Herança – History, Heritage and Culture Journal
2025, 8(2), 128-134
ISSN: 2184-3090
https://revistaheranca.com
Research Article

Compressive Strength of Ichu-Reinforced Adobe: A Comparative Analysis

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Citation: Loli Gutierrez, R. H., Yanac Toledo, L. M., Samamé Zegarra, E. K., Pulido Cavada, A. M., & González-Lezcano, R. A. (2025). Compressive strength of Ichu-reinforced adobe: A comparative analysis. *Herança, 8*(2), 128-134. https://doi.org/10.52152/heranca.v8i2/1100

ARTICLE INFO

Received: 22 Nov 2024
Accepted: 28 Apr 2025

ABSTRACT

In the context of sustainable construction, the strength of adobe reinforced with Ichu emerges as a critical issue in improving the mechanical properties of this traditional material. The main objective of this study is to comparatively analyse the compressive strength of adobe reinforced with different proportions of Ichu, as well as to evaluate the effectiveness of other natural additives in comparison with Ichu. For this purpose, compression tests were carried out on adobe specimens made with different concentrations of Ichu and other natural fibres, following standard mechanical characterisation techniques. The results obtained support the premise that the addition of organic materials such as Ichu improves the strength of adobe, which is especially relevant for construction in high Andean regions. In particular, it was found that a 5 % addition of Ichu optimises the compressive strength of adobe (42.75 kg/cm^2), while higher concentrations, such as 12 %, reduce this property (12.89 kg/cm^2). In addition, the effects of other natural fibres, such as banana and pine, were evaluated. It was observed that the use of banana fibres generated a higher strength (67.10 kg/cm^2), while pine fibre showed significant variability in the results. These findings highlight the importance of accurate formulation of adobe mixes with natural additives to achieve substantial improvements in strength and durability. On a practical level, the study provides valuable guidelines for mix optimisation, contributing to the design of stronger and more sustainable buildings in traditional and rural contexts.

Keywords: Mechanical Properties; Adobe Resistance; Sustainable Construction; Ichu; Earth Architecture.

INTRODUCTION

Throughout history, earthen construction has been a widely used practice in various cultures and regions of the world. It is estimated that about 30% of the world's population, approximately 1.5 billion people, now live in earthen buildings, a building technique with an unbroken tradition (Keefe, 2012). These structures have evolved in response to local conditions, noted for their low cost, accessibility and environmental sustainability.

The construction sector has a significant impact on biodiversity and natural resource consumption. Globally, it is estimated to account for approximately 30% of energy consumption and 25% of waste production, of which a high percentage corresponds to natural soils and materials discarded in construction processes (Deng et al., 2023).

Paradoxically, soil, used as a building material since the earliest human settlements, is now considered waste in many regions. The growing demand for sustainable buildings has led to a revaluation of traditional materials. Earth, in particular, has proven to possess favourable mechanical and thermal properties for construction, but its use faces various technical, economic and regulatory barriers (Morel et al., 2021).In many countries, the lack of specific regulation on earth construction hinders its large-scale implementation. However, in regions where this technique has been adopted, certain requirements have been established, such as the need to stabilise the mix with a minimum of 15% cement, lime or gypsum to improve its strength and durability (Hamard, Cazacliu, Razakamanantsoa, & Morel, 2016).

Despite these advances, there are still gaps in research on the stabilisation and optimisation of soil as a building material. In particular, there is limited documentation on the use of natural stabilisers, such as plant fibres and organic polymers, which could improve the mechanical properties of adobe without compromising its biodegradability. Furthermore, there is no consensus on the optimal proportions of these additives, nor on their long-term impact on the structural strength and sustainability of buildings.

In this context, the present research aims to contribute to the knowledge on the stabilisation of adobe by the addition of natural fibres, with emphasis on Ichu (Stipa Ichu), a typical Andean grass. The study will focus on determining the optimal proportion of Ichu in the adobe mix, comparing its effectiveness with other natural fibres and evaluating its influence on compressive strength. The results obtained will allow the generation of guidelines for the improvement of adobe as a sustainable construction material, providing a reference framework for future research and applications in the field of ecological architecture.

