Journal of Architecture, Engineering & Fine Arts

2022 4(1): 57-70

Available online at http://dergipark.org.tr/artgrid

Research Article

MOISTURE RESISTANCE OF EARTHEN COATINGS STABILIZED WITH GLYCEROL

Lilian GARCIA-ALONSO[1,*], Luis F. GUERRERO[2]

[1] National School of Conservation, Restoration and Museography, Mexico
[2] Metropolitan Autonomous University, Mexico

[*]Corresponding Author: lilian_garcia_a@encrym.edu.mx

ORCID ID[1]: 0000-0002-1275-2248 ORCID ID[2]: 0000-0001-8256-4851

Received: 22 February 2022; Accepted: 12 May 2022; Published: 30 June 2022

Abstract

One of the fundamental components of earth architecture is its coatings because they protect structures from atmospheric and anthropic agents. However, due to the hygroscopic nature of the earth, the plasters are highly vulnerable to rain and groundwater absorption. To deal with these agents of decay, experts and artisans have tested with different stabilizing substances throughout history. This article reviews a series of experiments based on verifying the use of small glycerol fractions to increase the durability and resistance of the earth coatings. Glycerol is a byproduct of various industrial processes, such as the production of biodiesel. Recently, there has been a significant increase in its production, making it a viable resource to consolidate and protect both historical building components and contemporary buildings. We analyzed comparatively mortars of natural earth, and others stabilized with glycerol to verify the cohesiveness, quantity of water required, and drying time. Subsequently, we performed flat tests and plasters applied on walls to undergo capillary absorption conditions and rain impact. An increase in the cohesiveness of the mortars added with glycerol of 12%, decreases the amount of water required for the mixtures by 18% and the drying time rises by almost 7 hours. The stabilized specimens absorbed 26% less water by capillarity, and the exposed coatings to weather conditions maintain their integrity after eight months of staying outdoors. Earthen mortars that were enriched with small volumes of glycerol developed a highly positive response to these factors, which are the most likely to provoke the earth plasters and the structures they protect. It is possible to have a material that improves the mixtures of soil and is sustainable from an economic, ecological, and cultural point of view.

Keywords: Glycerol, plaster, sustainability, traditional construction, moisture

Please cite this article as: Garcia-Alonso, L. & Guerrero, L. F. (2022), Moisture resistance of earthen coatings stabilized with glycerol. *ArtGRID-Journal of Architecture, Engineering & Fine Arts, 4*(1), 57-70.

Araştırma Makalesi

GLİSEROL İLE STABİLİZE EDİLMİŞ TOPRAK KAPLAMALARIN NEM DİRENCİ

Özet

Toprak mimarisinin temel bileşenlerinden biri, yapıları atmosferik ve antropik etkenlerden korudukları için kaplamalarıdır. Bununla birlikte, toprağın higroskopik doğası gereği, sıvalar yağmur ve yeraltı suyu emilimine karşı oldukça hassastır. Bu bozunma ajanlarıyla başa çıkmak için uzmanlar ve zanaatkarlar tarih boyunca farklı stabilize edici maddelerle testler yaptılar. Bu makale, toprak kaplamaların dayanıklılığını ve direncini artırmak için küçük gliserol fraksiyonlarının kullanımının doğrulanmasına dayanan bir dizi deneyi gözden geçirmektedir. Gliserol, biyodizel üretimi gibi çeşitli endüstriyel süreçlerin bir yan ürünüdür. Son zamanlarda üretiminde önemli bir artış olması, hem tarihi yapı bileşenlerini hem de çağdaş yapıları sağlamlaştırmak ve korumak için uygun bir kaynak haline getirmiştir. Yapışkanlığı, gereken su miktarını ve kuruma süresini doğrulamak için doğal toprak ve gliserol ile stabilize edilmiş diğer harçları karşılaştırmalı olarak analiz ettik. Ardından, kılcal emme koşullarına ve yağmur etkisine maruz kalmak için duvarlara uygulanan düz testler ve sıvalar gerçekleştirdik. Gliserol ilave edilen harçların yapışkanlığının %12 artması, karışımlar için gereken su miktarını %18 azaltmakta ve kuruma süresini yaklaşık 7 saat uzamaktadır. Stabilize edilmiş numuneler, kılcallık tarafından %26 daha az su emer ve hava koşullarına maruz kalan kaplamalar, sekiz ay dışarıda kaldıktan sonra bütünlüklerini korur. Küçük hacimlerde gliserol ile zenginleştirilmiş toprak harçlar, toprak sıvalarını ve korudukları yapıları en çok kışkırtan bu faktörlere oldukça olumlu bir tepki geliştirdi. Toprak karışımlarını iyileştiren ve ekonomik, ekolojik ve kültürel açıdan sürdürülebilir bir malzemeye sahip olmak mümkündür.

