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TOWARDS THE RESCUE OF A CONSTRUCTIVE CULTURE OF MORTARS WITH TRADITIONAL CONSTRUCTION MATERIALS AND TECHNIQUES FOR A CORRECT PATRIMONIAL INTERVENTION

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Abstract. This research seeks to establish the proper use of traditional materials such as: lime, mud, mountain, straw and nopal mucilage; to be applied in restoration from the investigation of the mechanical behavior of the new dosages. The traditional materials used in testing new mortar designs, are from the San Diego convent in the city of Quito. Three new mortar dosages were designed with different percentages in each of its elements. The purpose of the investigation is to obtain different parameters to make a comparison between each of the mechanical tests such as: compression, bending, and traction to which the new models were subjected. The traditional materials used are of similar characteristics to those found in the investigation of ancient mortars. In the experimental study, the new specimens were subjected to mechanical tests in which the characteristics and resistance to compression, tension, and bending were obtained and determined. These new dosages were experienced at different ages such as: 14, 21, and 56 days. All new specimens were kept in the same temperature and humidity conditions existing in the laboratory. Under these parameters, the dosage that met the best characteristics for an architectural restoration process was established.

Keywords: traditional materials, dosages, mortars, tests and restoration.

HACIA EL RESCATE DE UNA CULTURA CONSTRUCTIVA DE MORTEROS CON MATERIALES Y TÉCNICAS CONSTRUCTIVAS TRADICIONALES PARA UNA CORRECTA INTERVENCIÓN PATRIMONIAL

Resumen. Esta investigación busca establecer el buen uso de los materiales tradicionales como: cal, barro, paja de monte y mucilago[1] de nopal; para ser aplicados en la restauración a partir de la investigación del comportamiento mecánico de las nuevas dosificaciones. Los materiales tradicionales utilizados en el ensayo de los nuevos diseños de morteros, son los que se obtuvieron como resultado de la investigación realizada a los morteros originales del convento de San Diego de la ciudad de Quito. Se diseñaron tres nuevas dosificaciones de morteros con diferentes porcentajes en cada uno de sus elementos. El propósito de la investigación es obtener diferentes parámetros para realizar una comparación entre cada uno de los ensayos mecánicos como: compresión, flexión y tracción a los que fueron sometidos los nuevos modelos. Los materiales tradicionales utilizados son de similares características que los encontrados en la investigación de los morteros antiguos. En el estudio experimental las nuevas probetas se sometieron a pruebas mecánicas con las que se obtuvieron y determinaron las características y resistencia a la compresión, tensión y flexión. Estas nuevas dosificaciones se experimentaron a distintas edades como: 14, 21 y 56 días. Todas las nuevas probetas se conservaron en iguales condiciones de temperatura y humedad existentes en el laboratorio. Bajo estos parámetros se llegó a establecer la dosificación que cumplió las mejores características para ser utilizada en un proceso de restauración arquitectónica.

Palabras claves: materiales tradicionales, dosificaciones, morteros, ensayos y restauración.

Introduction

The study shows the complexity and interest in determining the characterization of old mortars of monumental buildings belonging to the Historical Heritage. Our interest is to establish the feasibility of safeguarding and correct restoration of the heritage with the use of new mortars appropriate for rehabilitation. These should be as similar as possible to the original ones both in materials and in traditional construction techniques to maintain the values of the heritage work.

Mortars prepared with traditional materials and techniques have been used throughout time as construction elements, both for private buildings and for monumental works. Within the city of Quito, Ecuador, there is an important Historic Center where colonial architecture built with traditional materials can be found. One of the important buildings that maintains much of its original construction is the convent of San Diego, where we find walls of mud, adobe, brick, stone, suro, chaguarquero, and wood, in general (Universidad de Las Américas, 2016).

The Municipality of the Metropolitan District of Quito is the entity in charge of applying a management policy focused on revitalizing historic areas recognized as essential elements of the local identity and maintaining the value of the historic ensemble of heritage elements, in order to guarantee their permanence in time through monumental restoration. Unfortunately, in certain restoration projects, there is evidence of a lack of adequate studies, coupled with the lack of specialization and professional knowledge of certain executors, the lack of research in the area of architectural restoration, and the

[1] Organic substance of viscous texture, similar to gum, obtained from nopal cactus by means of the aqueous extraction system

absence of proper monitoring of management policies applied to the intervention of heritage buildings has led to the fact that some projects, after a short time of having been recovered, have to be intervened again.

The appearance of Portland cement has caused the use of traditional materials for joints, masonry, and plastering to be reduced, causing their near disappearance in the use for construction in general and in the field of restoration, causing a loss in the historical authenticity of heritage buildings (Usedo, 2015).

This research aims to contribute with knowledge on the use of traditional materials for a correct restoration and recovery of heritage buildings. For this purpose, it was necessary to analyze the old mortars of a colonial building. In this case, the selected building was the convent of San Diego in the city of Quito.

Figure 1. Main façade of the "San Diego" convent. Quito, Ecuador
Note: Source*:* Own elaboration, 2021

Research design

This research has an experimental methodology to establish the behavior that is presented during the intentional manipulation of the materials (lime, mud, straw, nopal mucilage), which are used in the elaboration of the new mortars. The mechanical measurement of tension, compression and bending, to which all the specimens of the new mortars were subjected, was carried out. The values obtained allowed a quantitative measurement reading to be made, which is used to compare the proposed mortar models. With these results, we will proceed to evaluate which one or ones have the best physical and mechanical properties to be used in an architectural restoration process.

