BILINGUAL PUBLISHING GROUP

Journal of Building Material Science

https://journals.bilpubgroup.com/index.php/jbms

ARTICLE

Impact of Natural Fiber and Fatty Acid Organic Additives on the Permeability of Lime Mortars for Architectural Conservation

Parsa Pahlavan

Department of Architecture, Faculty of Architecture and Urbanism, Ferdowsi University of Mashhad, Mashhad 9177948974, Iran

ABSTRACT

Lime mortars have a rich history of being blended with organic additives to address weaknesses such as low setting time and hydric properties. This study specifically investigates the impact of incorporating straw and sesame oil into lime mortar mixes, focusing on their influence on open porosity, permeability, water absorption, and durability. While previous studies explored the effects of natural fibers and fatty acid additives on lime mortars separately, this study examines their simultaneous incorporation in mortars. The results demonstrated that the simultaneous addition of sesame oil and straw decreased the water absorption values of the mortars to 77%. Furthermore, the inclusion of sesame oil resulted in a significant 30% increase in impermeability values. However, when both sesame oil and straw were added together, the increase in impermeability was less than 20% compared to the reference mortar with no additives. These findings highlights that the combined addition of sesame oil and straw has a lesser impact on the permeability values of mortars, which is a positive outcome, as maintaining optimal permeability is essential for the long-term preservation of historical substrates. The combination of straw and sesame oil enhances hydric properties without undermining the mortar's structure and permeability. These results emphasize the sustainable nature of lime mortars in restoration projects, showcasing their compatibility with traditional masonry practices. By combining natural fibers with fatty acids, mortars demonstrate improved durability, offering a promising avenue for enhancing performance while retaining essential properties.

Keywords: Air Lime; Reinforced Lime Mortars; Natural Fibers; Restorative Mortars; Permeability

*CORRESPONDING AUTHOR:

Parsa Pahlavan, Department of Architecture, Faculty of Architecture and Urbanism, Ferdowsi University of Mashhad, Mashhad 9177948974, Iran; Email: parsa.pahlavan@um.ac.ir

ARTICLE INFO

Received: 15 December 2024 | Revised: 20 January 2025 | Accepted: 27 January 2025 | Published Online: 28 February 2025

DOI: https://doi.org/10.30564/jbms.v7i1.8084

CITATION

Pahlavan, P., 2025. Impact of Natural Fiber and Fatty Acid Organic Additives on the Permeability of Lime Mortars for Architectural Conservation. Journal of Building Material Science. 7(1): 20–29. DOI: https://doi.org/10.30564/jbms.v7i1.8084

1. Introduction

Repointing with restorative mortars stands out as one of the pivotal and frequently employed practices in the conservation of the built environment. The compatibility of lime-based mortars in the restoration of a substantial portion of our built heritage has been substantiated by both contemporary and historical studies [1]. This can be attributed to a range of properties, including moderate stiffness, reversibility, and high permeability [2–6].

Historically, lime mortars have commonly been strengthened with natural fibers like straw and wood to enhance their resistance to breakage. Improvement of some characteristics, such as enhanced resistance to deformation, achieved by incorporating various types of fibers in equal proportions could be generally observed [3]. Throughout history, lime has played a significant role in construction practices, with its peak usage observed prior to the 18th century before being gradually replaced by hydraulic limes and eventually ordinary Portland cement (OPC) binders [4, 5]. The incompatibility issues often associated with OPC binders have rendered them unsuitable for the repair and restoration of old buildings, particularly historical structures. In contrast, lime mortars demostrated that chemical, physical, and mechanical compatibility with historical masonries due to their permeability and moderate compressive strength.

Natural fibers have been incorporated into historical mortars, primarily to control shrinkage and reduce cracking. However, their addition could also lead to significant changes in the various characteristics of these mortars. Research indicates that incorporating fibers into lime mortars can significantly alter their permeability characteristics. Specifically, studies have shown that the addition of polypropylene micro-fibers reduces the permeability coefficient across various binder types, including hydraulic lime mortars [6]. To enhance the properties of lime mortars, various organic additives such as cheese, egg, and fatty substances have been historically incorporated into the mixtures to improve characteristics like setting time, adhesion, impermeability, hardness, and porosity. Moisture-related durability concerns in building materials have prompted the addition of fatty organic additives to lime mortars to enhance their hydric properties, with studies showcasing the hydrophobic effects achieved through the use of oils in lime mortar formulations [7–10]. Extensive research has been conducted to improve the hydric properties of lime mortars due to the significant role water plays in decay mechanisms. Recent studies have once again confirmed that the historical practice of incorporating various fatty organics into lime mortar mixes can enhance these properties. For example, adding oils like linseed and ghee has been found to notably improve the hydric characteristics of lime mortars, especially when exposed to realistic environmental conditions that are more favorable than controlled laboratory settings [8]. However, these studies also highlight several drawbacks associated with oiled mortars, including reductions in permeability and delays in setting times. Furthermore, historical practices have included the use of straw and other natural fibers to mitigate shrinkage in mortars. Despite this knowledge, the simultaneous use of multiple additives such as oils and straw requires further investigation to accurately assess their combined effects on mortar performance [9, 10].

