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Evaluation of the Properties of Adobe Blocks with Clay and Manure

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Abstract: The development of new building materials that meet technological, economic, and environmental criteria has been highlighted in recent decades, especially regarding the use of alternative raw materials or new production methodologies. In this context, the objective of this project was to promote the development of adobe blocks using clay and manure, contributing to the sustainable development of the construction sector due to the use of adobe blocks, produced by the raw earth technique. Initially, the raw materials were characterized through chemical composition by XRF, mineralogical composition by XRD, granulometry, and Atterberg limits. Later, adobe blocks were produced manually, measuring 20 × 10 × 8 cm^3, using three dosing techniques: (i) blocks with clay and manure; (ii) blocks with clay, sand and manure; and (iii) blocks stabilized by Portland cement and hydrated lime. The tests evaluated were compressive strength, water absorption, and durability. The characterization results of the raw materials show that the material used in the research are suitable for production of adobe blocks. The mechanical parameters prove a disadvantage of adobe blocks: their low resistance. Even so, the results with the use of adobe improve the strength of the material, due to the solidification of the adobe structure. In addition, the use of stabilization, mainly Portland cement, allows the results obtained in the research to be compatible with other published articles. Thus, it is concluded that the use of manure and stabilization, such as Portland cement, improve the mechanical behavior and stability of the blocks, which increases the durability of the material.

Keywords: adobe blocks; manure; durability

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1. Introduction

In the civil construction industry, the need for the development of ecological building materials that contribute to the sustainable development of the sector is becoming increasingly clear. The production of ceramic materials, for example, consumes a high amount of natural raw materials, such as clayey soil and sand, in addition to the high energy consumption arising from the calcination process of ceramic products [1]. Some authors suggest that to produce 1 billion pieces of red ceramic, 1.5 million m^3 of clay, and 150 thousand tons of coal are needed, depending on the oven. This generates the release of 0.57 million tons of CO_2 and SO_2 into the atmosphere, aggravating the greenhouse effect problems [2,3].

One of the viable materials to perform this substitution is the adobe block, obtained by mixing clay, sand, and natural fibers in adequate proportions, without the need for a calcination step using a technique known as raw Earth [4].

As examples are the works by Trang et al. (2021) [3], where the authors used waste from a sewage treatment plant to produce ecological blocks. The authors obtained blocks

with satisfactory mechanical performance and highlighted other advantages of the material, such as thermal and acoustic insulation. Another interesting work was carried out by Mellaikhafi et al. (2022) [5], where the authors incorporated fiber from leaves of natural trees in adobe blocks, obtaining results of thermal performance superior to conventional blocks. Another interesting study was carried out by Calatan et al. (2017) [6], where the authors produced adobe blocks with recycled clay and natural hemp fiber. The results obtained by the authors indicate viability to produce adobe blocks, contributing to the environmental sustainability of masonry. This proves the feasibility of using organic waste in the production of adobe blocks.

In addition to the environmental advantages, it is possible to highlight economic advantages because of the application of adobe blocks replacing ceramic materials. This is because the absence of the firing step and the use of materials in their natural state, with almost no processing makes adobe products cheaper. A study by Imada et al. (2021) [7] presented the costs for producing 1 m^2 of masonry with different commercial blocks. It is observed that the cost of solid ceramic bricks is BRL 125.40 (USD 23.50), while those made of adobe cost BRL 64.05 (USD 12.00). These values are concomitant with the study by Trang et al. (2021) [3] and make clear the economic advantage of the adobe block.

However, the use of the material involves some disadvantages which will be explored in this research project with the aim of mitigating these problems. These disadvantages include: the slow construction process, reduction of the productivity of the material; adobe blocks having low tensile and flexural strength compared to conventional masonry; handcrafting the component requiring considerable human effort; need for a considerable area for drying the adobe blocks; difficulty obtaining regular dimensions in the adobe block; and one of the main problems is the fact that the blocks absorb a significant amount of water due to their high porosity, thus compromising their durability in places with high humidity levels [8–10].

Although adobe blocks have disadvantages, it is important to highlight the need for studies with this building material. Performing a bibliometric analysis using the Scopus database starting from the keywords adobe bricks, it is possible to obtain a total of 496 works published in the main journals over 20 years (the results of this analysis are included as Supplementary Materials). Although the database does not present all international journals in building materials, searches with other keywords, such as ceramic bricks, result in 3645 works at the same time. This highlights the urgency of work in the field of adobe blocks. Figure 1 presents the bibliometric study obtained in this project. Interesting words are highlighted, such as compression strength, water absorption, and durability. These analysis techniques were used in this research.