Anahtar Kelimeler: Gliserol, alçı, sürdürülebilirlik, geleneksel yapı, nem

1. INTRODUCTION

In earthen architecture, any structure exposed to the elements is vulnerable to the invasion of parasitic fauna, fungi, mineral salts, as well as the affectations derived from atmospheric factors such as wind, rain, hail, and snow, to name just a few. Therefore, these structures must be protected from adverse environmental conditions and the components responsible for providing protection are coatings (Warren, 1999).

The earth coverings present a certain vulnerability to rain and to groundwater absorption due to their hygroscopic characteristics. To counteract these deterioration agents, and to give greater durability and resistance to these components, over centuries of experimentation, ancient civilizations and traditional communities have used different substances that serve to stabilize and improve the properties of mixtures. Cactaceae mucilage, especially those derived from the Opuntia Genus, have been used since ancient times in Mesoamerica to protect architectural surfaces (Torres et. Al., 2015). This material added to lime paints, mortars, and acts as a retardant to setting, decreases the percentage of contraction of the mixtures and increases the fluidity of the mortar (Pérez, 2009). Similar results have been achieved in studies carried out on mortars and earth coverings where it was found (Figure 1) that Opuntia Ficus mucilage increases the qualities of the mixtures by delaying drying and allowing the formation of more stable crystalline structures (Ávila & Guerrero, 2018).

Figure 1. Application of soil plasters stabilized with Opuntia mucilage in a historic furnace, during a restoration training workshop in Villa de Leyva, Colombia (Photo: L. Guerrero).

Glycerol is an alcohol that has three hydroxyl groups (-OH) commercially known as glycerin. It is a liquid compound at room temperature, viscous, colorless, odorless, and slightly sweet. The presence of the three-hydroxyl groups makes it highly hygroscopic, soluble in water and alcohols and insoluble in hydrocarbons. Glycerol is part of vegetable and animal oils, fats such as mono, di or triglycerides, as well as the phosphoglycerates that are part of the animal and plant cell membranes. Currently 70% of the global production of glycerol is a by-product during the transformation of biodiesel, representing 10% of the total produced. For every 10 kg of biodiesel, 1 kg of glycerol is generated (Betancourt et. Al., 2016).

To obtain glycerol, you first need biodiesel, this biofuel is a mixture of monoalkyl esters of fatty acids and is obtained by reacting transesterification or alcohol lysis of normally vegetable oils rich in triglycerides with alcohols such as ethanol or methanol the sub product (Lafuente, 2017). The increase in the volumes of glycerol as a by-product is becoming a technological and ecological problem. Due to the accelerated growth of biodiesel production, and the marked trend towards its increase, despite its high potential for application, it is being far from using it in its entirety, which means that there are surpluses that run the risk of affecting the environment. This problem can improve by promoting the use of glycerol in a wider range of applications.

In research carried out since 2015, the use of glycerol as a stabilizer has been developed mainly in the agricultural sector, since it works as organic matter added to the soil. These investigations have shown that when glycerol is applied to the soil, plant growth is increased and added nitrogen is immobilized as ammonium nitrate, which decreases the use of fertilizers and mitigates environmental contamination (Betancourt et. Al., 2016).