By exploring the feasibility and compatibility of utilizing waste-based lime mortars with hydrophobic properties for rendering applications in historic buildings, this study aims to provide insights into the role of waste additives in enhancing the hydrophobicity, performance, and durability of lime-based mortars compared to traditional rendering materials.

This study focuses on examining the synthesis of lime mortars with straw addition and assessing its permeability after 3 months curing period from mortar preparation. Many studies have focused on effect of natural fibers additions on lime mortars, but a few have examined the effect if these additions on permeability values in presence of additive oils. Hence, permeability of reinforced lime mortars is the main goal of this paper.

2. Materials and Methods

A lime putty characterized by high calcium content (calcium hydroxide), comprising 49 weight percent water, was produced using distilled water and micronized high calcium powder sourced as a commercial product (with $Ca(OH)_2$ content ranging between 90% and 93%). The slaking process spanned three months, and the resulting lime putty is classified as CL 90S in accordance with EN 459-1 standards [11]. The non-reactive component of the mortars consisted of a blend of various stone powders, including sandstone and sedimentary carbonate rocks, characterized by a particle size of approximately 10 µm as determined by laser granulometry. The straw was added to the mixes as additives in 1.5% by mortar volume, from Khorasan region. The addition of straw to lime mortars is frequently recommended at a rate of 1.5% of the mortar's volume, supported by various studies that identify this as the optimal amount. This practice has historical significance, as straw has been employed to improve the performance of lime mortars, particularly their resistance to environmental issues like shrinkage and cracking [12].

To assess the potential hydric improvements of mortars incorporating organic fatty acids with opted unsaturation level in form of linseed oil were added to the mixtures. Previous research has shown that increasing the unsaturation level of fatty acids in oils added to lime mortars enhances the hydrophobicity of the final product [13, 14]. The oil was incorporated into the mixtures at a rate of 1.5 wt.%, in line with the optimal addition levels recommended in the literature [15].

The preparation of mortar samples involved 4 main sets, distinguished by the type of lime putty used (simple/reinforced/oiled). In the laboratory, the dry mixture was blended with a small mortar mixer to replicate on-site conditions accurately. The abbreviated sample names, denoted as AL (air lime) and RL (reinforced Air Lime), OL (oiled), and ORL (with oil and straw additives) to indicate the 4 different formulations. **Table 1** illustrates the mass proportional composition of the mix-design. A consistent amount of extra distilled water was introduced to both mixes during kneading to achieve the desired consistency.

Table 1. Mix-design of the investigated samples.

Sample	$Ca(OH)_2$ [wt. %]	Straw Addition	Non-Reactive Part [wt. %]	Kneading Water [wt. %]	Additive Oil [wt. %]
AL	25	NO	66	7	-
RL	25	YES	66	7	-
OL	23.5		66	7	1.5
ORL	23.5	YES	66	7	1.5

The lime putties underwent homogenization using a mud mixer drill in preparation for mortar synthesis. For mortar mixes, a manual mixing process occurred for 2 minutes, followed by a 20-second pause, and then an additional 2-minute blending. To ensure the uniform distribution of the oiled mixes, sesame oils were incorporated into mortar mixes in the following manner. Sesame oil and a small amount of lime putty were hand-mixed in a plastic beaker for 2 minutes, and this mixture was then added to the remaining mortar mix. It was further stirred manually for an additional 4 minutes. In terms of the oiled mixes, a thorough dispersion of the oils within the mortars was visually confirmed, with no noticeable color change observed to the naked eye.

The mortars were molded into disc-shaped plastic molds (diameter = 60 mm, thickness = 20 mm) on a sturdy glass support surface. After 24 hours, the samples were demolded and left under laboratory conditions (Temperature = 22 ± 2 °C, RH = 50 ± 5 %) for 180 days. Initial testing of the mortars occurred after this 180-day curing period, enhancing comparability with characterizations and allowing for replication in line with a recent study.

Characterizations in this study were conducted after a 180-day curing period to ensure meaningful comparability with a previous study [13]. Mercury intrusion porosimeter (MIP) analyses were performed to determine total pore volumes and porosity measurements. Samples of approximately 0.8 cm^3 each were subjected to MIP using an AutoPore IV 9500 V1 porosimeter.