In this context, the objective of this work is to evaluate the effect of using clay and manure in the production of adobe blocks, evaluating parameters such as compressive strength, water absorption, and durability. These stand out as novelties, as shown in Figure 1: (i) absence of work using manure; (ii) low amount of work taking advantage of waste in adobes; (iii) lower proportion of work with adobe blocks in general.

The use of manure must be performed with care, due to the chemical-biological pathological process present in the material. Ren et al. (2021) [11] and Li et al. (2022) [12] points out that manure has a high content of Proteobacteria and Actinobacteria, a pathological condition that can cause diseases in humans if subjected to high content of the material. However, it is observed that the use of low levels of manure, in the order of 10%, is not enough to cause diseases in human beings. This information is proven in other studies [12,13], which used manures for other applications. Another interesting fact is that the use of binders, such as Portland cement and hydrated lime, helps to fix the manure and reduces these health problems. The use of these binders together with manure in adobe blocks is also a research topic in this article.

It should be noted that the use of binders (such as Portland cement and hydrated lime) reduces the ecological characteristics of the material, since only natural materials are used. However, some authors point out that the use of these materials increases the

useful life and durability of adobe blocks [14,15]. Therefore, indirectly, the use of binders has a positive impact on the behavior of the blocks and adobe, reducing the need to use more natural materials to replace the blocks that have been defined. In the long term, the use of these binders has a positive impact on the life cycle of adobe blocks highlighted by Arduin et al. (2022) [16], contributing to environmental advantages. According to these authors, even with the use of binders (Portland cement, mainly), the life cycle analysis of adobe blocks indicate that they are still more ecological than fired brick blocks.

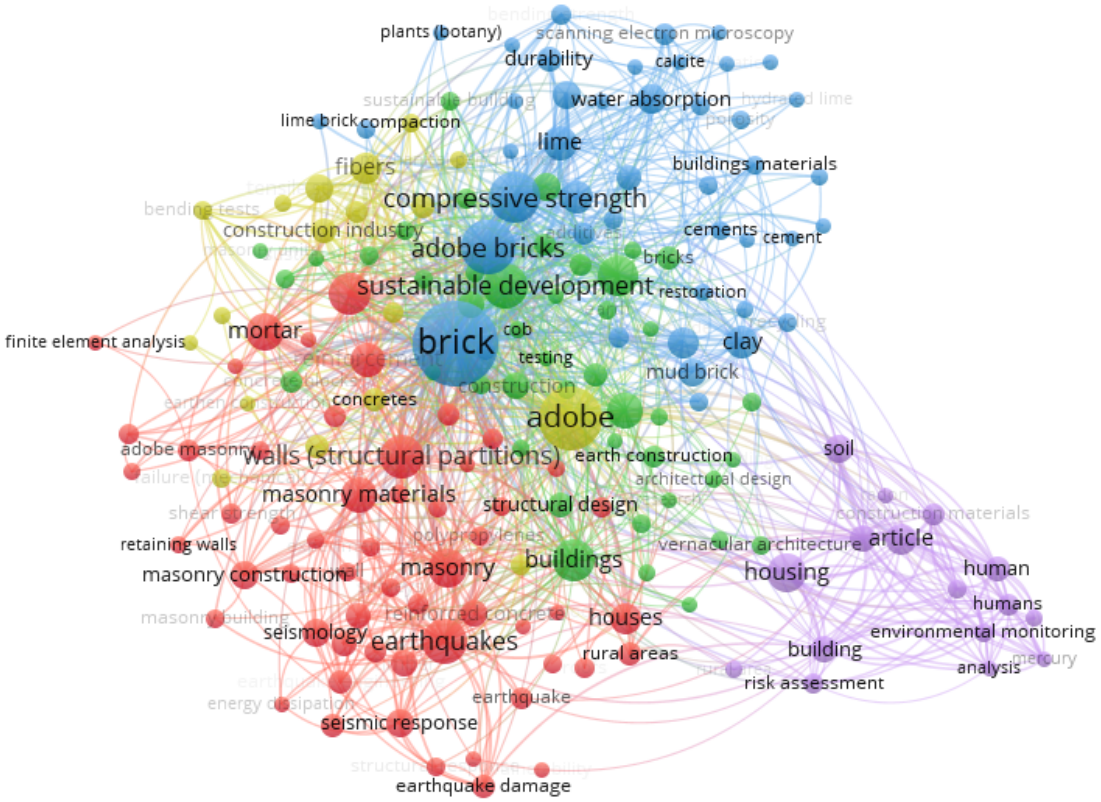


Figure 1. Bibliometric analysis of adobe blocks in the Scopus database.