METHODOLOGY

Both inductive and deductive methods were applied in this research due to the complexity of the comparative analysis of the compressive strength of Ichu-reinforced adobes. Initially, the inductive method was used to collect and analyse previous individual studies on the compressive strength of Ichu-reinforced adobe. From these studies, relevant data were extracted to identify patterns, trends and methodological differences in the results obtained. In the hypothesis testing phase, the deductive method was used. Principles of materials engineering were applied to assess the consistency and validity of the results obtained in the previous studies, contrasting them with established standards. The approach of this research is practical and applied, as it seeks to solve specific problems related to the improvement of the compressive strength of adobe by the addition of Ichu. Data collection and systematic analysis of the information identified opportunities for improvement in the application of this reinforcement technique, addressing real challenges in sustainable construction.

Given its exploratory and comparative nature, the research adopted a mixed approach. A quantitative method was used to collect and analyse statistical data on compressive strength from previous studies. For this purpose, descriptive statistical tools were used, such as the calculation of means, standard deviations and comparative analysis of strength values. In parallel, a qualitative approach was adopted to examine methodological differences between studies, considering factors such as the proportion of Ichu used, manufacturing procedures and test conditions. Data collection was carried out by means of a systematic literature review. Bibliographic sheets and research log sheets were used to collect detailed information on the methodology, the resistance values obtained and the variables controlled in each study. This process allowed the comparative analysis to be structured in a rigorous manner. In addition, observation sheets were used to document significant differences in experimental procedures and assess their impact on the results obtained. Several studies have explored the reinforcement of adobe with natural fibres to improve its mechanical strength. However, the results have varied considerably due to differences in the methodology applied. For example, some studies have used fibre proportions higher than 2.5%, while others have worked with mixtures stabilised with lime or cement in different proportions. Also, curing conditions and compaction techniques have influenced the values obtained in compression tests. These variations justify the need for a detailed comparative analysis.

In conclusion, it has been identified that the addition of 2.5% Ichu fibre in adobe bricks significantly improves their compressive and flexural strength compared to fibres such as pine. However, its lower water absorption capacity may imply changes in the hygrothermal behaviour of walls built with this material. These implications need to be evaluated in future studies, considering durability and structural stability under different climatic conditions. Furthermore, adobe blocks reinforced with Ichu showed deflection ranges between 0.6 mm and 1 mm, while unreinforced blocks reached a maximum of 0.26 mm. This increase in deflection indicates a greater capacity of the material to absorb stresses before fracture, which could translate into greater structural ductility and better resistance to dynamic loads, such as those caused by earthquakes.

The design of this research corresponds to a systematic review study, as it allowed a detailed evaluation of the factors influencing the compressive strength of adobe reinforced with Ichu. Previous studies were retrospectively analysed to identify the most relevant experimental conditions and to establish relationships between the proportion of Ichu and the mechanical performance of the material.

The study population consisted of all studies published to date on the compressive strength of adobe reinforced with Ichu. The sample was selected by non-probability-intentional sampling, based on criteria such as the availability of detailed experimental data, the use of standardised tests and the relevance of the study to the research objective. Only studies reporting quantitative compressive strength values were included, discarding those that did not provide comparable data.

Finally, it is important to consider the potential methodological biases of this research. These include variability in the experimental procedures of the studies analysed, the possible omission of environmental factors in some trials, and the limited availability of studies in certain regions. To minimise these biases, we prioritised the selection of research with well-documented methodologies and performed a critical analysis of the consistency of the reported data.