The ASTM C305 method is used to obtain the values to determine the mechanical qualities of the new mortars tested (Hernández, Collado, and Baptista, 2014).

Analysis of original mortars

For the present study, eight (8) samples were taken, each of them from different construction stages (four periods[2]) of the *San Diego convent.* The samples were taken from a historic monument, so we respect the criterion that this heritage property cannot

[2] Periods of construction of the San Diego convent

be altered. The ecclesiastical authorities decided the site and the amount of sample that could be taken (Kennedy Troya & Ortiz Crespo, 2010).

The analysis of the ancient mortars was performed in the chemistry laboratory of the National Institute of Cultural Heritage (INPC[3]), the investigation of the specimens for research was based on standards and methods such as, for example: ASTM C267 - 01(2012), PEE-LABINPC-04, Hernández, Pfeiffer Perea, & Cano Barrita, (10 of 1 of 1 of 2018). This study allowed to know the characteristics, properties and variants of the mixtures, all the mortars were subjected to several evaluations such as: the observation

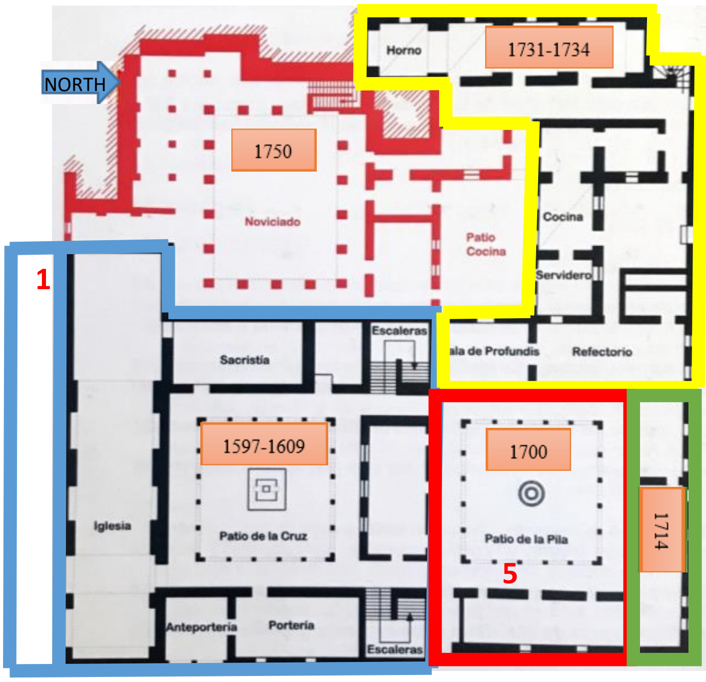

Figure 2. Delimitation of the construction periods of the San Diego Convent with the sampling points.
Note. Source*:* Own elaboration, 2019

petrographic analysis, volumetric and granulometric analysis, elemental chemical analysis, and the presence or absence of organic additives in the mortars were also analyzed. This information allowed us to know the structure of the original mortar, composed of lime, mud, bush straw, and cactus mucilage (Silva Cascante et al. 2020).

Based on the analysis of the old mortars and using the results of the general composition of the samples analyzed, research was started on the new mortars prepared with traditional materials. These studies expose the composition percentages of each original mixture, being the basis for preparing three (3) new dosages. This will establish the most appropriate combination to be used in architectural restoration processes.

The reference values are obtained by scanning electron microscopy analysis (SEM-EDS) on the originals. This procedure consists of obtaining the chemical and microscopic composition of each of the materials, determining the chemical structure of the fragments analyzed, and establishing the morphological characteristics and

[3] National Institute of Cultural Heritage (INPC)

combinations. These data will serve as the basis for new dosages to be applied in another mortar (INPC, 2019).

Table 1
General composition of old mortars

SAMPLE	% Lime as (CaCO3)	% Mud	% Vegetable fibers	% Mucilage [4]
19-07-05	8,06	76,28	1,23	9,42
19-07-6	18,19	74,79	1,03	5,99
19-07-7	3,64	92,97	1,74	1,88
19-07-8	10,90	85,73	1,74	1,63
19-07-9	3,52	87,88	1,11	1,49
19-07-10	11,35	85,72	0,99	1,93
19-07-12	3,79	95,61	-	-
19-07-13	4,58	93,48	1,62	-

Note: Source*:* INPC Chemistry Laboratory, 2020

Dosage approach for the production of new mortars

The samples obtained of original mortars from the different stages of construction of the San Diego convent are made of lime, mud, straw, and cactus mucilage. The goodness, characteristics, and proportions of these traditional mortars were also established. The research made it possible to recover part of the ancestral knowledge about the value and quality of the traditional materials.

To make the new formulations, the highest values of the original mortars analyzed were considered; in this way, the mathematical average was used to establish the new dosages with which the laboratory experimentation of the new mortars was carried out.

