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Experimental study of air lime and hydraulic lime mortar coatings with additives for capillary moisture control in historic buildings.

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ABSTRACT

One of the most common issues in brick masonry walls of Cultural Heritage buildings is the deterioration caused by rising damp through capillarity. Traditionally, these walls have been coated with air lime mortar, but hydraulic lime mortar with additives is now being used to improve drying in cases of capillary moisture. This experimental study aims to identify the behavioral differences between air lime and hydraulic lime coatings with additives in terms of moisture absorption and drying. Tests were conducted on brick and mortar samples coated with both types of mortar. The results showed that the samples treated with hydraulic lime with additives absorbed less water and presented a better visual appearance than those coated with air lime, despite having similar water content. This study contributes to selecting more effective materials for the preservation of historic buildings affected by capillary moisture, improving their durability and aesthetic.

Keywords: brick; Cultural Heritage; rising damp; render; rehabilitation.

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Estudio experimental de revestimientos de mortero de cal aérea e hidráulica con aditivos para el control de la humedad capilar en edificios históricos.

RESUMEN

Uno de los problemas más comunes en los muros de ladrillo de tejar del Patrimonio Cultural es el deterioro causado por la humedad ascendente por capilaridad. Tradicionalmente, estos muros han sido revestidos con mortero de cal aérea, sin embargo, se ha empezado a utilizar mortero de cal hidráulica con aditivos para mejorar el secado en casos de humedad capilar. Este estudio experimental tiene como objetivo identificar las diferencias en comportamiento entre revestimientos de cal aérea y cal hidráulica con aditivos en términos de absorción y secado de humedad. Se llevaron a cabo ensayos en probetas de ladrillo y argamasa revestidas con ambos tipos de mortero. Los resultados mostraron que las probetas tratadas con cal hidráulica con aditivos absorbían menos agua y presentaban un mejor aspecto visual que las revestidas con cal aérea, a pesar de mantener un contenido de agua similar. Este estudio contribuye a la selección de materiales más eficaces para la conservación de edificios históricos afectados por humedad capilar, mejorando su durabilidad y estética.

Palabras clave: ladrillo; Patrimonio Cultural; humedad capilar; revoco; rehabilitación.

Estudo experimental de revestimentos de argamassa de cal aérea e hidráulica com aditivos para o controle da umidade capilar em edifícios históricos.

RESUMO

Um dos problemas mais comuns nas paredes de tijolo do Patrimônio Cultural é o desgaste causado pela umidade ascendente por capilaridade. Tradicionalmente, essas paredes foram revestidas com argamassa de cal aérea, no entanto, a argamassa de cal hidráulica com aditivos começou a ser utilizada para melhorar a secagem em casos de umidade capilar. Este estudo experimental tem como objetivo identificar as diferenças de comportamento entre revestimentos de cal aérea e cal hidráulica com aditivos em termos de absorção e secagem de umidade. Foram realizados ensaios em amostras de tijolo e argamassa revestidas com ambos os tipos de argamassa. Os resultados mostraram que as amostras tratadas com cal hidráulica com aditivos absorviam menos água e apresentavam um melhor aspecto visual do que as revestidas com cal aérea, apesar de manterem um teor de água semelhante. Este estudo contribui para a escolha de materiais mais eficazes para a conservação de edifícios históricos afetados pela umidade capilar, melhorando sua durabilidade e estética.

Palavras-chave: tijolo; Património Cultural; humidade ascendente; reboco; reabilitação.