RESULTS

Adobe has been used as a building material since ancient times due to its availability and low cost. However, its limited structural strength has prompted the search for reinforcement techniques to improve its mechanical properties. One such technique is the addition of Ichu, an Andean plant fibre, to the adobe mix. Uchu, an Andean herbaceous plant, has been investigated as a reinforcement material due to its fibrous structure, which improves the cohesion of the mix and contributes to the uniform distribution of stresses within the adobe. In addition, its resistance to degradation and low cost make it a viable option for improving the mechanical properties of adobe without compromising its sustainability.

Several studies have explored this technique with the aim of increasing the compressive strength of adobe, but results have varied considerably due to differences in methodology, proportion of Ichu used and test conditions. In recent studies on building materials, the impact of different natural fibres on the compressive strength and durability of adobes has been investigated. Vásquez Vásquez et al., 2021 conducted a comparative analysis between the addition of Ichu fibre and pine fibre, highlighting that Ichu fibre shows a better compressive response at use levels of 2.5%, 5% and 7%. Specifically, the compressive strength values are 42.75 kg/cm^2 for a 7% use level of Ichu fibre, 35.65 kg/cm^2 for a 2.5% level of pine fibre, 34.68 kg/cm^2 for a 5% level of pine fibre and 28.95 kg/cm^2 for a 7% level of pine fibre. This study concluded that the incorporation of 2.5% Ichu fibre in the manufacture of adobes provides higher compressive and flexural strength compared to the use of pine fibre in proportions of 2.5%, 5% and 7%. However, adobes with Ichu fibre have lower water absorption compared to those made with pine fibre. These studies underline the importance of an adequate proportion of Ichu to optimise the mechanical properties of adobe. In this context, 2.5% has been shown to be the optimal amount to improve strength without compromising the workability of the mix or increasing water absorption. Likewise, other studies have explored different natural fibres such as coconut (Chàvez & Alva, 2020) and straw (Parisi, Asprone, Fenu, & Prota, 2015) to improve adobe properties. Altamirano (2019) found that the compressive strength of adobe increases with the addition of straw by up to 0.80%, with strength values up to 14.57 kg/cm^2 . However, by increasing the amount of straw to 1.20%, the strength decreases, indicating that a higher amount may negatively affect the workability of the mix.

From another perspective, Hoyos (2020), and Taipé and Yaranga (2023) analysed how the addition of Ichu in combination with other materials affects the mechanical properties of adobe. Their studies showed that the addition of Ichu to adobe, whether traditional or stabilised with 20% lime, has different effects: as the size and quantity of Ichu fibre increases, compressive strength decreases, but flexural strength increases. Furthermore, the inclusion of sheep wool in combination with Ichu can improve the compressive strength, reaching values up to 29.32 kg/cm^2 with 2% Ichu and 0.5% sheep wool. On the other hand, Cacha Lázaro (2022) evaluated adobe reinforced with poultry feathers, finding that the compressive strength was evaluated according to Standard E.080, where conventional adobe averaged 6.68 kg/cm^2 , below the minimum acceptable value of 10.2 kg/cm^2 . However, the adobe reinforced with 5% poultry feathers showed an average strength of 11.77 kg/cm^2 , significantly exceeding the minimum standard. This highlights the potential of bird feathers as an effective reinforcement for adobes, improving not only compressive strength but also reducing water suction.

The study by Balila & Vahdati (2024) highlights that biologically inspired stabilizers, such as bovine serum albumin (BSA), can significantly improve the compressive strength of adobe bricks. The inclusion of glycoproteins such as BSA was found to be more effective than traditional stabilizers such as cement and lime, providing a more sustainable alternative to adobe construction. In terms of comparison with other additives, Ichu fiber has proven to be effective in improving the mechanical strength of adobe, albeit with certain limitations. Unlike coco coir or straw, which have shown increases in compressive and flexural strength with moderate water absorption, Ichu can reduce compressive strength in certain cases if its size and quantity in the mix are not properly controlled. In addition, its lower water absorption capacity compared to other fibers could be a limiting factor in humid climates.