Table 2
Dosages for the experimentation of the new mortars

Mortar type	Cal	Mud	Nopal slime	Bush straw % of
Type 1 mortar	2	6	1	1%
Type 2 mortar	1.5	6.5	1.5	1%
Type 3 mortar	1	7	2	1%

Note: Source*:* Own elaboration, 2021

[4] Organic substance of viscous texture, similar to gum, obtained from the nopal plant by the aqueous method.

The experimental test was carried out in the soil laboratory of the Universidad Católica de Quito (PUCE), which conducted the study under the American standards ASTM C305: *Standard Test Practice for Mechanical Mixing of Hydraulic Cement of Hydraulic Cement pastes of Plastic Consistency,* from which the mortars' interpretation values were obtained.

For the new models, the volumes of each material were formulated and their proportions are a function of volume and weight of the different ingredients used. For their interpretation: lime (binder); mud/nopal mucilage (vegetable additive); mountain straw (% of volume of the mixture). For purposes the proportion was: (1:5:2:2%).

For this test of the new dosages to be analyzed, 27 specimens were taken for each new sample, i.e., a total of 81 models were made with which the mechanical tests were performed, which were tested at "14, 21, and 56" days of age with each prototype.

The mechanical tests carried out were as follows:

Compression. - fm=P/A

Tension/Traction. - RT=50*Max Load/Cross-sectional Area

Bending. - K ring=3.43 kg/1/10000

Material selection

The mortars used in restoration are characterized by their nature, their history, their structural behavior, low cost, easy to replace, and compatible with the environment as well as their constituent parts are the aggregates, binders, and additives; according to the analysis obtained from the investigation of the old mortars, traditional materials, such as lime, mud/clay, moor straw, and cactus slime were selected.

However, it is worth mentioning that in the country (Ecuador) there is no quality control on the stone materials that are used in construction, despite the existence of the Ecuadorian Construction Standard (NEC) (NEC-SE-MP), which is in force since January 10, 2015, and its compliance is mandatory; thus, the control on traditional materials is null and in this case we proceed to look for local materials that maintain similarities with the original materials that are part of the building to be intervened.

Cal

Historically, lime is the most used product and currently of necessary use and interest in conservation, considering that this material is not very industrialized and commercialized in our environment. In addition, there is no certified brand of production that complies with national standards; in spite of this, it is possible to obtain it in certain points of sale, it can be acquired as quicklime (in stone) to undergo the slaking process. For this research, slaked lime was used (Pinganrrón and Villaseñor, 2013).

However, it is essential to determine the good quality of the limestone, which must have a high calcium carbonate content and be adequately hydrated to obtain the lime paste, for which different requirements must be met:

To make a careful selection of the limestone, which must have enough purity.

1. One of the indispensable requirements is that the limestone must have a high degree of burned out (900 °C).
2. Another factor that must be taken into account is the slaking process of limestone. This depends on the amount of water and the time it is kept submerged, i.e., if the

slaking time is longer, the paste will be of higher purity and better quality (Villalobos Ruiz, 2014).

Figure 3. View of slaked lime
Note: Source*:* Own elaboration, 2019

In the experimentation, slaked lime was used since the research of old mortars determined its presence in the analyzed mixtures. For its application, the study of quicklime and its similar in water (slaked lime) was carried out to reach the results these were subjected to FTIR-ATR analysis.

Mud / earth

Mud or clay is the finest disintegrable material of the earth that forms part of the natural soil. According to its formation, the mineral that predominates in a clay will determine its volume, which is established by its location and collection site. In addition, it should be considered whether these are of inorganic character, i.e., they are the product of the decomposition of rocks or organic originate from the decomposition of living organisms. These are the factors that determine the characteristics of existing clays and establish their different uses (La Spina, 2014).

For this experimentation, ancestral knowledge on the use and management of traditional materials was used. First of all, a visual verification of the sector where excavation was carried out to collect the soil was made, it was evidenced that it was free of organic impurities, a factor that helped to determine that the clay of this site is suitable or not to be used in the elaboration of the mixtures. The most adequate soil (mud/earth) was extracted prior to the excavation at an adequate depth. The soil with the best characteristics for construction use is generally collected at a depth of 50 centimeters from ground level, as it is the most appropriate and has a varied granulometric composition, which allows the soil to remain more stable by modifying its moisture conditions (Gatti, 2012).

Figure 5. Selected mud view
Note: Source*:* Own elaboration, 2019

Nopal mucilage

The nopal (Opuntia ficus-indica) is a cactus from which an organic substance known as mucilage is obtained in the field of construction in general and specifically in the restoration plays the role of adhesive. This material is a biopolymer that waterproofs and binds materials in this case to traditional materials, such as earth and lime. This nopal gum improves the mechanical characteristics in mortars. The selected nopal cactus should be 2 to 3 years old. The stalks should be approximately 25 to 30 cm long and should be cut at the bottom of the stems.

To use the cactus stalks, the thorns are cleaned and then washed in drinking water in order to prevent them from becoming embedded in the skin, facilitating its handling, then cut into small square pieces about 2 cm, a step that facilitates the extraction of mucilage.

There are several methods for the extraction of cactus mucilage and its application in traditional construction, especially in restoration (Martínez et al., 2008).

Some ways to perform the extraction are:

1. Cold (room temperature) aqueous extraction process.
2. Cooking extraction process (at an average temperature of 90º C).
3. Drying process (dehydration of the cactus paddle), then the paddle is subjected to a grinding process, and finally the cactus powder is obtained to be used in the blends.

