, it allows reducing the density of mortars by up to 24.87%, compared to those mortars where sand is used as fine aggregate.

Thus, it is found that mixtures made with perlite have better compressive strengths than those containing sand, given the high absorption capacity of perlite, which contributes to reducing lime setting times by absorbing kneading water quickly, unlike sand, which does not have this property.

The 5050AM2 mixture (50% lime, 50% cement, perlite, with additive) turned out to be the optimal one for the manufacture of a mortar, as it meets the minimum required strength of 6.89 MPa (according to the IRC 2018) to be used as a coating on straw walls. This mixture contains a greater amount of lime. It allows obtaining mortars with a compressive strength of 7.22 MPa after 28 days, with a density of 1.45 g/cm^3, lower than the characteristic density of conventional mortars.

In terms of the dosage of the 5050AM2 mixture (50% lime, 50% cement, additive, and perlite), for one cubic meter of low-density mortar to be used as a coating on straw walls, 205.71 kg of lime, 261.82 kg of cement, 552.50 kg of perlite, 371.72 kg or liters of water and, finally, 13.09 kg of additive are required.

In conclusion, the findings of this research support the suitability of the coating mortar made with the 5050AM2 mixture (50% lime, 50% cement, perlite, with additive). When applied on both sides of the panel, it protects and controls the humidity inside it and increases the ultimate load and compressive strength up to 47.91% and 68.07%, respectively.

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