1. INTRODUCTION

One of the most common issues in historical buildings constructed with handmade fired bricks is rising damp caused by capillarity, which originates from the ground and severely affects their conservation. The foundations of these buildings, composed of masonry, lime, and infill materials, are not entirely impermeable, allowing water to rise through the porous materials, such as brick. This phenomenon worsens when the building's surroundings are urbanised, raising the level of the external pavement and using impermeable materials. In such cases, groundwater rises through the most porous materials, facilitating its spread through the brick walls. When the brick walls are coated with aerial lime mortar, the render gradually deteriorates. In the initial stages, moisture stains and efflorescence often appear, caused by the crystallisation of salts on the surface. Over time, the render may start to detach, accelerating the decay of the brickwork. In response to this issue, one of the current solutions is to replace the aerial lime render with hydraulic lime mortars that have greater porosity and larger pores. These mortars allow the moisture present in the walls to evaporate more easily, while also maintaining a better appearance on the rendered façades. Previous studies have shown that the characteristics of the render mortar play a crucial role in the height of rising damp and the subsequent amount of evaporation (Fassina et al., 2002; Silva et al., 2015). As a result, hydraulic lime mortars with additives such as lapilli, volcanic ash, or even gypsum, are increasingly being used in the restoration of historical buildings (Durán-Suárez et al., 2018). To evaluate the behaviour of these macroporous renders and compare them with traditional aerial lime renders, experimental tests were carried out on brick samples with both types of render, as well as on unrendered bricks. The results showed that in the water absorption tests from the base, the samples coated with aerial lime mortar absorbed a significantly greater amount of water compared to those coated with macroporous hydraulic lime mortar. However, the core of the brick, both in samples coated with aerial lime and with hydraulic lime, showed similar levels of absorbed water. Regarding the drying process, once the samples were saturated, both types of mortar displayed similar behaviour (Camino-Olea et al., 2024). However, it is important to note that these results obtained in the laboratory could vary under real conditions, where the proportion of brickwork and rendered surface is different. In order to further explore the behavioural differences between the two types of render, additional tests (Prado Govea et al., 2009) were conducted on samples of aerial lime mortar and hydraulic lime with additives. The results of these tests are presented in this study, contributing to a better understanding of the behaviour of these materials and their effectiveness in conserving historical buildings affected by rising damp.

2. MATERIALS AND METHODS

This study evaluates two types of lime mortar for brick masonry rendering: a traditional lime mortar made with aerial lime and sand, and an industrial pre-dosed hydraulic lime mortar with additives, with the following characteristics:

- **Aerial lime mortar with sand,** composed of calcium hydroxide CL-90 S, washed river sand (0-4 mm, granulometry according to UNE-EN 933-1, 1999), and water in a 1/3/2 ratio, manually prepared in the laboratory.
- **Hydraulic lime mortar,** an industrial, pre-dosed mortar made with natural hydraulic lime, pozzolanic fillers, selected aggregates, and special additives. It contains an air-entrained proportion of >30% according to UNE-EN 1015-7 (1999). It is classified as R (rendering/plastering mortar for renovation, UNE-EN 998-1, 2018).

In order to determine their water-related characteristics, various tests were conducted on samples with both types of mortar: cubic samples of 40 mm (Figure 1) and prismatic samples of 160x40x40 mm (Figure 2).

The cubic samples were subjected to two specific tests for cultural heritage conservation:

- The **water absorption by capillarity test** was performed on 40 mm cubic samples following the procedure of UNE-EN 15801 (Aenor, 2010). This test measures the rate and quantity of water absorbed by capillarity through the base of the samples. A saturated permeable bed was used to analyse the behaviour of both types of mortar (Figure 1).
- The **drying test,** based on UNE-EN 16322 (Aenor, 2016), evaluated the drying capacity of the saturated samples of both mortars. The weight loss was measured in two phases: capillary rise over 24 hours, followed by immersion until a constant weight was reached.

To prevent desorption, the lateral faces of the samples were sealed, leaving only the top face and the base exposed.

Both tests were carried out simultaneously on twelve aerial lime samples and twelve hydraulic lime samples, under controlled laboratory conditions, temperature between 20 and 22°C and 40-50% HR.