In this context, the objective of this research is to evaluate the effect of using manure in adobe blocks produced with clay and clay/sand. Another objective is to evaluate the influence of Portland cement and hydrated lime on the behavior of adobe blocks produced with manure.

2. Materials and Methods

The materials used in the research were: clayey soil from Rio Paranaíba—MG, Brazil; quartz sand to correct the adobe mass; cattle manure as a source of organic matter (Figure 2) to improve the tensile strength properties of adobe and reduce the shrinkage effect; Portland cement and hydrated lime as stabilization to improve compressive strength.

The main raw materials to produce the blocks were characterized through qualitative mineralogical analysis of the raw materials carried out by means of X-ray diffraction analysis (XRD), using monochromatic Cu-Kα radiation at a high speed of 1.5° (2θ) per minute, in a conventional diffractometer; X-ray fluorescence spectrometry performed to define the chemical composition; granulometric analysis of raw materials determined through procedures in accordance with NBR 7181 (ABNT, 1984) [10], by the combined process of sieving and sedimentation; and Atterberg indices, through the definition of the liquidity limit according to NBR 6459 (ABNT, 2016) [11], and through the plasticity limit, according to NBR 7180 (ABNT, 2016) [12].



Figure 2. Manure extraction in Rio Paranaíba—MG, Brazil.

The compositions evaluated in the research are shown in Table 1. The first analysis performed is the influence of manure content. Adobe blocks containing only clay were produced, replacing this material with manure at levels of 0–15%. The percentages of manure evaluated (5, 10, and 15%) were chosen to evaluate another similar research project by Munoz et al. (2020) [17], where the authors evaluated the use of pulp waste at levels of 2.5–20%. Evaluating the results obtained, the authors concluded that considering the overall block performance, there was an optimal replacing ratio of 10%. Therefore, in the present research, it was decided to use 3 replacement percentages: 10%, which is the ideal according to the authors, one content below (5%), and another above (15%) was the ideal percentage found by Munoz et al. (2020) [17].

Table 1. Adobe proportions.

Composition	Clay		Sand		Manure		Cement		Lime		Water
Ref-0%	100%	1800.0 g	-	-	-	-	-	-	-	-	
Ref-5%	95%	1710.0 g	-	-	5%	90.0 g	-	-	-	-	
Ref-10%	90%	1620.0 g	-	-	10%	180.0 g	-	-	-	-	
Ref-15%	85%	1530.0 g	-	-	15%	270.0 g	-	-	-	-	
Mod-0%	65.0%	1170.0 g	35.0%	630.0 g	-	-	-	-	-	-	
Mod-5%	62.7%	1128.6 g	32.3%	581.4 g	5%	90.0 g	-	-	-	-	Between the LL and PL
Mod-10%	58.9%	1060.2 g	31.1%	559.8 g	10%	180.0 g	-	-	-	-	
Mod-15%	55.5%	999.0 g	29.5%	531.0 g	15%	270.0 g	-	-	-	-	
C-0% + L-0%	58.9%	1060.2 g	31.1%	559.8 g	10%	180.0 g	-	-	-	-	
Cem-10%	52.0%	936.0 g	28.0%	504.0 g	10%	180.0 g	10.0%	180.0 g	-	-	
Lime-10%	52.0%	936.0 g	28.0%	504.0 g	10%	180.0 g	-	-	10.0%	180.0 g	
C-5% + L-5%	52.0%	936.0 g	28.0%	504.0 g	10%	180.0 g	5.0%	90.0 g	5.0%	90.0 g	

Second, the effect of the sand content was evaluated. The compositions were produced with 5–15% of manure, presenting enough sand to correct the granulometry of the clay used. Finally, an analysis of the influence of Portland cement and hydrated lime on the production of blocks was carried out. The definition of the water content must be enough for the soil used to be in the plastic state. Therefore, some authors recommend the use of a moisture content between the liquidity limit (LL) and plasticity limit (PL). This information was extracted from the work of Trang et al. (2021) [3], Gandia et al. (2019) [18], and Mellaikhafi et al. (2022) [5].

The materials used to produce the adobe blocks were manually mixed in the appropriate proportions. The mixing process is carried out individually for each block, to ensure that the proportion used is adequate. Furthermore, it follows the same procedure adopted in the mixing of adobe blocks in real applications that was replicated in other studies [5,19]. The composition was used in the molding of the specimens, using wooden molds, in the dimensions of 20 × 10 × 8 cm^3. The blocks have curved corners, with an overhang of approximately 1 cm. After the production stage, the density of the blocks produced is 1.45 g/cm^3. The block production flowchart is shown in Figure 3.