Derived from the investigations, and from the physicochemical properties of glycerol, it was decided to carry out a series of experiments to use glycerol as an addition to soil coverings and verify its performance when exposed to the elements under real weather conditions. We sought to test its level of effectiveness in soil architecture, specifically in the case of its coatings, under the hypothesis that this compound has more suitable characteristics as an additive in soil plasters than substances more commonly used as Opuntia Ficus prickly pear mucilage. (Pérez et. Al., 2017). This substitution of stabilizers can suppose better characteristics in mixtures for earth coatings applied to new works, but especially as protective and sacrificial surfaces in a wide range of heritage structures. In this way, it is possible to take advantage of the overproduction of a resource such as glycerol, which contributes to the sustainable management of resources, in construction and conservation processes that are totally friendly to the environment.

2. MATERIALS AND METHODS

The present work describes a series of experiments aimed at the verification and feasibility of the use of glycerol stabilized earth coatings, applied both on earth surfaces and in other construction materials. It is expected to obtain coatings resistant to environmental and ecological effects by taking advantage of a resource that today faces overproduction. Detailed comparative tests of mixtures with the same type of soil are added, one part only with water and the other with a regulated measure of glycerol. Tests of cohesion, absorption, adhesion on different surfaces and resistance to rain were carried out. The research was carried out in various stages in the Laboratory of Traditional Technologies of the National School of Conservation, Restoration and Museography (ENCRYM-INAH). It is important to mention that for the purposes of this article, only the results referring to two mixtures are exposed: compensated earth-water and compensated earth-glycerol solution to have a comparison pattern. However, a wide range of tests and dosages have been performed during the investigation. The land that was used to prepare the samples was extracted from the Tepecoacuilco area, Guerrero, in the south of the Mexican Republic. The data provided by the "Geotechnical and Soils" laboratory indicated that it contained 17% sand and 83% clay and silts, with a Liquid Limit of 64.3; a Plastic Limit of 26.3 and a Plasticity Index of 38, therefore, according to the Unified Soil Classification System (SUCS) it corresponds to the “CH” type, that is, a “Sandy Clay”.

A material with a high clay content was chosen with the intention of being able to compensate it by adding predefined volumes of sand and, thus, having a regular raw material for all the tests. We proceeded to formulate the amount of sand required to form coatings that, on the one hand, had adequate plasticity and adhesion to the substrates, but which were not so high that they generated fissures in their surfaces. Then, to compensate for the high clay content that the earth had, determined volumes of sand were sieved by a # 10 mesh (2mm) and different mixtures were made where the relative dosage of the volume was varied with each mixture.

Coating samples of 20cm x 20cm x 2mm were made on a smooth surface that was left to dry outdoors. Once they hardened, it was verified which was the mixture that presented a minor or no cracking pattern, while retaining the resistance to manual abrasion. The 1: 1.5 ratio (earth-sand) was determined to be ideal for use in the rest of the experiments. This mixture was analyzed again in the soil mechanics laboratory, and it was verified that after the compensation process a volume of 81% sand and 19% clay and silt had been reached, so that its Liquid Limit was now 23, 4; its Plastic Limit of 15.0 and its Plasticity Index of 8.4 being classified according to the SUCS as a “SC” type soil, that is, an “Claylike Sand”. To form the glycerol-water solution, the dosage derived from the work carried out in previous investigations in which 1% of nopal mucilage was used as stabilizer was taken as a reference and 10 ml of USP vegetable glycerin was added in one liter of water.

The study continued with the comparative evaluation to measure the cohesiveness of the mixture. In the absence of Mexican standards for earth construction systems, the procedure used since the 1980s at the University of Kassel (Minke, 2005) with some dimensional variations was taken as a reference. The cohesion test consisted in the elaboration of mixtures of soil with water and of soil with the glycerol solution until it had the necessary consistency that would make it possible to form a sphere between the hands. Then a cylindrical bar 20 cm long by 1.5 cm in diameter was formed, which was placed on a sheet of paper and placed on the edge of a table so that it hung to the point of breaking (Figure 2). This test seeks to evaluate the length at which each bar breaks, which is correlated with the cohesiveness of the material. The greater length of the fractions means that the earth is better cohesive. For reference, it has been documented that break lengths of 5 to 8 cm are appropriate for plasters (Minke, 2013, p. 11).

Figure 2. Cohesiveness test carried out on earth bars in a plastic state (Photo: L. Guerrero).