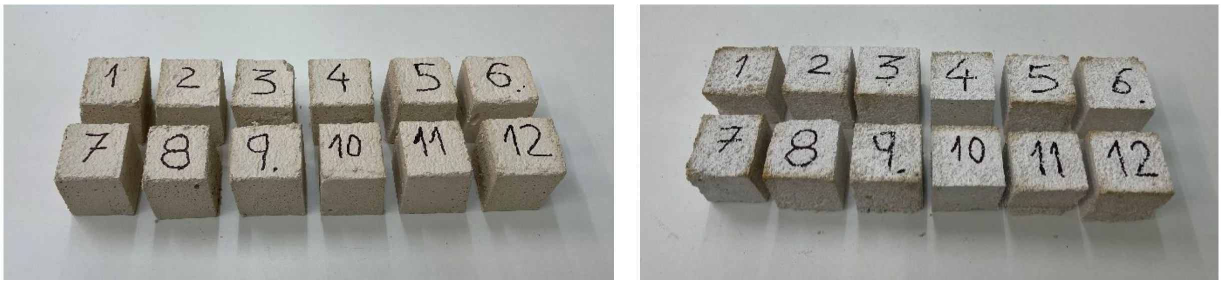

Figure 1. Cubic mortar samples of hydraulic lime and aerial lime.

The prismatic samples were subjected to various tests following the standards for hardened mortar testing:

- The **Water Absorption Test** was conducted on 160x40x40 mm prismatic samples, according to UNE-EN 1015-18 (Aenor, 2003), to determine the water absorption coefficient by capillarity in hardened mortars. In this test, the samples were dried to constant mass before submerging one face in water and measuring the increase in mass (Figure 2).

This test was performed on six samples of aerial lime mortar and six samples of hydraulic lime mortar under the same laboratory temperature and humidity conditions as the previous tests.

Figure 2. Prismatic mortar samples. On the left, aerial lime samples; on the right, hydraulic lime samples.

Finally, tests were conducted on 30x30x20 mm samples to determine porosity using mercury intrusion. Cubic pieces of 10 mm were cut from each mortar for this purpose, and although their small size may not fully represent the complete mortar, the results obtained provide valuable information about their porous behaviour (Figure 3).

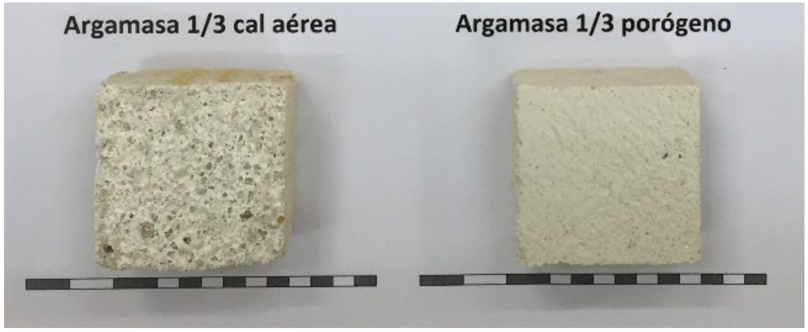

Figure 3. Mortar samples used for the porosimetry test.

3. RESULTS

After obtaining the results from the various tests, a thorough comparison of the values was carried out to evaluate the behavioural differences between the two types of mortar, as previously observed in the coating tests on brick samples. This comparison allowed for the identification of clear patterns in the mortars' behaviour under absorption and drying conditions, providing a more accurate understanding of their effectiveness in coating applications for historic buildings.

3.1 Absorption tests on cubic samples

The results of the absorption test are shown in Figure 4 and Table 1.

These results show the hydraulic lime mortar have a significantly lower absorption rate (0.0080 Kg/m²·s^1/2) when compared to the aerial lime mortar, which has a much higher absorption rate of 0.3348 Kg/m²·s^1/2. This substantial difference highlights the slower rate at which hydraulic lime absorbs water compared to the highly permeable aerial lime. The low absorption rate of hydraulic lime is a key characteristic that contributes to its durability and resistance to water ingress, making it more suitable for heritage preservation where controlling moisture is crucial.