For this experiment, the mucilage was extracted using the cooking method to obtain the greatest amount of the product. This method was preferred because in the study carried out on traditional mortars, it was determined that the cooking method was used. The comparison standards used to determine the presence of an organic vegetable additive were mucilage obtained at cold (room temperature) and cooking (90º C) **(Silva Cascante et al., 2020)**.

The mucilage obtained by firing has a thicker, adhesive, and light green structure, according to the spectrum found in the analysis of ancient mortars.

Figure 7. View of the nopal obtained by cooking (mucilage*)*.
Note: Source*:* Own elaboration, 2019

Paramo straw

For the study of the new mortars, paramo straw of native origin (Calamagrostis effusa), a plant from which a natural fiber is obtained, is a plant characteristic of semi-arid areas and is found at an altitude of more than 3,000 m. and grows naturally. It has a composition of lignocellulose (combination of lignin and cellulose), the amount of straw provided by the plant is given by its variety and age. This fiber is biodegradable and low cost.

In addition, there are several types of straw as an agricultural by-product, dried stalks of cereals, such as wheat, barley, rye, and other species that are used in the field of traditional construction.

In the analysis of ancient mortars, this element of organic origin was found, which improves the mechanical characteristics of the final product. For its use, it is recommended that the straw be in a dry state, that the plant should be cut at full moon, and dried in the open air by means of the sun's rays to avoid rotting; this natural fiber in the mortars in the drying process prevents the plaster from cracking without altering the characteristics of the traditional materials, preventing the erosion of the plaster.

In the experimentation of the new mixtures, straw was used in a dry state and with an average length of 2 to 4 cm in length (Sánchez, 2012).

Figure 8. View of the weighing of the paramo straw
Note: Source*:* Own elaboration, 2019

Experimentation

For this research, data obtained from the study of the original mortars of the building of the San Diego convent were used to determine the components and composition percentages of the analyzed mixtures. On this basis, it is intended to demonstrate that coatings made with traditional materials, such as lime, mud, mountain straw, and cactus mucilage can be a solution for an appropriate restoration. These dosages should have similar characteristics to the traditional mixtures, with properties, such as durability, permeability, and compatibility with the materials that make up the building.

The objective of carrying out this test through a laboratory is to measure, by means of the tests, the capacity to withstand the different mechanical stresses to which the specimens are subjected. To achieve this objective, three new formulations were designed, different from each other, but with the same type of material: lime, mud, and cactus mucilage. They are interpreted in volume and the straw is a percentage (1%) in relation to the sum of the total volume of the three previous ones. The standard dosages are shown in tables 3, 4 and 5.
Interpretation of the dosage:
(Mud: lime: mucilage: straw in % of the volume of the mixture).

Table 3

Dosage of the new formulation mortar No. 1

DOSAGE NO. 1		
	Measurement / Weight = 167.92 gr.	
Material	Proportions	Weight (gr)
Mud (B)	7	1175.44
Lime (C)	1	244.00
Nopal Mucilage	2	309.88
Straw (P)	1% of total weight of B+C+N	17.29

Note: Source*:* Own elaboration, 2019

Table 4

Dosage of the new formulation mortar No. 2

DOSAGE NO. 2		
Measurement / Weight = 167.92 gr.		
Material	Proportions	Weight (gr)
Mud (B)	6.5	1091.48
Lime (C)	1.5	366.00
Nopal Mucilage	2	229.80
Straw (P)	1% of total weight of B+C+N	17.29

Note: Source*:* Own elaboration, 2019

Table 5

Dosage of the new formulation mortar No. 3

DOSAGE NO. 3		
Measurement / Weight = 167.92 gr.		
Material	Proportions	Weight (gr)
Mud (B)	6	1007.52
Lime (C)	2	488.00
Nopal Slime	1	154.94
Straw (P)	1% of total weight of B+C+N	17.29

Note: Source*:* Own elaboration, 2019

The experimentation of the models of the present study is based on the breakage of the samples in different tests where the mechanical resistance to compression, tension, and bending is measured. For each of the tests, 27 samples were taken for each formulation. The experimentation of each sample was tested at "14, 21, and 56 days" of age of each model.

Figure 9. View of *test* specimens
Note: Source*:* Own elaboration, 2019

To weigh the materials, a container was used as a unit of volume, with a capacity of 170 g (1 unit), which was used to weigh the new formulations.

In the elaboration of the models for the different mechanical tests, different molds were used. Their shapes vary depending on the type of mechanical test to be performed; thus, we can indicate:

- Mold for *compression* test, cube-shaped, 5.0 x 5.0 x 5.0 cm.

Figure 10. Mold for compression test
Note: Source*:* Own elaboration, 2019

- Model for *bending* test. It has a rectangular bar shape of 16.0 x 4.0 x 4.0 cm.

Figure 11. Mold for flexural test
Note: Source*:* Own elaboration, 2019

- Matrix for the *traction* experiment. It has the shape of a bow tie and its dimensions are 7.5 x 2.5 x 4.0 cm.