In the process of developing the cohesion tests, it was observed that it was required to add less amount of glycerol-water solution for the bars than that required in the control mixtures to which only water was added. It was also noted that the consistency and plasticity of the glycerol mixture improved markedly. For this reason, a series of additional tests were developed to verify the exact point of liquid required for the mixture to reach its optimum workability condition, always comparing the use of water with that of the glycerol solution.

Subsequently, mixtures of soil-water and soil-glycerol solution were made, forming 10 cm x 10 cm x 0.5 cm thick tablets emptied into wooden moulds. These tablets were used for direct water absorption tests based on the Spanish standard UNE-EN-16302, in the absence of national standards for such evaluations. The test consists of taking the time it takes for a defined quantity of water to penetrate a given surface of the material to be evaluated. The instrument to carry out the tests was a Karsten tube. The tube joint and the contact surface are sealed with a waterproof putty to prevent leaks and concentrate water flow (Figure 3). "With this arrangement the water column exerts a pressure on the surface of 961.38 Pa. This pressure corresponds to an action of raindrops hitting the wall with a static wind speed of 140 km / h perpendicular to the surface” (Pérez, 2016, p. 75).

Figure 3. Water emptying in the direct absorption test with the Karsten tube. Source: Luis Guerrero

The subsequent study consisted of the comparative evaluation of capillary absorption for which 5 cm x 5 cm x 5 cm cubic specimens corresponding to soil-water and soil-glycerol were made. All the specimens were dried for a period of 28 days at ambient temperature and humidity. As there are currently no standards in Mexico to determine this variable in land components, the Italian Standard 11-85 (Normal, 1985) was taken as a reference. This test consists of placing each sample on a cloth saturated with water in a tray for periods of 30 seconds for subsequent weighing on a precision scale. This process is repeated at intervals until the sample begins to lose material due to disaggregation.

For the last evaluation, 20 cm x 20 cm x 0.2 mm coatings were applied on earth walls and cement blocks to evaluate the adherence and behaviour of the plasters on said surfaces. The samples were left outdoors to document their response to direct rain. It is important to highlight that, during the elaboration of the cubic specimens, the tiles and the plasters, a phenomenon of notable relevance was registered as an explanation of the role that glycerol plays in soil mixtures and that is derived from the fact that the drying time Initial of the three types of components was much higher when they were stabilized compared to those of land and water only. As can be seen in Figure 10, while the ground plaster with water was already practically dry and cracked, the test piece made with glycerol showed a dark colour that evidenced the presence of moisture, which remained almost two hours more. In the case of the tiles, evaluations of the weight during the initial drying at ambient temperature and humidity were carried out with this it was possible to document that the weight in which both series of samples stabilized turned out to be approximately 2 hours and 15 minutes for the mixtures of water and about six hours for those containing glycerol. In the case of cubic specimens, it was not possible to carry out the comparative verification of the drying weight because the release periods were different, and this obviously has a direct influence on the final time. Special tests will need to be designed to evaluate this variable in future trials.

3. RESULTS AND DISCUSSION

The cohesiveness test served to determine the consistency of the mixture and the amount of water required to reach the optimum workability condition. It was observed that the fractions corresponding to the bars made with water had an average breaking point of 7.5cm. However, the glycerol bars broke at 8.5cm (Figure 4).

Figure 4. On the left soil-water mixture and the right soil-glycerol mixture. (Photo: L. Guerrero)

Regarding the amount of water required to obtain a suitably consistent mixture, which allowed a uniform kneading, it was observed that the mix with water demanded 170 ml, while that of glycerol only 125 ml. This data translated into percentages determines that the glycerol solution reduces the required mixing liquid by 28%.

For the absorption and release of humidity test, 10 cm x 10 cm x 0.5 cm tablets were used, the first of soil-water and the second of soil-glycerol solution. We began weighing each tablet with a precision scale to record the data in the dry state; after this process, the placement of the Karsten tube continued where the water absorption in each sample was timed for a period of 4 minutes. The absorbed milliliters could be observed in the graduation of the box; after the 4 minutes had elapsed, the tube was removed, and the tablet was reweighed to record the amount of water contained in its mass.