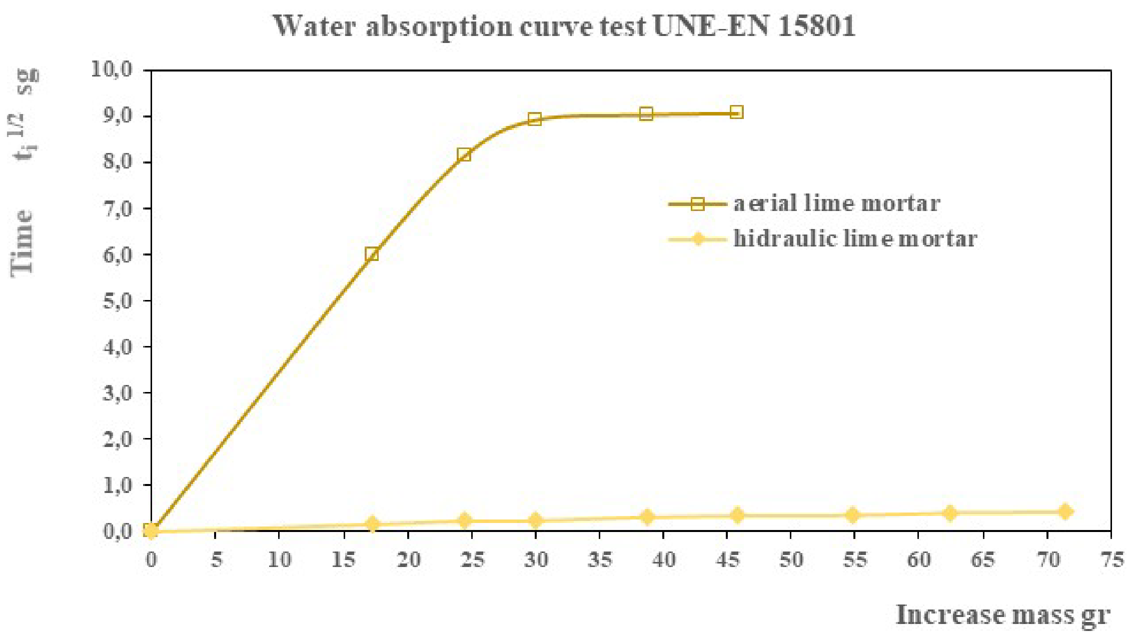

Figure 4. Average results of the absorption test measurements on aerial lime and hydraulic lime mortar samples.

When analyzing the percentage of water absorbed by weight, the contrast becomes even more evident. The hydraulic lime mortar absorbs only 0.72% of its weight in water, with a small standard deviation of 0.07%. In contrast, the aerial lime mortar absorbs 13.05% of its weight in water, with a standard deviation of 0.12%. This indicates that hydraulic lime not only absorbs significantly less water but also shows more consistent performance, reducing the risk of water damage over time.
Table 1 shows the average values of the absorption rate in $kg/m^2·s^{½}$, water absorption, and the time until the samples stop absorbing water from the base for both types of samples.

Table 1. Absorption test results

Mortar	**Absorption rate** $Kg/m^2·sg^{1/2}$	**Standard deviation**	**Absorption (% by weight)**	**Standard deviation**	**Time H min**
Hidraulic lime	0,0080	0.0009	0.72%	0.07%	1h 25 min
Aerial lime	0,3348	0.0133	13,05%	0.12%	25 min

In terms of the time taken for the mortars to stop absorbing water, hydraulic lime takes considerably longer, with a total time of 1 hour and 25 minutes, compared to just 25 minutes for aerial lime. This prolonged absorption time of hydraulic lime reflects its slower water uptake but also suggests better control over moisture regulation in wall structures, which is especially important in historic buildings where maintaining controlled humidity levels is essential for long-term preservation.

3.2 Drying tests on cubic samples

The results of the drying test are shown in Figure 5 and Table 2.
In this case, the hydraulic lime mortar has a drying rate of 0.229 $Kg/m^2·h^{1/2}$, which is significantly higher than the drying rate of the aerial lime mortar, which is 0.114 $Kg/m^2·h^{1/2}$. This indicates that hydraulic lime dries more quickly than aerial lime.