Figure 12. Mold for tensile test
Note: Source*:* Own elaboration, 2019

The mixtures were carried out mechanically. A three-speed industrial *mixer* (*mortar mixer*) was used, with a paddle for mixing. In this research, the mixing of the different materials was done at a low speed, and fixed mixing times were used for each material added. The times used per sample were:

- Mud + straw for 30 seconds.
- Addition of lime for 30 seconds.
- Addition of nopal mucilage for 60 seconds.

In order to make the mixture more homogeneous, the mortar was subjected to an additional 30 seconds of high-speed mixing.

Figure 13. Industrial mixer
Note: Source*:* Own elaboration, 2019

With the final mixture, we proceed to fill each of the prototypes. This is done manually; the mixture is poured into each of the molds in two stages. Between each of the periods, each layer will receive 15 strokes so that the mixture fills all the voids and the air leaves the mold. Once the filling of the prototypes is completed, they are subjected to a drying process inside the mold at room temperature for a period of 7 days. After this period, the matrices were disassembled and the specimens were removed, which were then subjected to a curing process. When the models reached the programmed age cycles for the tests (14, 21, 56 days), they were subjected to the different mechanical tests.

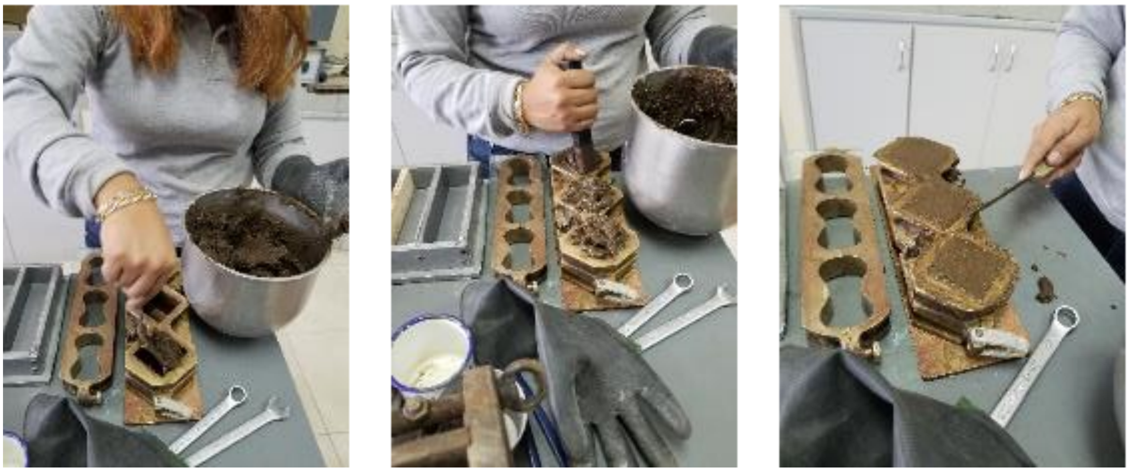

Figure 14. Mold filling process
Note: Source*:* Own elaboration, 2019

The results of the mechanical tests performed on each of the dosages were collected through direct observation and were recorded in Excel tables. Likewise, the necessary information was analyzed, interpreted, and obtained to arrive at the final result of each of the tests.

Subsequently, each of the results were analyzed to establish possible inconsistencies, errors, and correct them if necessary. All the information collected was carefully verified in order to write the final report of the tests recorded in standard forms of the soils laboratory of the Catholic University (PUCE).

Mechanical laboratory tests

To identify, determine the quality, and establish the best characteristics of the mortars, the specimens were subjected to the following mechanical tests in the laboratory:

Compression. - fm=P/A

Compression testing of the mortars was performed in accordance with ASTM C109: *Standard Test Method for Compressive Strength of Hydraulic Center Mortars (using 2-in. or [50-mm] Cube Specimens).*

For each mortar, three specimens per dosage were prepared for each breaking age. Three units per model were broken, obtaining three resistance records. The average between the three values obtained for each age of breakage was made in order to perform an analysis of the characteristics of each specimen.

Figure 15. Compression test specimens

Note: Source*:* Own elaboration, 2019

Figure 16. Schematic of compression rupture test.

Note: Source*:* Own elaboration, 2019

Tension/Traction. - RT=50*Max Load/Cross-sectional Area

Tensile tests were performed on the new dosages under AASHTO T132: *Standard Method of Test for Tensile of Hydraulic Cement Mortars.*

For the determination of the mortar's tensile strength, as in the other tests, three samples were used per dosage for each age of rupture proposed, with the strength data obtained from each sample. The average of the three values obtained from each sample analyzed was taken to evaluate its characteristics.

Figure 18. Tensile test specimens

Note: Source*:* Own elaboration, 2019

Figure 19. Tensile stress rupture test scheme.

Note: Source*:* Own elaboration, 2019

Bending. - K ring=3.43 kg/1/10000

Flexural tests were performed in accordance with AST C348: *Standard Test Method for Flexural Strength of Hydraulic - Cement Mortars.*

The execution of the tests to establish the flexural strength of the new dosages were also carried out with three specimens for each mix for the programmed breaking ages. For each period, three specimens were tested and their results were recorded and the arithmetic mean was calculated with their values, which are used to evaluate their characteristics.

Figure 21. Flexure test specimens

Note: Source*:* Own elaboration, 2019

Figure 22. Schematic of flexure rupture test.