The results obtained the necessary information to graph and analyze the relative behaviour. Mixture 1, which was made only with soil and water, shows excellent water absorption in a brief period, while mixture 2 of glycerol absorbed less amount. It retained less than three times the percentage of water than Mix 1 (Figure 5).

Mixture No.	Initial weight in grams	Final weight in grams	Increase in grams	Porcentual increase
1	74.2	75.3	6	1.48%
2	76.8	77	2	0.26%

Figure 5. Increase in grams of the test tubes in the dry state and after applying water with the Karsten tube.

In addition to the amount of water absorbed at the end of the experiment, the graph indicates the regularity of the absorption process, given that equal volumes of water penetrate in equal periods (Figure 6). Likewise, the partial amounts that are absorbed with the glycol cohesive soil are much lower, which guarantees the stability of its application as a coating because, without becoming a component whose permeability conditions the hygroscopic balance of the soil substrates that require exchanging water with the environment that surrounds them, this process is regulated in time. A gradual inflow of water can be adequately managed by the entire system, this is not possible with a sudden inflow of liquid that can disintegrate the components of the soil.

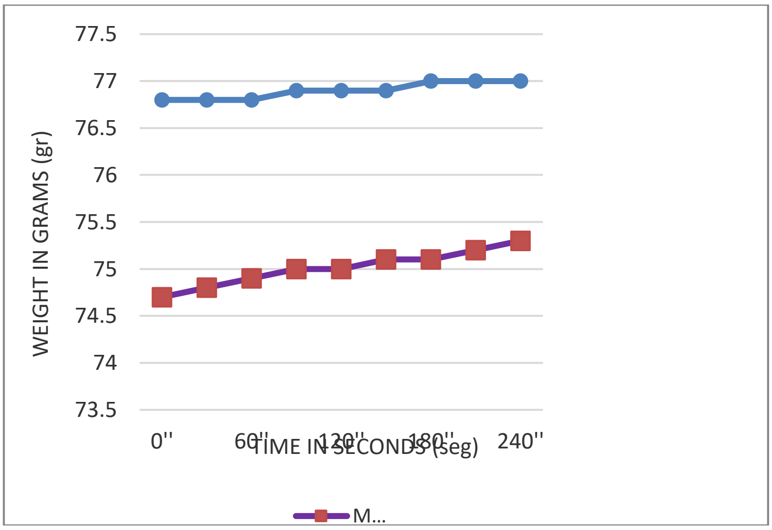

Figure 6. Graph showing the behaviour of mixtures 1 (earth-water) and 2 (earth-glycerol) increasing their weight by the amount of water absorbed in a period of 4 minutes

As a complement to the absorption test, a moisture release test was carried out that considers the time measurement of the total loss of water in a building system of soil at ambient temperature and humidity. The tablets analyzed and weighed at their saturation level at 4 minutes were left in a space with controlled conditions at 25 ° C temperature and a relative humidity of 66%, without the presence of wind. The test consisted of weighing each tablet in periods of 30 minutes until they reached their initial weight, an indication of the total release of the contained water.

According to the information obtained, and once the monitoring of the progressive drying of each mixture was completed, a graph with a decreasing trend (figure 7) was generated, contrary to that obtained in the previous test. This graph allows to compare the behavior and the variation of time between the drying of each test tube, the trend line indicates if the release of humidity occurs constantly or intermittently.