Water absorption (WA) was assessed on three disc-shaped samples for each formulation. Initially, the mortars were dried in an oven at 100 °C for 24 hours. After cooling and achieving mass stabilization, the dry mass (mdry) was recorded. Subsequently, the mortars were immersed in distilled water for 24 hours, and the new mass value under "saturated surface dry condition" (mssd) was recorded. Water absorption of the mortars after 24 hours of immersion in water (WA_{24h}) was then calculated.

$$WA_{24h} = [(m_{ssd} - m_{dry})/m_{dry}]\times 100 \quad (1)$$

The water vapor permeability of the mortars was assessed using three samples for each mix design. The evaluation was conducted in accordance with EN 1015-19 [16] standards, under controlled environmental conditions (temperature of 22 ± 2 °C and relative humidity of approximately 40 ± 2%). Disc-shaped specimens, measuring 60 mm in diameter and 20 mm in thickness, were tightly sealed with impermeable silicone gel onto the openings of glass containers filled with KNO3 saturated solutions. These solutions maintained a consistent water vapor pressure within the container, with an air gap of about 10 mm separating the sample from the solution. The pressure variance between the container's interior and the surrounding environment facilitated the movement of water vapor through the lime mortar specimens. The change in mass over time within the container indicated the amount of water vapor that passed through the samples. The sealed containers containing the lime mortar samples were placed in the specified conditions for a duration of 30 days. The permeability of mortars indicates their capacity to permit water vapor passage, which is affected by the material's pore structure. This permeability is quantified using the water vapor diffusion resistance coefficient. A higher value of this coefficient signifies increased resistance to water vapor movement, suggesting that the sample is less permeable and less breathable.

To ensure accurate final calculations as stipulated by the UNI EN 1015-19 standard, the discs weight measurements were collected at regular intervals over a period of approximately 20–30 days. The results are then plotted on a graph (weight loss versus time) to determine the permeability coefficient, which is theoretically represented as the slope of the resulting line.

To calculate the water vapor flow, the permeability to water vapor is determined using the following formula:

$$P = \frac{\Delta m}{A \cdot \Delta t \cdot (p1 - p2)} \tag{2}$$

Where:

P = permeability (in kg/(m²·s·Pa))
Δm = change in mass (in kg)
A = area of the sample (in m²)
Δt = change in time (in seconds)
p1 = vapor pressure inside the jar (in Pa)
p2 = vapor pressure outside the jar (in Pa)

To evaluate the superficial durability of the mortars—a crucial property for outdoor repointing and rendering applications—three disc-shaped specimens from each formulation underwent 10 freeze-thaw cycles after being cured for 180 days. The procedure involved immersing the specimens in water for 30 minutes in a controlled laboratory setting (with a temperature of 22 ± 2 °C and relative humidity of 50 ± 5). After immersion, the specimens were drained on a plastic mesh under the same conditions (T = 22 ± 2 °C and RH = 50 ± 5) for an additional 30 minutes to remove excess water, followed by placement in a freezer at −20 ± 2 °C for 3 hours. Each cycle simulates damaging conditions in cold environments, where the water trapped in the pores of the mortars freezes overnight, leading to frost damage due to the expansion of ice. The superficial deterioration resulting from visible qualitative changes was assessed after completing the 10 freeze-thaw cycles.

3. Results

The mortars underwent characterization, with reported values for their open porosity (measured by MIP) and water absorption after 24 hours of immersion (WA_{24h}), and permeability values presented in **Table 2** and **Figure 1**, respectively. In comparison to the reference mortar, which involves conventional lime putty and aggregates, the mortar incorporating the straw as reinforcement showed a slight increase in open porosity and water absorption values.

Table 2. Physical properties of the investigated mortars: open porosity (by MIP) and water absorption (WA_{24h}). The values of WA_{24h} correspond to the average (±standard deviation).

Samples	Open Porosity by MIP [%]	WA_{24h} [%]
AL	35.6	14.85 (±0.3)
RL	32.3	15.02 (±0.4)
OL	25.5	5.02 (±0.4)
ORL	25.9	6.04 (±0.3)

The abbreviated sample names, denoted as AL (air lime) and RL (reinforced Air Lime), OL (oiled), and ORL (with oil and straw additives).

The results indicate that the addition of straw to the lime mortar mixes led to a slight increase in open porosity and water absorption values of the samples. This finding aligns with similar observations in other studies, which also reported higher permeability values when incorporating additional fibers [10]. The study of lime mortars enhanced with natural fibers and fatty acids provides valuable insights into their physical properties, particularly in terms of porosity and water absorption. Traditional lime mortars are esteemed for their durability and breathability, but the incorporation of organic materials can further improve their performance.