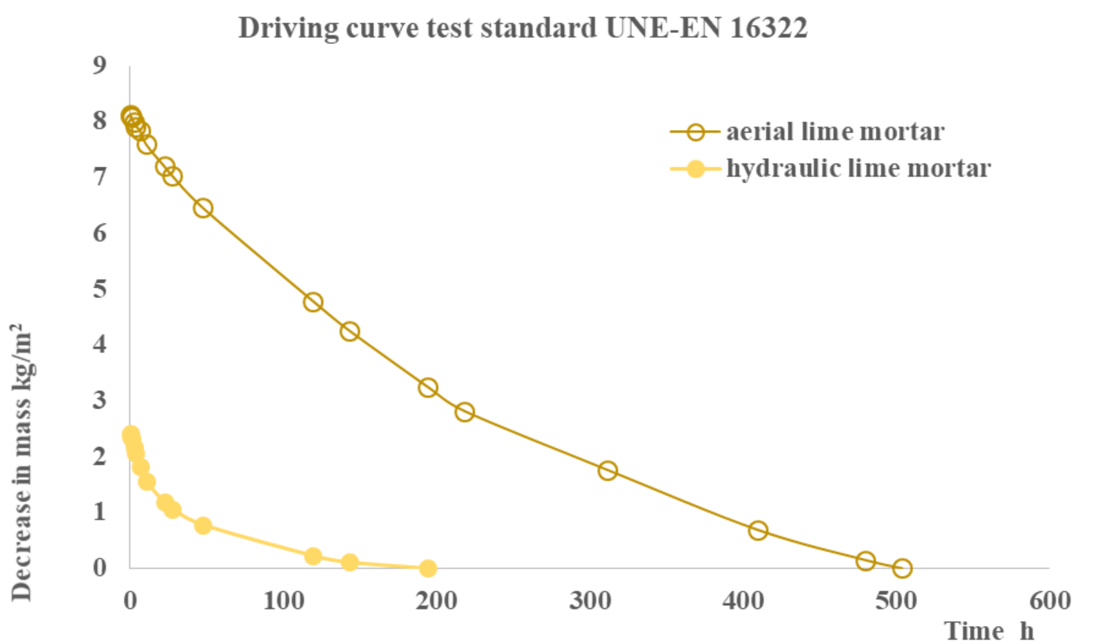

Figure 5. Average result of the measurements from the drying test on the air lime and hydraulic lime mortar specimens.

Table 2 shows the average values for both types of samples, including the mass loss during drying over time in square root hours.

Table 2. Drying test results

Mortar	Drying rate D1 $Kg/m^2 \cdot h^{1/2}$	Standard deviation
Hidraulic lime	0,229	0,018
Aerial lime	0,114	0,017

Both mortars have a relatively small standard deviation in their drying rates (0.018 for hydraulic lime and 0.017 for aerial lime), indicating consistent performance in both types of mortar. This suggests that both materials behave reliably during the drying process, with minimal variation between different test samples.

3.3 Absorption tests on prismatic samples

The results of the tests on prismatic samples, carried out according to the UNE-EN 1015-18 standard procedure, are presented in Table 3.

Table 3. Results absorption test

Mortar	Water absorption coefficient Kg $(m^2 \cdot min^{0,5})$	Standard deviation
Hidraulic lime	0.34	0.17
Aerial lime	1.52	0.18

The coefficient of water absorption for hydraulic lime mortar is 0.34 kg $(m^2 \cdot min^{0.5})$, which is significantly lower than that of aerial lime mortar, which has a value of 1.52 kg $(m^2 \cdot min^{0.5})$. This indicates that hydraulic lime mortar absorbs water much more slowly compared to aerial lime mortar, which absorbs water at a higher rate. The lower absorption coefficient of hydraulic lime suggests its superior resistance to water penetration, making it a better choice for applications where moisture resistance is a key factor, such as in environments prone to high humidity or direct water exposure.

3.4 Mercury intrusion porosimetry tests

The results of the porosimetry test are shown in Figure 6 and Table 4, where the obtained data is presented. The average pore diameter for hydraulic lime is 1.2082 µm, while for aerial lime, it is 1.0422 µm. The slightly larger pore diameter in hydraulic lime expose that it may have a more open, macroporous structure compared to aerial lime. At the same time, the apparent density of hydraulic lime is 1.7147 g/ml, slightly lower than that of aerial lime, which has a density of 1.8247 g/ml.