In conclusion, research into improving adobe through the use of natural fibers and other additives is still ongoing. Although additives have been shown to improve adobe bricks, more studies need to be done on the combination of materials and their impact on performance. Commercial production still faces challenges, such as the standardization of methodologies and the public acceptance of these materials. However, the use of waste and natural fibres in sustainable construction remains a viable and environmentally friendly alternative, with great potential for the future.

DISCUSSION

In ancient times, the means of transport were limited, forcing builders to adapt to the materials available in their local environment. Construction with earth offered advantages such as ease of transport and the possibility of being worked on site. Currently, this technique should become more relevant in the construction sector due to its sustainability and accessibility. However, historical perception has associated adobe with lower quality compared to industrialized materials such as concrete and steel, relegating it to areas with fewer resources or to exclusive architectural projects. One of the main challenges of adobe is its mechanical resistance, particularly in seismic regions. To address this problem, several studies have proposed the reinforcement of adobe by adding natural fibers. Boggiano Burga, Moreno Arellano, and Guzmán Gutierrez (2024), and De Posgrado, Virgilio, and Carrasco (2019), and Saroza, Rodríguez, Menéndez, and Barroso (2008) suggest that reinforcing adobe can improve its response to natural disasters, while Saroza et al. emphasize the importance of an adequate proportion of components in the mix to ensure its cohesion. In this sense, Altamirano found that the addition of Ichu can improve the resistance of adobe to a certain percentage, which highlights the need to determine optimal proportions in its application.

Ichu, an Andean herbaceous plant, has been extensively researched as a reinforcement material for adobe due to its structural properties. Its fibrous structure allows for a better distribution of stresses within the material, which increases flexural strength and minimizes crack formation. Vásquez Vásquez et al. (2021) found that the addition of 2.5% Ichu significantly improves compressive and flexural strength compared to pine fiber. However, Altamirano (2019) observed that an excess of Ichu in the mixture can reduce the workability of the material, affecting its mechanical strength. In addition, Hoyos (2020), and Taipe and Yaranga (2023) indicated that both the size and quantity of Ichu influence the resistance of adobe, since an excessive increase in these variables can decrease compressive strength, although it improves bending and water absorption. These results underscore the importance of finding a proper balance in the proportion of Ichu used in the mix. Figure 1 shows the compressive strength values obtained in previous studies for Ichu-reinforced adobes. It is evident that an addition of 5% Ichu provides the highest compressive strength (42.75 kg/cm ^{2}), while an addition of 1.2% straw shows the lowest resistance (12.89 kg/cm ^{2}).

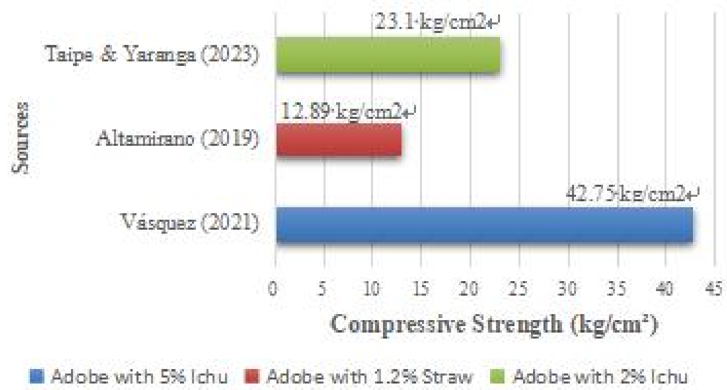

Figure 1. Compressive Strength (kg/cm2) in Adobe with the addition of Ichu

Note: The graph represents the comparison of the compressive strength of adobe with the addition of Ichu from data obtained in previous studies

Comparison with Other Natural Fibers and Additives

Other studies have explored the use of different natural fibers to improve the mechanical properties of adobe. For example, Chavez and Alva (2020) looked at coco coir, while Parisi et al. (2015) evaluated straw as reinforcement. In a comparative study, Marwan and Uddin (2016) and Carhuanambo Villanueva (2016) showed that banana fibers and wood chips can increase compressive and flexural strength, although with variations in water absorption.