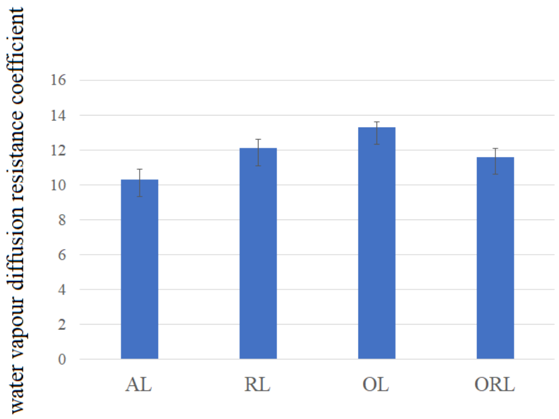

Figure 1. Resistance to water vapor diffusion of the investigated samples at 180 days of curing: The abbreviated sample names, denoted as AL (air lime) and RL (reinforced Air Lime), OL (oiled), and ORL (with oil and straw additives).

Incorporating natural fibers into lime mortars has been found to slightly decrease open porosity, leading to a denser structure that may enhance mechanical properties. However, this integration also results in a modest increase in water absorption. The fibers can create additional pathways for moisture retention, potentially affecting the long-term durability of the mortar in varying environmental conditions. Research indicates that while natural fibers, such as sugarcane bagasse, can improve certain mechanical strengths, excessive amounts may reduce ductility [17, 18].

The addition of fatty acids to lime mortars similarly decreases open porosity. This reduction is linked to the hydrophobic properties of fatty acids, which alter the mortar's microstructure. By transforming hydrophilic pores into hydrophobic ones, the water absorption capacity of the mortar is significantly reduced. This characteristic is particularly important for applications where moisture control is essential, such as in historical restoration or in humid environments [19, 20].

Interestingly, previous studies have shown that while both natural fibers and fatty acids modify porosity, the inclusion of oils in lime mortar mixes leads to a marked decrease in water absorption. Oils fill voids within the mortar matrix, enhancing its hydrophobic characteristics and facilitating the transformation of pore types from hydrophilic to hydrophobic. Such organic additives can also initiate carbonation processes that improve strength and reduce permeability, underscoring the benefits of incorporating these materials into lime mortars [21–23].

The integration of natural fibers and fatty acids into lime mortars yields a dual effect: they enhance certain mechanical properties and reduce porosity while slightly increasing water absorption. In contrast, oils have a more pronounced effect on reducing water absorption due to their ability to modify pore structures. Understanding these interactions is crucial for optimizing lime mortar formulations for specific applications, particularly those requiring effective moisture management. Future research should focus on the long-term effects of these additives on durability and performance in diverse environmental conditions.

It is crucial to note that permeability is a significant factor for many restoration materials, as it directly impacts the durability of these materials. Enhanced permeability enables the mortar to breathe and release trapped moisture through vaporization, contributing to its overall performance and longevity. Permeability of the mortars can be important index to demonstrate their suitability to be served as a restorative mortar [22].

The water vapor diffusion test results presented in **Figure 1** reveal a subtle uptick in impermeability values of the mortars when fibers are introduced. This phenomenon likely arises from alterations in the mortar matrix's pore structure, resulting in a denser configuration that hinders fluid movement [10]. Comparative analyses have shown that fibers can indeed decrease permeability in hydraulic lime mortars, but their efficacy is influenced by factors such as fiber type and length. Shorter fibers, for example, may enhance specific mechanical properties without markedly impacting water absorption rates, whereas longer fibers could elevate air content while diminishing consistency [23, 24].

Permeability plays a vital role in the effectiveness and longevity of restoration materials, particularly lime mortars used in the preservation of architectural heritage. It is crucial to understand the impact of permeability on these mortars, as it directly affects their moisture management capabilities, which is essential for their durability and success in restoration efforts.

Permeability is defined as the capacity of a material to allow fluids, especially water vapor, to pass through. For restoration materials like lime mortars, increased permeability is beneficial because it allows the mortar to "breathe." This characteristic enables trapped moisture to escape through vaporization, thereby minimizing the risk of damage caused by moisture accumulation within the material. High permeability can help prevent problems such as efflorescence, mold growth, and structural degradation due to retained moisture. Consequently, assessing the permeability of mortars is essential for determining their appropriateness as restoration materials.