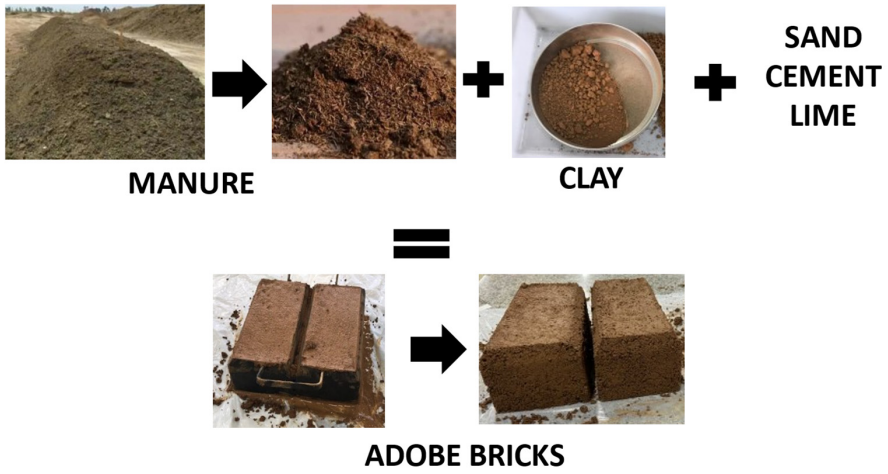


Figure 3. Flowchart of production of adobe blocks with clay and manure.

The samples were dried in the sun for a period of 28 days, after which they were used in the proposed tests. During the drying period, the ambient temperature range was 18–29 °C and the relative humidity range was 48 to 65%. Three samples were used for each test and for each composition proposed in this work, following the same amount of other research with adobe blocks [19]. The blocks used in the research are illustrated by Figure 4.

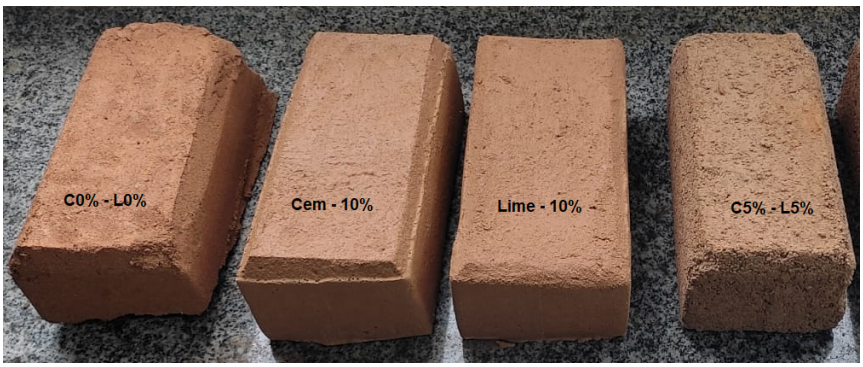


Figure 4. Adobe blocks used in the research containing manure.

After the drying period, the adobe blocks were tested using the following parameters: axial compressive strength, using a test speed of 0.5 mm/min, an INSTRON universal test press (INSTRON, Norwood, MA, USA; Figure 5); water absorption, using procedures adapted from ASTM C373 (2018) [20], for ceramic materials.



Figure 5. Compressive strength test.

Finally, durability tests were conducted through wetting and drying cycles, following an accelerated degradation procedure. The test consists of submitting the specimens to a period of 24 h of immersion in distilled water at an ambient temperature of 25 ± 2 °C, followed by a period of 24 h in an oven at 105 °C for evaporation of the absorbed water. This 48 h process completes a degradation cycle. Twelve cycles were performed on the evaluated adobe brick compositions. After the degradation procedure, the blocks are evaluated in terms of compressive strength and mass loss.