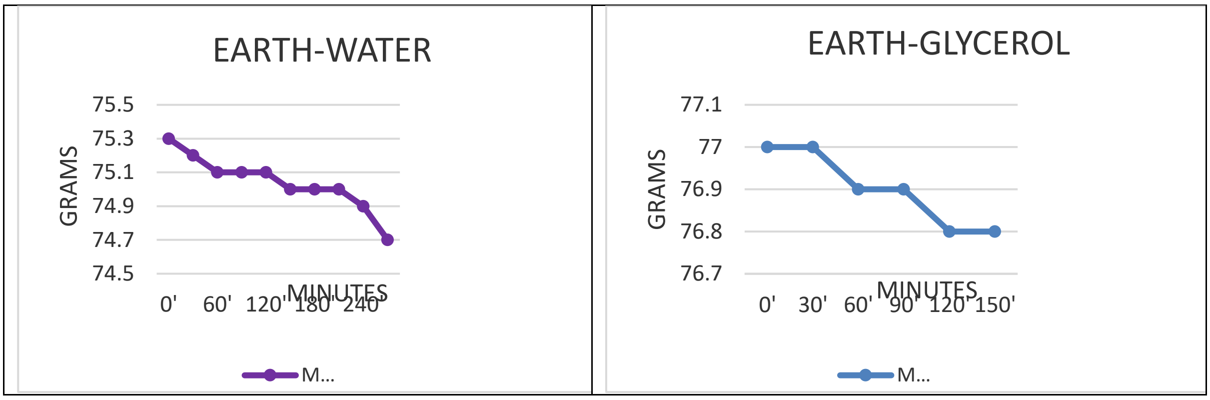

Figure 7. Release of moisture. Graphs show the weight loss in grams equivalent to the water contained (by the absorption test) until reaching the initial weight corresponding to the test piece in the dry state.

The drying time range was obtained with this test, being the slowest in mix 1 with 270 minutes and the fastest in mix 2 with 150 minutes.

The capillary absorption test was carried out by recording and tabulating the increase in weight of 5 cm x 5 cm x 5 cm cubes placed on a cloth saturated with water in a tray for intermittent periods of thirty seconds for a total period of eight minutes. The amount of water absorbed by the samples was plotted to compare the difference in weights at each moment. The mixtures that were tested were: soil-water and soil-glycerol solution.

To determine the absorption coefficient (Abs), the following formula was used:

$$Abs(\%) = \frac{Ps - Pd}{Pd}\ x\ 100$$

Where: Abs: Absorption coefficient (%)
As seen in Table 8, the mixture of soil with water has a higher absorption coefficient than that mixed with the glycerol solution, in which the absorption coefficient is reduced.

Sample	Mixture	Desiccated weight (gr)	Saturated weight (gr)	Absorbed water (gr)	Absorption coefficient (AC) (%)
1	Earth-water	50,7	55,3	4,6	9,07%
2	Earth-glycerol	57,2	60,7	3,5	6,11%

Table 8. Absorption coefficient.

Figure 9 shows that, as happened with the direct absorption of the Karsten tube, the absorption intervals are continuous in both cases. However, the slope of the graph of the land with water is slightly higher because the amount of water contained rose in less time.

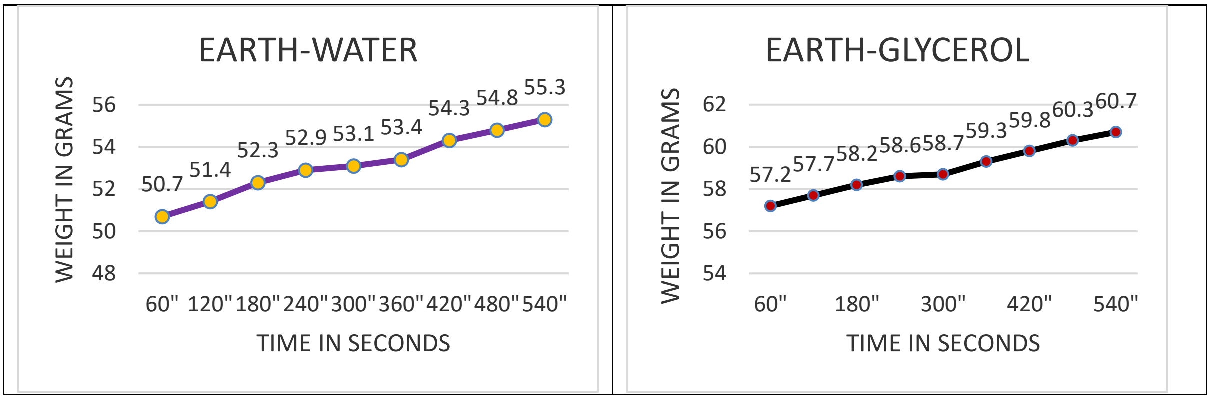

Figure 9. Graph on the left is the water absorption coefficient of the land-water mixture. Graph on the right is a graph of the water absorption coefficient of the soil-glycerol solution mixture

Finally, the plasters applied outdoors and subjected to rainy conditions were made in sections of 20 cm x 20 cm x 0.2 cm thickness. They were initially placed by hand, and the surface was subsequently smoothed with a metal trowel to obtain a uniform surface. The mixtures of soil-water and soil-glycerol solution were left exposed to the elements, and their behavior was monitored for eight months.