Figure 1 demonstrates the resistance to water vapor diffusion for different mortar samples after 180 days of curing. The results show a slight increase in impermeability when natural fibers are added to the mortar mix. This change is linked to alterations in the pore structure of the mortar matrix, resulting in a denser configuration that restricts fluid movement. Adding fibers to hydraulic lime mortars can reduce permeability; however, the degree of this effect varies depending on factors such as fiber type and length. For example, shorter fibers may enhance certain mechanical properties without significantly impacting water absorption rates. Conversely, longer fibers can increase air content, potentially compromising consistency. This complex relationship highlights the importance of carefully selecting fiber types for lime mortar formulations.

The incorporation of natural fibers into lime mortars effectively reduces permeability. Likewise, the addition of fatty acids also contributes to this reduction by enhancing the hydrophobic properties of the mortar. Interestingly, when both natural fibers and fatty acids are used together, the overall change in permeability is less pronounced than when each additive is employed separately. Nevertheless, the permeability remains within acceptable limits for restoration mortars.

This observation emphasizes the need to study organic additives in conjunction rather than in isolation. The interaction between natural fibers and fatty acids may produce synergistic effects that optimize performance while maintaining desirable permeability levels. All tested samples demonstrated an impermeability coefficient of less than 15, which is consistent with standards appropriate for restoring architectural heritage structures [25].

A comparative analysis indicates that while both natural fibers and fatty acids positively influence permeability reduction in lime mortars, their effectiveness can vary significantly depending on the context of their application. For instance, traditional concrete structures often struggle with water infiltration due to low-permeability materials that can trap moisture. In contrast, lime mortars with higher permeability are better suited for restoration projects where moisture management is crucial.

Moreover, research has shown that utilizing permeable materials in construction not only enhances durability but also supports sustainability by decreasing the environmental impact associated with repairs and replacements. By allowing moisture to escape rather than accumulate within walls or structures, these materials contribute to healthier indoor environments and longer-lasting buildings.

The ways in which natural fibers and fatty acids affect the permeability of lime mortars are complex. When fibers are introduced, they create a network within the mortar that influences pore distribution and connectivity, leading to a denser microstructure that restricts fluid flow pathways. In contrast, fatty acids interact with the mortar matrix at a molecular level, potentially filling voids and converting hydrophilic pores into hydrophobic ones. This transformation is essential as it reduces water absorption while still permitting vapor diffusion—a necessary balance for effective moisture management in restoration applications. The hydrophobic qualities imparted by fatty acids can also help protect against external moisture intrusion during adverse weather conditions.

Permeability is a crucial factor affecting the durability and effectiveness of restoration materials like lime mortars. The ability of these mortars to manage moisture through enhanced permeability significantly influences their long-term performance. The addition of natural fibers and fatty acids has been shown to effectively reduce permeability; however, using them together offers unique opportunities for optimizing mortar formulations without sacrificing essential properties. Future research should further investigate the interactions and effects of these organic additives on lime mortar performance under various environmental conditions. Gaining insights into these dynamics will be vital for developing innovative solutions that enhance restoration practices while preserving historical integrity.

Superficial durability of the lime mortars were assessed in freezing-thawing cycles. As a confirmation to previous studies oiled mortars demonstrated substantially higher superficial durability compared to their non-oiled references, thanks to their low water absorption and their ability to discharge the absorbed water content before freezing due to possession of hydrophobic pores. Superficial detachments were visible for the non-oiled mortar samples after 5 destructive cycles. The same formulation with addition of natural fibers demonstrated soundness up to 10 destruc-tive cycles. Such effect of curing was not reported in previous studies generally when mortars are reinforced with fibers. The oiled mortars with and without additive fibers passed over 15 freeze-thaw cycles that demonstrates addition of oils in fiber lime mortars can significantly improve their superficial durability.

The durability of lime mortars is an essential factor in restoration efforts, especially when exposed to environmental challenges like freeze-thaw cycles [26]. This evaluation concentrates on the superficial durability of lime mortars, specifically analyzing how oil and natural fibers impact their performance in these conditions.

Superficial durability refers to a material's capacity to resist surface-level deterioration caused by environmental factors. Freeze-thaw cycles present a significant risk for lime mortars, as the expansion of freezing water can lead to cracking and separation from the substrate. Recent research indicates that oiled mortars show considerably better superficial durability than non-oiled versions. This improved performance is attributed to their low water absorption and the presence of hydrophobic pores, which facilitate effective moisture release prior to freezing. In laboratory tests, non-oiled mortar samples displayed noticeable superficial detachments after just five freeze-thaw cycles, while oiled mortars exhibited exceptional resilience, enduring over fifteen cycles without substantial damage. The hydrophobic characteristics of oiled mortars enable them to efficiently expel absorbed moisture, thus reducing the risks associated with freezing temperatures. These results are consistent with earlier studies emphasizing the benefits of incorporating oils into lime mortar formulations to enhance durability under challenging conditions.