The compressive strength values of adobes with different natural fibers are presented in Figure 2. It is noteworthy that banana fiber provides the highest compressive strength (67.1 kg/cm^2), followed by coconut fiber (36.83 kg/cm^2) and pine fiber (35.65 kg/cm^2). In contrast, adobe reinforced with bird feathers shows the least resistance (11.77 kg/cm^2). These results indicate that, although Ichu is an effective material to improve certain properties of adobe, other fibers may present greater advantages in terms of mechanical resistance. In addition to natural fibers, various additives have been evaluated as stabilizers of adobe. Balila and Vahdati (2024) proposed the use of bovine serum albumin, achieving significant improvements in compressive strength compared to traditional stabilizers such as cement and lime. Javiliano (2023) observed that the inclusion of eucalyptus ash increases the resistance of adobe, while Cacha (2024) reported similar improvements with the addition of bird feathers. However, some additives can negatively affect the resistance of adobe, as Villacaquí (2022) points out with the use of eucalyptus sawdust.

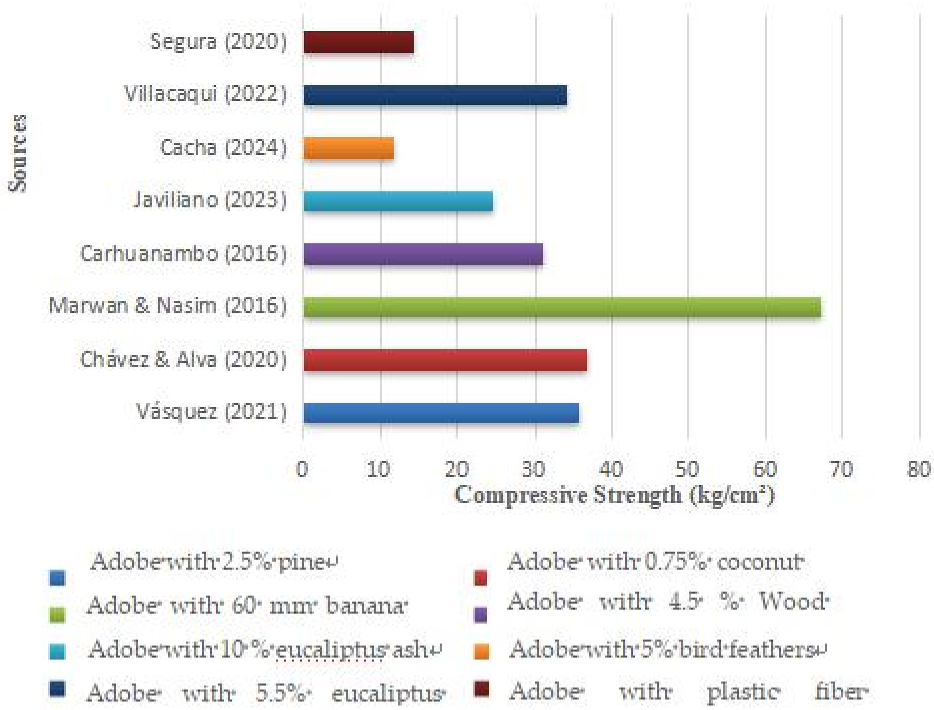

Figure 2. Compressive Strength (kg/cm2) in Adobe with the Addition of Other Natural Fibers

Note: The graph represents the comparison of the compressive strength of adobe with the addition of other natural fibers, where the data are those obtained in previous studies

Limitations of the Use of Ichu as a Reinforcement

While Ichu has proven to be an efficient booster in certain proportions, it has some limitations. Its excessive addition can hinder the workability of the mixture, reducing the compressive strength (De Posgrado et al., 2019). Likewise, studies such as Hoyos (2020), and Taipe and Yaranga (2023) show that the size and quantity of Ichu affect the cohesion of the material, which could compromise its structural performance. In terms of water absorption, although Ichu improves flexural strength, it can increase the porosity of adobe if its proportion in the mixture is not properly controlled. It is essential to emphasize that an accurate formulation of adobe mixture not only improves its mechanical properties, but also ensures its longevity and efficiency in practical applications. The granulometry of the Ichu and its interaction with the adobe matrix must be carefully considered to maximize its performance without compromising the manageability of the material.