3. Results

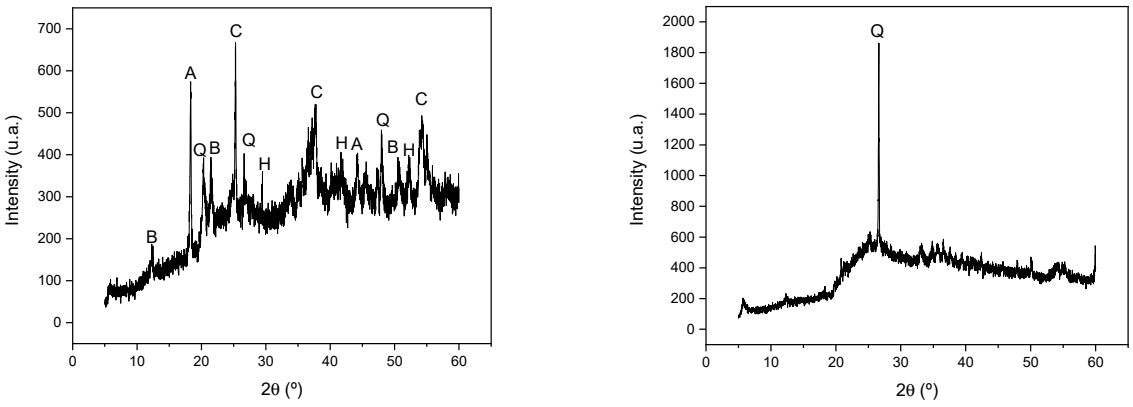
3.1. Characterization of Raw Materials

Table 2 presents the chemical composition of clay and manure used in the study. It is observed that the manure has a high content of SiO_2, Fe_2O_3, and Al_2O_3. The presence of SiO_2 indicates the possibility of contamination of manure with sand, while Fe_2O_3 and Al_2O_3 are typical of this type of waste [21,22]. About the chemical composition of the clay extracted in the municipality of Rio Paranaíba, MG where the research was conducted, it is observed that the presence of high content of Fe_2O_3 and Al_2O totals 72.52%. This is typical of red oxisols, common in the region [23]. It is still possible to observe the presence of SiO_2 and TiO_2. This information will be related to the mineralogical analysis results, discussed below.

Table 2. Chemical composition of clay and manure.

Composition (% in Weight)	SiO_2	Fe_2O_3	CaO	Al_2O_3	TiO_2	SO_3	K_2O	Others
Manure	37.75	29.30	3.34	17.53	5.25	2.49	2.85	1.49
Clay	12.97	21.87	0.96	50.65	10.80	1.87	-	0.88

Figure 6 presents the XRD results of clay and manure used in the study. It is observed that the mineralogical analysis of the manure suggests a large amorphous peak, which is expected due to the organic nature of the material. The only different peak is that of quartz, proving the contamination by sand of the material. The mineralogical analysis of the clay indicates the presence of quartz particles, considered the main contaminants in clayey soils [24,25]; kaolinite is a clay mineral typically found in tropical soils, being responsible for the plasticity property of clay; anatase and brookite are typical minerals of oxisols, coming from the presence of TiO_2 (10.80%) as indicated in Table 2. They add hardness to oxisols [26]. Finally, the presence of hematite is observed and attributed to the Fe_2O_3 content. This mineral is considered a dye in clays, being responsible for the reddish color of the material [27].



(**a**) (**b**)

Figure 6. Mineralogical analysis by XRD: (**a**) clay; (**b**) manure used in the production of adobe blocks. Caption: A = anatase; B = brookite; C = kaolinite; H = hematite; Q = quartz.

Table 3 presents the physical parameters of the clay, using the limits of liquidity and plasticity. As highlighted by Gandia et al. (2019) [18], Gandia et al. (2019) [28], and Santos et al. (2020) [29], the added water content must be adequate so that the mixture presents a humidity between the liquidity limit and the plasticity limit. This proves the need for characterization of raw materials when dosing the adobe compositions, using 40% water contents for all compositions, except for the composition with 10% lime as 4% more than water, totaling 44%.

Table 3. Physical parameters of clay.

Material	Liquidity Limit (%)	Plasticity Limit (%)	Liquidity Ratio (%)
Clay	41.21	29.48	11.73

Figure 7 shows the granulometry of the clay and sand used in this research. The sand must be used in adobe blocks as a corrector for the granulometry of the clay used. It is noteworthy that the sand used in the research is a material typically used as an aggregate in construction materials, with a DMC of 2.36 mm and a fineness modulus of 2.97. The amount of sand added must be sufficient to adjust the ideal particle size fractions. As highlighted by Gandia et al. (2019) [18], the ideal material to be used as adobe should have a clay + silt fraction of approximately between 35 and 45%, and a sand fraction between 50 and 60%. The clay used to produce the adobe blocks has a sand fraction of approximately 32%, according to the granulometric curve. This information leads to the need to use 530 g of sand for every 1000 g of clay. Making the calculations proportionally, the total material amount would be 1530 g, of which the sand fraction represents: 530 g + 0.32 × 1000 g = 850 g. This would represent a total of approximately 55.5% of sand fraction, following the recommendation of the authors of the area. By way of comparison, in the work by Gandia et al. (2019) [18], the authors used 600 g of sand for every 1000 g of clay. It is worth noting that these calculations are only approximate, as there is an experimental error in the percentage of sand in clay. The most accurate method would be to determine through particle discrete element method (PDEM), as established by Sun and Huang (2022) [30]. However, the calculations used are an estimate to verify whether the selected raw materials are suitable to produce adobe blocks.