Adding natural fibers to lime mortars has been shown to further enhance their performance during freeze-thaw events. Mortars reinforced with natural fibers maintained structural integrity through ten destructive cycles, a significant improvement over non-oiled samples. This finding is particularly noteworthy, as previous research has not consistently demonstrated similar durability improvements with fiber additions.

Natural fibers bolster the overall strength of the mortar matrix by improving its mechanical properties and potentially modifying its pore structure. The inclusion of fibers can establish a more interconnected network within the mortar, helping to distribute stress more evenly during freeze-thaw cycles, which is vital for preserving structural integrity against environmental stresses.

Bond strength is another critical characteristic of restorative materials, particularly for repointing or repairing historical structures. An initial evaluation of bonding was carried out to determine the potential efficacy of various mortar formulations in practical conditions. The bond strength of lime mortars is heavily influenced by the condition of the substrate, making it essential to replicate site conditions for a more accurate assessment.

In this study, all mortar samples underwent a repointing simulation, providing an initial evaluation of their bonding capabilities. Throughout the first year of observation, no signs of biological attacks or durability issues were noted, suggesting that the mortars retained their integrity under natural conditions. However, further monitoring and more comprehensive studies are needed to gain deeper insights into their microstructures and mechanical properties.

Following each natural freeze cycle, oiled mortars exhibited frozen surfaces, whereas non-oiled samples showed dry surfaces despite higher water absorption rates. This difference can be explained by the freezing point of sesame oil (−6 °C), which may bond with any frozen water on the surfaces of the oiled mortars. This interaction underscores the importance of understanding how organic additives affect moisture behavior in lime mortars. The frozen surface of oiled mortars is visible in **Figure 2**.

Figure 2. Frozen surfaces of the oiled mortars and dry surfaces of non-oiled mortars after every natural freezing cycle.

Despite encouraging findings on superficial durability and bond strength, additional research is necessary to investigate the long-term performance and potential uses of these modified lime mortars. Extended monitoring will be crucial for evaluating how these materials endure various environmental conditions over time. Moreover, advanced characterization techniques will shed light on microstructural changes and moisture properties that evolve as these materials age. Such investigations are currently in progress and will be reported in future publications. The superficial durability of lime mortars is significantly improved by the addition of oils and natural fibers. These enhancements not only bolster resistance to freeze-thaw cycles but also positively influence bond strength in practical applications. As restoration methods advance, understanding the effects of various additives on mortar performance will be vital for developing effective solutions that protect architectural heritage while ensuring durability under challenging environmental conditions.

Future research will continue to delve into these aspects, providing valuable insights into optimizing lime mortar formulations for restoration initiatives while maintaining compatibility with historical structures.

4. Conclusions

Throughout history, lime mortars have been combined with organic additives to address deficiencies such as slow setting times and hydric properties. These additives, which have included oils, straw, and more, have been traditionally used to enhance the performance of lime mortars. This study specifically examined the effects of incorporating straw and sesame oil into lime mortar mixes, focusing on their impact on open porosity, permeability, water absorption, and durability. While previous studies have explored the effects of natural fibers and fatty acid additives on lime mortars separately, this study investigated their simultaneous inclusion in mortar mixes.

The results revealed that the simultaneous addition of sesame oil and straw led to a decrease in water absorption values of the mortars by 77%. Additionally, the incorporation of sesame oil resulted in a notable 30% increase in impermeability values. However, when both sesame oil and straw were added together, the increase in impermeability was less than 20% compared to the reference mortar without additives. These findings suggest that the combined addition of sesame oil and straw has a lesser impact on the mortar's permeability values, which is beneficial for the long-term preservation of historical substrates. The combination of straw and sesame oil enhances hydric properties without compromising the mortar's structure and permeability.

These results emphasize the sustainable nature of lime mortars in restoration projects, highlighting their compatibility with traditional masonry practices. By combining natural fibers with fatty acids, mortar durability is improved, offering a promising avenue for enhancing performance while retaining essential properties. This study recommends further research on lime mortar additions for architectural restoration projects, focusing on maintaining historical authenticity while enhancing functionality. Incorporating straw into lime mortar mixes has been shown to slightly enhance open porosity and water absorption values, aligning with previous studies emphasizing the relationship between fiber additions and increased permeability. Although reducing permeability is often a goal in developing new materials, it is crucial to recognize that permeability plays a vital role in ensuring the durability and conservation of historical substrates. The modest increase in permeability observed with straw incorporation remains within acceptable limits for restoration purposes.