CONCLUSION

More and more technicians and people in industrialized countries recognize the potential of earth as a building material in combination with additives and stabilizers, attracted by its bioclimatic advantages, its malleability and its compatibility with contemporary techniques. The conclusions of this study highlight the relevance of the addition of Ichu and other natural fibers to improve the compressive strength of adobe, based on a thorough review of previous studies and comparative analyses.

Firstly, it was determined that the addition of 5% Ichu to adobe optimizes its compressive strength, reaching values of 42.75 kg/cm^2. This finding builds on previous studies that looked at different ratios of Ichu and their impact on the mechanical properties of adobe. This ratio is considered to be optimal because it represents a balance between structural reinforcement and the workability of the mixture, avoiding an excessive concentration of fiber that could reduce the cohesion of the material and affect its performance in terms of compression.

Secondly, when comparing Ichu with other natural fibres, it was observed that banana fibres provide an even higher compressive strength (67.10 kg/cm^2). However, Ichu showed a superior performance to other fibers such as pine, coconut and shavings, whose resistance values ranged from 24.63 kg/cm^2 to 36.83 kg/cm^2. These results suggest that, although Ichu is an effective material, there are other fibers that could offer additional improvements in terms of structural strength.

Thirdly, best practices and ratios for mixing adobe with Ichu and other natural additives were identified. The literature review and data analysis indicated that the use of 2.5% to 5% Ichu in the adobe mixture generates adequate reinforcement without compromising the workability of the material. Studies have also shown that combining Ichu with stabilizers such as lime or other fibers, such as sheep's wool in proportions of 0.5% to 2%, can further improve compressive strength without negatively affecting water absorption or adobe's durability.

Finally, the results obtained offer valuable guidelines for the optimization of mixtures, thus improving the mechanical properties of reinforced adobe in traditional construction contexts. In particular, it was established that the incorporation of Ichu contributes significantly to compressive and flexural strength, increasing the ability of adobe to support loads and reducing the brittleness of the material. In addition, the control of the granulometry and the amount of Ichu is key to avoiding negative effects on the cohesion and workability of the mixture. These conclusions have practical applications for the development of sustainable and resilient constructions in high Andean areas and other environments where adobe continues to be a predominant material.

Recommendations

1. Conduct additional studies to determine the optimal proportion of Ichu under various environmental and soil conditions. This will allow a more precise standard to be established that maximizes the compressive strength of Ichu-reinforced adobe.

2. Since banana fibers have shown superior results in terms of compressive strength, it is suggested to further investigate their use in combination with Ichu and, based on this, compare their effectiveness in different proportions. This could lead to the creation of an even more robust and long-lasting mixture.

3. To evaluate the durability of adobe reinforced with Ichu and other natural fibers over time through accelerated aging tests and resistance to extreme climatic conditions. These studies can provide valuable information for practical application in construction.

4. To promote the adoption of adobe mixtures reinforced with Ichu and other natural fibers in sustainable construction projects, especially in high Andean regions. To this end, it is recommended to develop dissemination and awareness programs about the benefits of these mixtures, implement regulations and certifications that endorse their use, and encourage research and development through subsidies and government support. Collaboration with academic institutions and local communities is also essential to facilitate its effective implementation.

5. Train local builders on best practices and proportions for mixing, which could improve the quality and durability of traditional constructions. This can be achieved through practical workshops, accessible technical guides and the inclusion of this knowledge in sustainable construction training programmes.

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ETHICAL DECLARATION

Conflict of interest: No declaration required. **Financing:** No reporting required. **Peer review:** Double anonymous peer review.