Note: Source*:* Own elaboration, 2019

Results

In the laboratory research process, the mechanical characteristics of the mortars were demonstrated by means of compressive, tensile, and flexural strength tests for each new dosage analyzed, according to the methodology proposed in the research. Results were obtained for the strengths of the three new dosages at ages of 14, 21, and 56 days; according to the established test times, it can be established that the three dosages present an ascending behavior in their strength in relation to the age of the test.

The compressive test data are recorded in a table of average results by age of rupture in which it can be observed that dosage 1 has a better compressive strength at 56 days, followed by dosages 2 and 3. However, at the age of 14 and 21 days, its compressive strength is lower than the other dosages. Nevertheless, it can be seen that dosage 3 at 14 and 21 days has a higher compressive strength.

Table 6
Table of Compressive Strength Test Results

Compression Test Results					
Dosage N 1 B:C:N:P (7:1:2:1%)		Dosage N 2 B:C:N:P (6.5:1.5:2:1%)		Dosage N 3 B:C:N:P (6:2:1:1%)	
Age (days)	Resistance Average (Mpa)	Age (days)	Resistance Average (Mpa)	Age (days)	Resistance Average (Mpa)
14	0.30	14	0.35	14	0.46
21	0.44	21	0.53	21	0.55
56	0.68	56	0.62	56	0.59
*Conversion factor: 1 Mpa = 10.2 Kg/cm^2					

Note: Source*:* Laboratorio de materiales PUCE, 2020

With the data obtained from the analysis, an average of these values is made with which each of the dosages is plotted to determine the resistance curve of each model. Figure 17 shows how the increase in compressive strength develops according to the age of rupture of each sample. Considering the 3 dosages, it can be shown that at 14 days of age there is an upward increase in which dosage 3 maintains the highest strength with 0.46 (Mpa). Similarly, in the breakage of the samples at the age of 21 days, there is also an increase in the resistance where dosage 3 has the highest resistance with a reading of 0.55 (Mpa); in the final test of the three dosages at 56 days of age, according to the data obtained in the readings, the highest resistance is presented by dosage 1 with 0.68 (Mpa), and the lowest resistance is presented by dosage 3 with a value of 0.59 (Mpa).

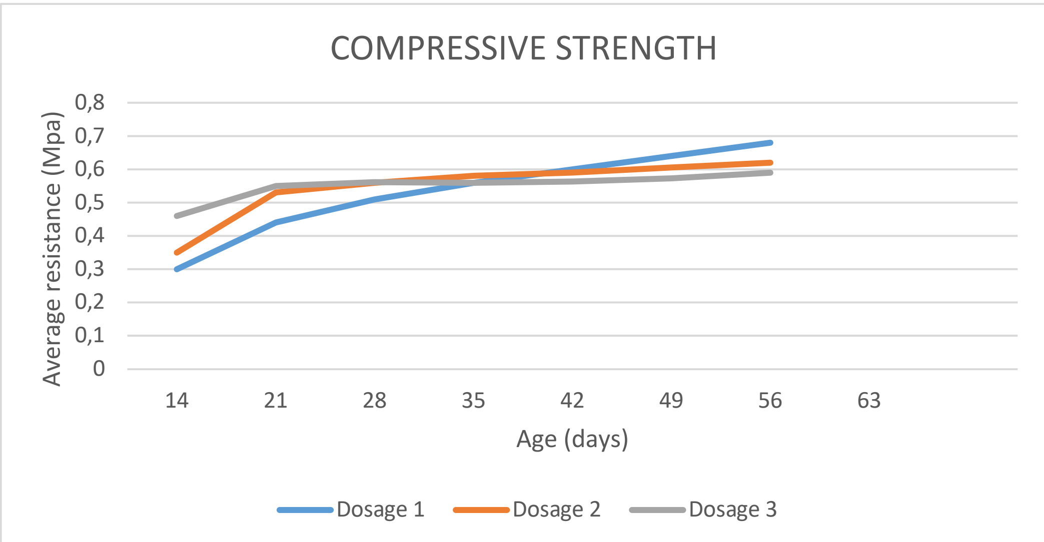

Figure 17. Table of test results Compressive strength
Note: Source: Laboratorio de materiales PUCE, 2020

With the values obtained from the tensile test, the table of resistance results was prepared. Consequently, the values obtained are analyzed comparing the dosages; thus, we have that sample 2 maintains higher tensile strength at the age of 56 days in dosage 3, followed by dosage 2. However, at the age of 14 days, the tensile strength is lower than the other samples. Nevertheless, it can be estimated that dosages 2 and 3 at 14 and 21 days of age present equal value of resistance, surpassing the value of the tension maintained by dosage 1.