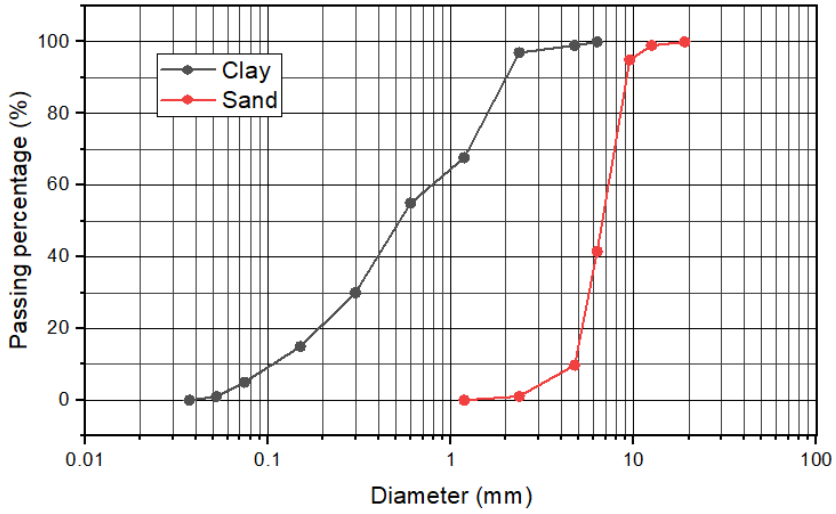


Figure 7. Granulometry of the materials used in the production of adobe blocks.

3.2. Parameters of Adobe Blocks

Figure 8a presents the compressive strength results of adobe blocks containing only clay and manure. It is observed that the values obtained for the composition with 5% manure were around 130 kPa, higher than those for the composition without manure, around

115 kPa. This increase in strength with the use of manure is related to the densification of the material matrix. These blocks harden by drying the clay used in the production of blocks [19,31]. The presence of fibrous material helps to gain mechanical strength [32]. However, values greater than 10% impair the performance of adobe due to the high presence of organic material in the material. It is noteworthy that in these compositions, high shrinkage was observed, due to the absence of sand in the blocks [33]. As highlighted by Gandia et al. (2019) [18], the presence of sand particles in the adobe block is necessary for the shrinkage to be controlled.