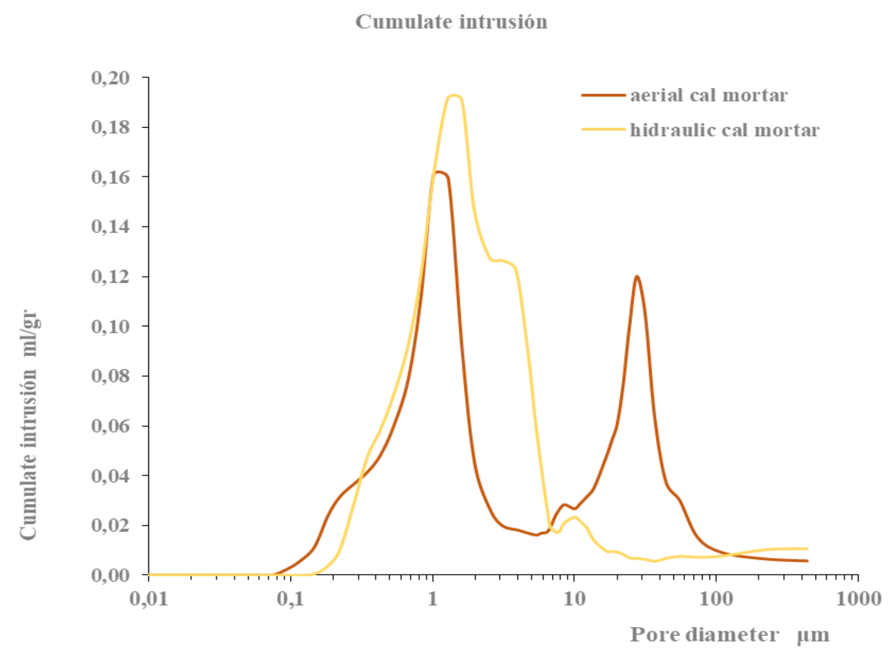

Figure 6. Pore diameter results of the samples.

Table 4. Average pore diameter, apparent density and porosity of the samples

Mortar	Average pore diameter (µm)	Apparent density (g/ml)	Porosity %
Hidraulic lime	1,2082	1,7147	29,72%
Aerial lime	1,0422	1,8247	28,04%

4. DISCUSSION

By analyzing the results of the tests conducted on the mortar samples used for the coating of masonry, following heritage conservation standards, a notable difference in water absorption between the two types of mortars was observed.
In the capillary water absorption test, conducted according to the UNE-EN 15801 standard, the air lime samples absorbed 13.0% of water by mass, while the hydraulic lime samples only absorbed 0.7%. Furthermore, the absorption rate in the hydraulic lime samples was 0.0075 $kg/m^2 \cdot s$ ½, compared to 0.3348 $kg/m^2 \cdot s$ ½ in the air lime samples. This behavior was replicated in the hardened mortar water absorption test, following the UNE-EN 1015-18 standard, where the air lime samples showed an absorption coefficient of 1.52 $kg/m^2 \cdot min$ 0.5, whereas the hydraulic lime samples had a considerably lower value of 0.34 $kg/m^2 \cdot min$ 0.5. These results show that, although different testing methods were used, the air lime samples absorbed a significantly greater amount of water at a faster rate compared to the hydraulic lime samples.
Regarding the drying process, conducted similarly to the UNE-EN 16322 standard, the air lime samples exhibited a higher drying rate, although it took them longer to complete the process—20 days compared to 8 days for the hydraulic lime samples. However, this behavior should be interpreted considering that the air lime samples had absorbed 13.8% of their mass during the absorption process and immersion in water, compared to 4.8% absorbed by the hydraulic lime samples. When comparing drying rates, the air lime samples showed a value of 0.082 $kg/m^2 \cdot h$ ½, slightly higher than the 0.052 $kg/m^2 \cdot h$ ½ of the hydraulic lime samples, although the difference in

this case was smaller than in the absorption process.
Finally, the results from the porosimetry test indicated that the average pore size is larger in the hydraulic lime samples, which is consistent with the presence of additives in this mortar, designed to generate macropores, a characteristic well-known in hydraulic lime mortars.