While the addition of oils typically reduces water absorption significantly, it can introduce microstructural changes that may compromise mortar mechanical properties. However, the simultaneous inclusion of natural fibers and oils presents a promising strategy, enhancing hydric properties while inducing only minor microstructural and permeability alterations. Lime mortars are inherently sustainable materials for restoration due to their historical masonry compatibility.

Despite facing challenges like low carbonation rates and inadequate mechanical strength, lime mortars have numerous advantages, including improved mechanical properties and enhanced durability. Adding straw not only addresses these limitations but also positively influences overall mortar performance. Combinations of natural fibers and fatty acids have demonstrated improved durability, suggesting effective performance enhancements without significant compromise to other essential properties.

Research consistently shows positive effects of fatty acids on lime mortars, particularly in hydrophobizing cavities. While these cavities reduce mortar water absorption significantly, microstructural alterations resulting from oil presence can be disadvantageous. Moreover, the reduction in permeability can pose challenges for oiled lime mortars. This study demonstrates that straw can mitigate the impermeability increase caused by fatty acid addition, partially addressing a crucial question that requires further investigation.

Future research should explore how straw interacts with various additives, including fatty acids, to better understand their combined effects. This exploration will address existing knowledge gaps and reveal opportunities for leveraging fiber-reinforced lime mortars in sustainable building practices. Advancements in this field will contribute to more effective restoration strategies that respect historical integrity while promoting environmental sustainability. This study highlights the potential of organic additives such as straw and sesame oil in lime mortars to enhance their properties while remaining compatible with traditional construction practices. It suggests careful consideration of additive combinations to optimize performance without compromising essential characteristics like permeability. As interest in sustainable building materials grows, further research into innovative additive combinations will be crucial for developing effective solutions that maintain historical authenticity and modern functionality.

Funding

This research received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon request. Please contact them at [parsa.pahlavan@um.ac.ir] for access to the research data.

Acknowledgments

The author gratefully acknowledges the support of all individuals at University of Bologna and Ferdowsi University of Mashhad who contributed constructive comments and suggestions to this research project.

Conflict of Interest

There is no conflict of interest to disclose.

References

[1] Apostolopoulou, M., Aggelakopoulou, E., Siouta, L., et al., 2017. A methodological approach for the selection of compatible and performable restoration mortars in seismic hazard areas. Construction and Building Materials. 155, 1–14. DOI: https://doi.org/10.1016/j.conbuildmat.2017.07.210

[2] Ventolà, L., Vendrell, M., Giraldez, P., et al., 2011. Traditional organic additives improve lime mortars: New old materials for restoration and building natural stone fabrics. Construction and Building Materials. 25(8), 3313–3318. DOI: https://doi.org/10.1016/j.conbuildmat.2011.03.020

[3] Kesikidou, F., Stefanidou, M., 2019. Natural fiber-reinforced mortars. Journal of Building Engineering, 25, 100786. DOI: https://doi.org/10.1016/j.jobe.2019.100786

[4] Maravelaki-Kalaitzaki, P., Bakolas, A., Karatasios, I., et al., 2004. Hydraulic lime mortars for the restoration of historic masonry in Crete. Cement and Concrete Research. 35(8), 1577–1586. DOI: https://doi.org/10.1016/j.cemconres.2004.09.001

[5] El-Turki, A., Ball, R.J., Carter, M.A., et al., 2010. Effect of dewatering on the strength of lime and cement mortars. Journal of the American Ceramic Society. 93(7), 2074–2081. DOI: https://doi.org/10.1111/j.1551-2916.2010.03667.x

[6] Islam, T., 2019. Air-Void Characteristics and Permeability of Fibre Reinforced Repair Mortar for Conservation [Ph.D. Dissertation]. University of Alberta: Edmonton, AB, Canada. DOI: https://doi.org/10.7939/r3-akka-dd69

[7] Grilo, J., Faria, P., Veiga, R., et al., 2014. New natural hydraulic lime mortars – Physical and microstructural properties in different curing conditions. Construction and Building Materials. 54, 378–384. DOI: https://doi.org/10.1016/j.conbuildmat.2013.12.078

[8] Piválk, A., Pavlíková, M., Záleská, M., et al., 2024. Development and Characterization of Lime-Based Mortars Modified with Graphene Nanoplatelets. Materials. 17(20), 5022. DOI: https://doi.org/10.3390/ma

17205022

[9] Yang, J., Cheng, Y., Cui, D., et al., 2024. Experimental Study on the Effect of Environmental Water on the Mechanical Properties and Deterioration Process of Underground Engineering Masonry Mortar. Sustainability. 16(12), 5186. DOI: https://doi.org/10.3390/su16125186

[10] Chen, Z., Liu, H., Xu, L., et al., 2024. A review of mechanical properties and carbonation behavior evolution of lime mortar for architectural heritage restoration. Minerals and Materials. 3, 3. DOI: http://dx.doi.org/10.20517/mmm.2023.26

[11] EN 459-1, Building lime. Part 1: Definitions, specifications and conformity criteria, 2010.