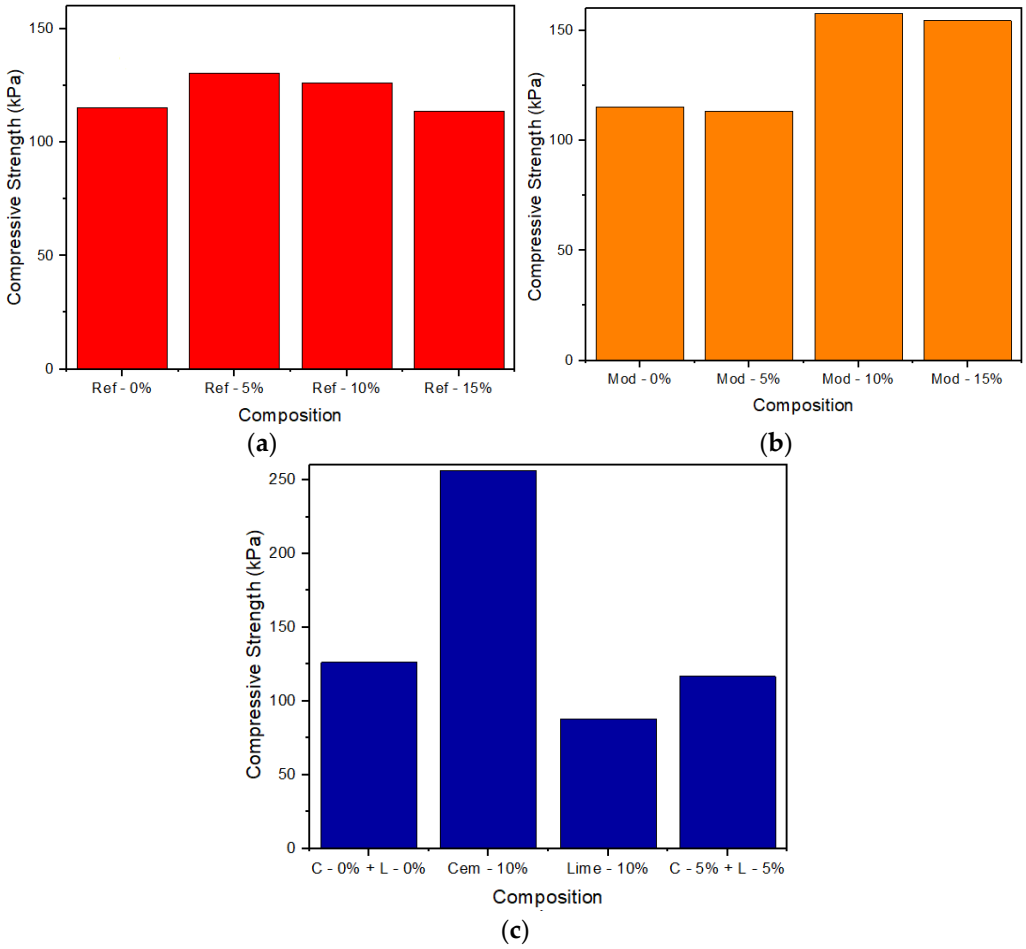


Figure 8. Compressive strength results: (**a**) adobe blocks with clay and manure (Ref-0%, 5%, 10% and 15%); (**b**) blocks containing sand (Mod-0%, 5%, 10% and 15%); (**c**) blocks containing cement and lime (C-0% + L-0%, Cem-10%, Lime-10%, and C-5% + L-5%).

Figure 8b presents the compressive strength results of adobe blocks containing clay, sand, and manure. It is observed that the strength values of the blocks containing sand had an increase, with the block containing 10% of manure reaching almost 160 kPa. This happens due to the control of retraction and is in accordance with what is defended by the authors of the area. Figure 8c shows the compressive strength results of the adobe blocks containing the stabilization materials. It was decided to include cement and lime in the Mod-10% composition, which had the best mechanical results. In this analysis, the stabilization effect of Portland cement is clear, with the mechanical strength reaching almost 260 kPa. However, lime stabilized blocks did not have the same effect, which can be attributed to the nature of this binder, which hardens in a slow reaction with atmospheric air [34]. Although the values seem low, it is noteworthy that the values are consistent for adobe blocks with manual molding: Sharma et al. (2015) [35] obtained adobe blocks with natural fibers (*Grewia Optivia* with a diameter of 0.48 mm, a length of 324 mm and an elongation at

break of 10.68%) presenting compressive strength in the order of 190 kPa; Hussain et al. (2022) [36] presented blocks with resistance in the order of 300 kPa; Silveira et al. (2013) [10] presented blocks with strength in the order of 300 kPa; Salih et al. (2020) [37] highlights that adobe blocks produced by hand by molding do not reach the same strength parameters as blocks produced by extrusion or pressing.

Figure 9 presents the Load × Displacement curve for the reference compositions (C-0% + L-0%) and Cem-10% composition. It is important to point out that although 3 experimental units were used, the curves obtained show similar behavior. The Cem-10% composition showed maximum load results ranging between approximately 350 and 410 kgf, while the C-0% + L-0% composition showed loads ranging from 150 to 300 kgf. It is also verified that the Cem-10% composition, in addition to presenting higher strength values, presents greater displacement until failure.

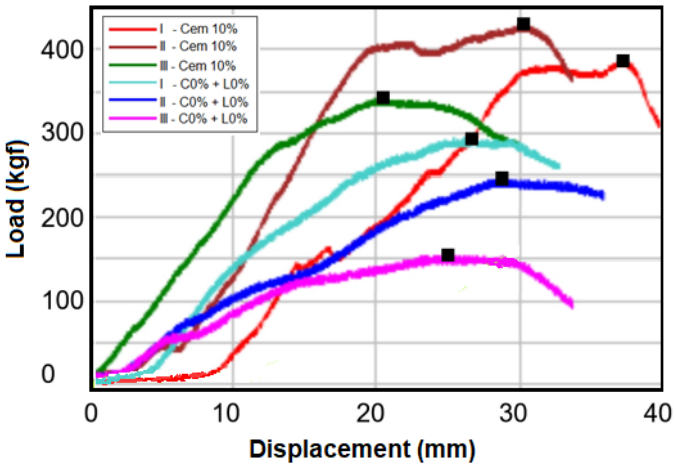


Figure 9. Load × Displacement curve for Cem-10% and C-0% + L-0% compositions.

Water absorption (Figure 10) and durability (Figure 11) tests were carried out. Both tests are extremely relevant since the main degradation mechanisms of adobe blocks happen by water attack. The water absorption values reduced with the use of cement and lime. The effect was more intense with the use of lime since the material has high water retention. The values for the composition with 10% of cement were around 25%, which is compared to the values found by Millogo et al. (2008) [38], whose results were between 20–30%; and equivalent to the research by El-Mahallawy et al. (2014) [39], whose water absorption was around 25–28%.