Table 7

Table of Tensile Strength Test Results

Tensile Test Results					
Dosage N 1 B:C:N:P (7:1:2:1%)		Dosage N 2 B:C:N:P (6.5:1.5:2:1%)		Dosage N 3 B:C:N:P (6:2:1:1%)	
Age (days)	Resistance Average (Mpa)	Age (days)	Resistance Average (Mpa)	Age (days)	Resistance Average (Mpa)
14	0.0100	14	0.0198	14	0.0198
21	0.0157	21	0.0220	21	0.0220
56	0.0197	56	0.0243	56	0.0258

*Conversion factor: 1 Mpa = 10.2 Kg/cm^2

Note: Source: Laboratorio de materiales PUCE, 2020

For a better appreciation of the results obtained in the mechanical tensile test, they are analyzed graphically. Figure 20 confirms the behavior of the samples in the resistance test based on the study carried out on the specimens at the corresponding age of rupture. The first analysis carried out on the 3 dosages was at the age of 14 days. Here it can be seen that there is an upward increase in their values. Dosage 1 has a resistance of 0.0100 (Mpa); thus, being the lowest and that the mixture with the highest resistance is 3, presenting a resistance of 0.0198 (Mpa). In the analysis carried out on the samples at 21 days of age, it can be seen that dosage 1 has the lowest resistance with 0.0157 (Mpa), but an increase in resistance can be noted in mixes 2 and 3, where a constant value is maintained between these two mortars with a resistance of 0.0220 (Mpa). In the experimentation at 56 days of age, the 3 dosages present ascending data, as can be observed in its result. The lowest resistance is presented by dosage 1 with 0.0197 (Mpa); contrary to this, the one that presents the highest resistance is dosage 3 with 0.0258 (Mpa).

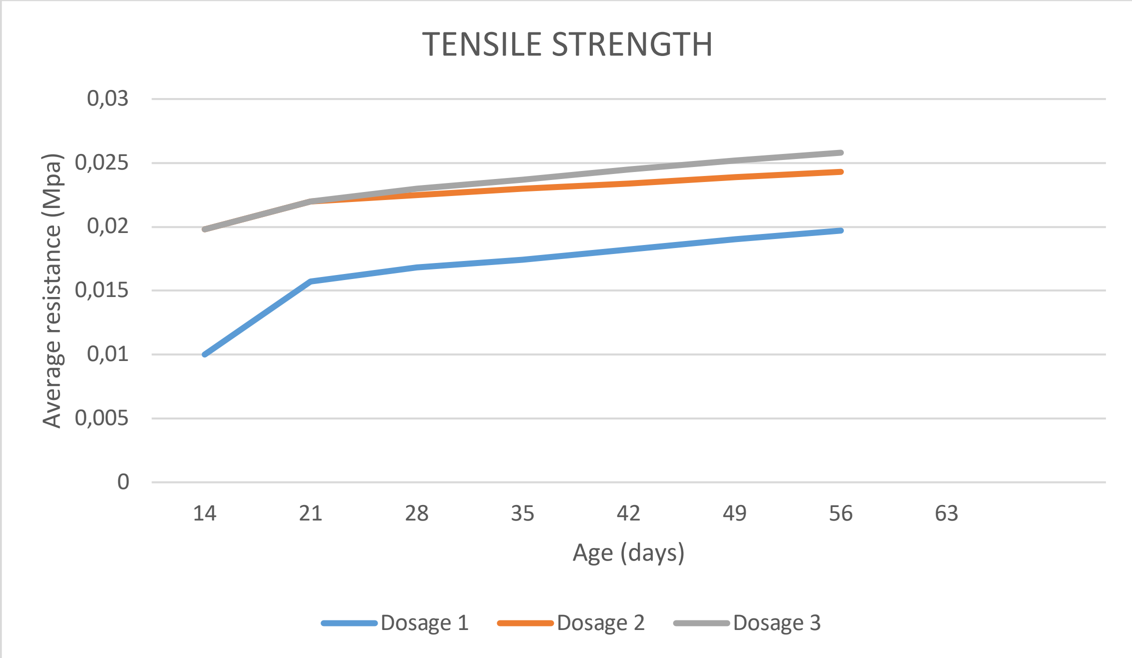

Figure 20. Table of Tensile Strength Test Results
Note: Source: Laboratorio de materiales PUCE, 2020

With the results achieved in the test with the mortars in the flexural tests, it can be established that dosage 2 shows a higher resistance at the age of 56 days, followed by dosages 3 and 1. However, at the age of 14 and 56 days, its resistance to flexure is the lowest in relation to the other dosages. Nevertheless, it can be observed that dosage 1 at 14 and 21 days of age shows a higher resistance.

Table 8
Table of Flexural Strength Test Results

Flexural Test Results					
Dosage N 1 B:C:N:P (7:1:2:1%)		Dosage N 2 B:C:N:P (6.5:1.5:2:1%)		Dosage N 3 B:C:N:P (6:2:1:1%)	
Age (days)	Resistance Average (Mpa)	Age (days)	Resistance Average (Mpa)	Age (days)	Resistance Average (Mpa)
14	0.147	14	0.124	14	0.084
21	0.151	21	0.141	21	0.114
56	0.169	56	0.249	56	0.193

*Conversion factor: 1 Mpa = 10.2 Kg/cm^2

Note: Source: Laboratorio de materiales PUCE, 2020

For a better interpretation of the results, these are represented graphically. Figure 23 shows the results of the analysis performed on the samples that were subjected to the flexural tests carried out at the test ages programmed for their rupture.