[12] Van Audenrode, F., De Kock, T., 2024. Testing historical recipes with organic additives to alter the water absorption of traditional lime mortar. MATEC Web of Conferences. 403, 03010. DOI: https://doi.org/10.1051/matecconf/202440303010

[13] Pahlavan, P., Manzi, S., Rodríguez-Estrada, et al., 2017. Valorization of spent cooking oils in hydrophobic waste-based lime mortars for restorative rendering applications. Construction and Building Materials. 146, 199–209. DOI: https://doi.org/10.1016/j.conbuildmat.2017.04.001

[14] Pahlavan, P., Manzi, S., Shariatmadar, H., et al., 2021. Preliminary valorization of climatic conditions effects on curing of air lime-based mortars for restorative applications in the Pasargadae and Persepolis World Heritage Sites. Applied Sciences. 11(17), 7925. DOI: https://doi.org/10.3390/app11177925

[15] Nunes, C., Slížková, Z., 2016. Freezing and thawing resistance of aerial lime mortar with metakaolin and a traditional water-repellent admixture. Construction and Building Materials. 114, 896–905. DOI: https://doi.org/10.1016/j.conbuildmat.2016.04.029

[16] EN 1015-19, Methods of test for mortar for masonry, Determination of water vapour permeability of hardened rendering and plastering mortars, 1998.

[17] Manoharan, A., Umarani, C., 2022. Properties of Air Lime Mortar with Bio-Additives. Sustainability. 14(14), 8355. DOI: https://doi.org/10.3390/su14148355

[18] Daliposa, K.P., Bo-Ot, L.M., 2024. Effects of Sugarcane Bagasse Fiber Additives on the Mechanical Properties of Lime-Based Composites and their Compatibility with Traditional Lime-Based Mortars. MATEC Web of Conferences. 403, 02004. DOI: https://doi.org/10.1051/matecconf/202440302004

[19] Shivakumar, M., Selvaraj, T., Dhassaih, M.P., 2021. Preparation and characterization of ancient recipe of organic Lime Putty-Evaluation for its suitability in restoration of Padmanabhapuram Palace, India. Scientific Reports. 11(1). DOI: https://doi.org/10.1038/s41598-021-91680-8

[20] Shivakumar, M., Singh, A., Selvaraj, T., 2022. Production of the traditional organic mortars of Padmanabhapuram Palace—A characterization study on the simulated mortars for their compatibility. Buildings. 12(9), 1466. DOI: https://doi.org/10.3390/buildings12091466

[21] Silva, B.A., Ferreira Pinto, A.P., Gomes, A., 2014. Influence of natural hydraulic lime content on the properties of aerial lime-based mortars. Construction and Building Materials. 72, 208–218. DOI: https://doi.org/10.1016/j.conbuildmat.2014.08.004

[22] Sassoni, E., Pahlavan, P., Franzoni, E., 2016. Valorization of brick waste by alkali-activation: A study on the possible use for masonry repointing. Ceramics International. 42(13), 14685–14694. DOI: https://doi.org/10.1016/j.ceramint.2016.06.093

[23] Cobo Escamilla, A., Bautiste Villanueva, P., Prieto Barrio, M., 2024. Effect of basalt fiber length on the behavior of natural hydraulic lime-based mortars. REVIEWS ON ADVANCED MATERIALS SCIENCE. 63(1), 20230191. DOI: https://doi.org/10.1515/rams-2023-0191

[24] Bendjillali, K., Goual, M.S., Chemrouk, M., 2011. Study of the reinforcement of limestone mortars by Polypropylene fibers waste. Physics Procedia. 21, 42–46. DOI: https://doi.org/10.1016/j.phpro.2011.10.007

[25] Moropoulou, A., Bakolas, A., Moundoulas, P., 2013. Optimization of compatible restoration mortars for the earthquake protection of Hagia Sophia. Journal of Cultural Heritage. 14(3), e147–e152. DOI: https://doi.org/10.1016/j.culher.2013.01.008

[26] Santos, A.R., Veiga, M.D.R., Matias, L., 2018. Durability and Compatibility of Lime-Based Mortars: The Effect of Aggregates. Infrastructures. 3(3), 34. DOI: https://doi.org/10.3390/infrastructures3030034