5. CONCLUSIONS

The main conclusions of the study are as follows:

- The tests conducted on the samples of the two types of mortar coatings, in accordance with heritage conservation standards and the characteristics of hardened mortar, reveal that the water absorption in the hydraulic lime mortar samples with additives is significantly lower compared to the air lime samples.
- Regarding water absorption, it is confirmed that the hydraulic lime mortars exhibit minimal water absorption, with a considerably slower absorption process. During drying, the hydraulic lime samples reach dehydration faster, although they start with a significantly lower amount of water (between 4.8% and 13.8%).
- Regarding the rate of water absorption and desorption, it is observed that the values are always higher in the air lime samples compared to the hydraulic lime ones. These results are consistent with those obtained in previous studies on brick samples coated with different types of mortars (Camino-Olea, M.S. et al., 2024). In these studies, it was concluded that one of the main advantages of macroporous hydraulic lime coatings, in addition to their better aesthetic preservation, is their ability to absorb significantly less water compared to traditional air lime coatings.

The final conclusion of this study confirms that the hydraulic lime mortar samples have significantly lower water absorption compared to the air lime samples, highlighting the efficiency and advantages of hydraulic lime in terms of durability and behavior against moisture.

6. ACKNOWLEDGMENTS

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7. REFERENCES

Aenor (1999), *UNE-EN 1015-7:1999 Métodos de ensayo de los morteros para albañilería. Parte 7: Determinación del contenido en aire en el mortero fresco.*

Aenor (2003), *UNE-EN 1015-18 Métodos de ensayo de los morteros para albañilería. Parte 18: Determinación del coeficiente de absorción de agua por capilaridad del mortero endurecido.* España.

Aenor (2010), *Norma UNE-EN 15801 Conservación del patrimonio cultural. Métodos de ensayo. Determinación de la absorción de agua por capilaridad*. España

Aenor (2012), *Norma UNE-EN 933-1 para las propiedades geométricas de los áridos. Parte 1: Determinación de la distribución del tamaño de partícula. Método de tamizado.*

Aenor (2016), *UNE-EN 16322 Conservación del patrimonio cultural. Métodos de ensayo. Determinación de las propiedades de secado*. España.
Aenor (2018), *Norma UNE-EN 998-1 Especificación para mampostería con mortero. Prt1: Mortero de enlucido y enlucido.*
Camino-Olea, M. S., Cabeza-Prieto, A., Sáez-Pérez, M. P., Llorente-Álvarez, A., Rodríguez-Esteban, M. A. (2024). *Ocena zachowania macroporowatej powłoki zaprawowej w odniesieniu do podciągania kapilarnego.* Inżynieria Mineralna, 2.
Durán-Suárez, J. A., Sáez-Pérez, M. P. (2018). *Characterization of Classical Construction Materials used in Ethiopian Architecture for the Restoration of their Historic and Artistic Heritage*. International Journal of Architectural Heritage. https://doi.org/10.1080/15583058.2018.1489014.
Fassina, V., Favaro, M., Naccari, A., & Pigo, M. (2002). *Evaluation of compatibility and durability of a hydraulic lime-based plaster applied on brick wall masonry of historical buildings affected by rising damp phenomena.* Journal of Cultural Heritage, 3(1), 45-51. https://doi.org/10.1016/S1296-2074(02)01158-5.
Prado Govea, R. H., Louis Cereceda, M., Spairani-Berrio, Y., Huesca Tortosa, J. A. (2009). *Estudio y caracterización de morteros para la restauración arquitectónica.*
Silva, B. A., Pinto, A. F., & Gomes, A. (2015). *Natural hydraulic lime versus cement for blended lime mortars for restoration works.* Construction and Building Materials, 94, 346-360. http://dx.doi.org/10.1016/j.conbuildmat.2015.06.058.