The initial analyses were carried out at 14 days. These results allow us to show that the values have a descending development, where it can be seen that dosage 1 has the highest resistance of 0.147 (Mpa), followed by dosage 2, which has a resistance of 0.124 (Mpa). It can also be observed lower data that present a lower resistance, and it is presented by dosage 3 with 0.084 (Mpa). In relation to the analysis made to the samples at the age of 21 days, it is also evidenced that the breakage at 14 days dosage 1 maintains the highest resistance with 0.151 (Mpa). On the other hand, dosage 2 shows a decrease in its resistance at 0.141 (Mpa), and the lowest resistance is presented by dosage 3 with 0.114 (Mpa). Likewise, in the experimentation carried out at 56 days of age, the data maintain an upward trend, the lowest resistance corresponds to dosage 1 with 0.169 (Mpa), while the highest resistance is given by dosage 2 with 0.249 (Mpa); whereas the average estimated resistance is given by dosage 3 with 0.193 (Mpa) (PUC, 2020).

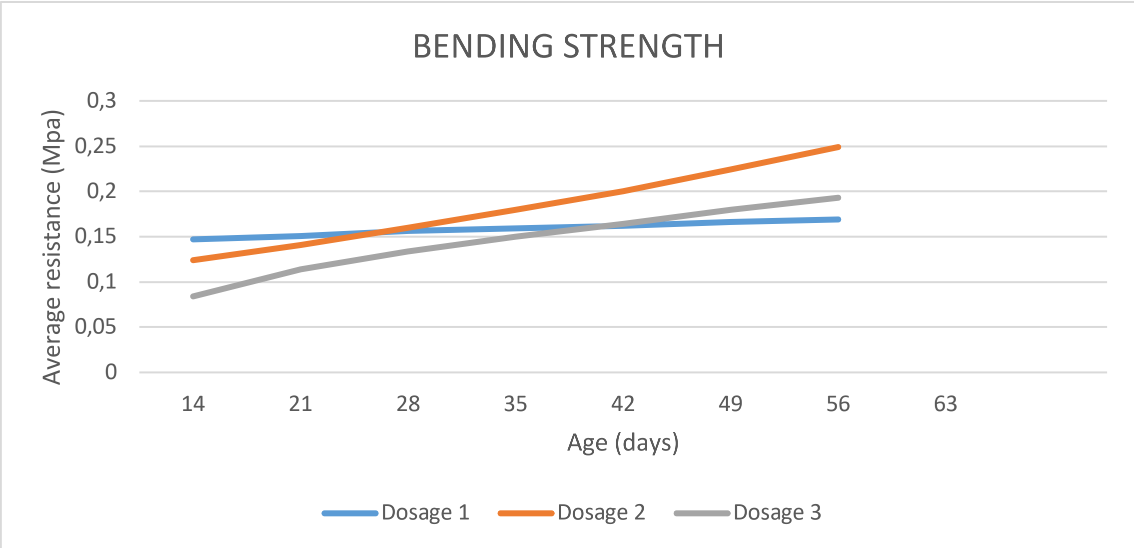

Figure 23. Table of Flexural Strength test results.

Note: Source: Laboratorio de materiales PUCE, 2020

In summary, dosage 1 has a higher compressive strength at 56 days, followed by dosage 2, while dosage 3 has a higher compressive strength at 14 and 21 days. Dosage 2 presents at 56 days a higher flexural strength, while at 14- and 21-days dosage, 1 has a higher flexural strength followed by dosage 2. Dosage 3 at 56 days has a higher tensile strength, followed by dosage 2, while at 14- and 21-days, dosage 2 presents a similar tensile strength.

From the results obtained, it can be determined that dosage 2, according to the values reached, which correspond to a mathematical average of the resistances with respect to the other dosages analyzed, presents better mechanical properties, being the optimum for application in restoration processes.

Table 9

Table of results dosage 2

Dosage N 2 B:C:N:P (6.5:1.5:2:1%)						
Age (days)	Compressive Strength		Tensile Strength		Flexural Strength	
	(Mpa)	Kg/cm²	(Mpa)	Kg/cm²	(Mpa)	Kg/cm²
14	0.35	3.57	0.0198	0.20	0.124	1.26
21	0.53	5.41	0.0220	0.22	0.141	1.44
56	0.62	6.32	0.0243	0.25	0.249	2.54
*Conversion factor: 1 Mpa = 10.2 Kg/cm²						

Note: Source: Laboratorio de materiales PUCE, 2020

Conclusions and recommendations

Once the experimentation was concluded, it can be determined that the three new dosages studied present very similar properties in relation to the research carried out on the tests of mechanical resistance to compression, tension and flexion applied to the mortars elaborated in the laboratory, after having analyzed the tests at the programmed ages of 14, 21, and 56 days in the laboratory, it can be considered that the results obtained are reliable.

On the basis of this study, it is intended to establish new guidelines for the use of traditional techniques and materials, so that they can be applied in heritage restoration processes and avoid the use of contemporary materials that alter and damage heritage monuments. In addition, this research is established as a starting point for further research with new dosages of traditional materials.

Mortars based on traditional materials are irreplaceable in an architectural restoration process since they are even the solution to structural problems for the protection of adobe, adobe, brick, or stone masonry. These mortars allow buildings to recover their integrity.

Research should continue on the properties of mortars with traditional materials, producing variations between each one of them. From these modifications, it is possible to obtain quantified mechanical properties that determine the quality of the mortars.

Given that the aggregate varies from one site to another, and, therefore, it has a notable influence on traditional mortars. This means that in each restoration project a study of the quality of the clay to be used in the elaboration of new mixtures must be carried out.

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