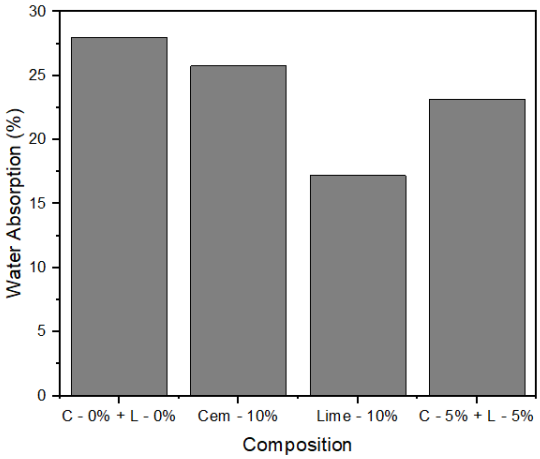


Figure 10. Water absorption results for the adobe blocks with manure.

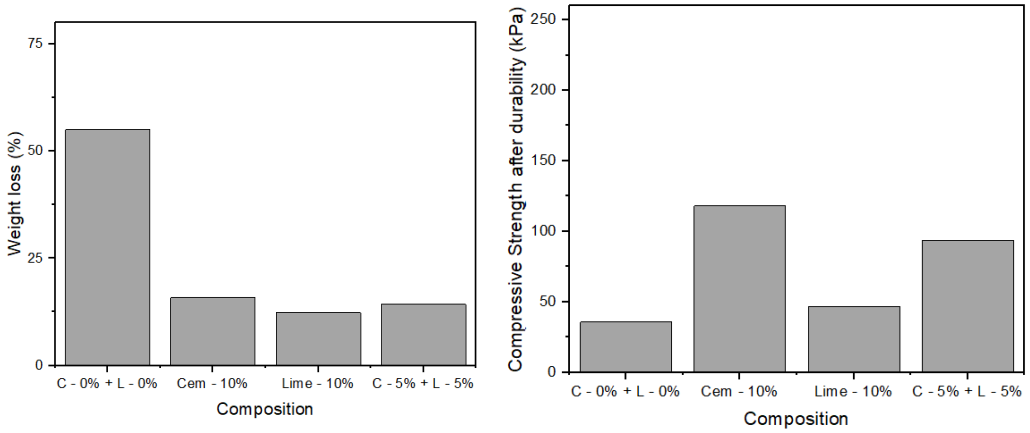


Figure 11. Durability results for the adobe blocks with manure: (**a**) mass loss; (**b**) compressive strength.

Regarding the durability results, it is possible to notice that there was a drop in the compressive strength of the adobe blocks. This can be attributed to the degradation of the clay structure because it is not a binder, and because it does not undergo an effective firing step, the material is not stable in water [10,37,39]. It is observed that for the composition containing 10% of cement, the drop was from approximately 260 kPa to approximately 120 kPa, a drop of approximately 45%. Regarding the mass loss values (Figure 11b), it is observed that they were around 15% for the composition containing 10% cement. This value is very promising since the mass loss in durability cycles is very high for adobe blocks and can make the application of the material unfeasible. By way of comparison, Castrillo et al. (2021) [40] obtained a mass loss of 80% for the reference composition of their research. This indicates that the block degradation was too excessive. Therefore, the degradation values around 15% are very promising.

4. Conclusions

Based on the results of this research, it is possible to conclude:

- The raw materials used to produce the blocks are adequate. The clay used has chemical and mineralogical parameters that characterize it as a Red Latosol, with potential for adobe blocks. This was confirmed by the presence of anatase, brookite, kaolinite, and hematite. The manure used has organic material with quartz as an impurity.
- The compressive strength results demonstrate the need for clay granulometric correction with the use of sand. Including this material, the resistance increased from approximately 115 to 160 kPa. The use of manure contributes to the compressive strength. This happens because the material densifies the adobe blocks, improving their behavior when subjected to loads.
- In addition, the need to stabilize the blocks with the use of Portland cement became clear. This binder contributes to the mechanical resistance of adobe blocks, information known based on another research. The compressive strength values are compatible with the international bibliography.
- The results of water absorption and durability demonstrate that adobe blocks produced with clay and manure, corrected with sand, and stabilized with cement are stable in the presence of water. This result is very promising and reflects a mass loss of approximately 15% in the stabilized blocks.

As a suggestion for future works, the production of adobe blocks with clay and manure by pressing or extrusion is recommended. This change in the production of blocks, which was done manually, can be a path to improvements in mechanical properties.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/buildings13030657/s1.

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