During the placement of the plasters, it was found that the mixtures that stabilized with glycerol took longer to dry than those of soil with water. On the other hand, during their application, they did not present cracks when drying, contrary to what happened with the mud mixed with water, which presented an unusual cracking pattern (Figure 10). It is worth mentioning that these coating samples were applied on different types of substrates to verify their workability, adhesion, and compatibility. They were placed on red brick, cement blocks, and adobes, but the result was similar in all cases.

Figure 10. The water-based mixtures are presented on the left, and the glycerol mixtures are on the right. Above are the coatings the day after they were placed and below their current state after eight months.

After the intense rainy season of 2018, it was observed that the land-water coating had a loss of close to 80%, while the one made with glycerol remains with a notably lesser degree of deterioration, having a surface loss of less than 10%.

4. DISCUSSION AND RESULTS

The results obtained in all the tests allow us to recognize that, despite the relatively low amount of glycerol used to make the tested mixtures as coatings, the role of this substance is positive.

Firstly, it was observed that during the initial realization of mortars in which glycerol solution is used both to make cubic specimens, the tiles, and in the plasters, an average 260% slower drying of the construction component is achieved, compared to mixtures that were made only with water. As it is known from various construction traditions with earth, when an element of this material loses its molded humidity too quickly, retraction processes are usually generated on its surfaces that manifest in cracks and a consequent reduction in resistance and durability. (Stazi et al., 2016). If during the construction of earth elements care is taken that the hardening of the mixtures occurs gradually, a better crystalline organization is achieved inside the material, be it an adobe, a mortar, or a plaster (Mattone et al., 2016). This effect translates into obtaining more homogeneous and dense building components inside, giving them greater mechanical and water resistance, as verified in the studies carried out (Guerrero, 2007).

Secondly, the cohesiveness test revealed the increase in this property in the order of 13.33%, having broken the bars from 7.5cm in the formulation with water to 8.5cm when using the glycerine solution. This property is very relevant to the workability of the mixtures that will be applied as coatings since, being more ductile, they can be compressed better, resulting in denser, more robust, and better-adhered surfaces substrates (Mattone et al., 2017). At the same time, it was found that it is possible to achieve the optimum level of soil workability with 28% less liquid. This contribution is also of high ecological value because it implies a significant saving of mixing liquid during the development of the earth's mortars.

Regarding the capillary absorption and drying tests, the results were equally promising. The use of glycerol delays the capillary absorption time by 300% during the same period. It is possible to obtain coatings that are highly resistant to humidity from both rain and water tables.

The result was also optimistic regarding desorption time because the mixtures made with glycerol dry 55.5% more quickly. This data allows us to recognize that the water is inserted between the micelles of the clays, which generates a very long drying time, while the glycerol present in them provides a kind of waterproofing protection that promotes rapid evaporation. Finally, the effect of direct rain is more difficult to quantify. Still, it is evident from the series of photographs that were taken during the time the test lasted and that, although it ended eight months after it started because the coating made only with water has been completely lost, the one made with glycerol remains more than a year after being applied.

5. CONCLUSIONS

Among the main problems that arise in the design of surface protections for archaeological remains or historical land buildings, the need to guarantee their correct operation in the face of humidity stands out. Because water is the substance that allows the construction of earth-building elements. It also becomes its main enemy as an agent of deterioration by presenting itself as rain, hail, or internal freezing or by capillary absorption of groundwater tables. (Kita et al., 2013). The land used as a construction material has very stable water response limits, but when they are overcome, destruction processes difficult to reverse occur (Stasi et al., 2016).

For this reason, for decades, different resources have been tested for the surface protection of earth structures, many of which have been designed based on the wrong logic of waterproofing, which derives from the use of construction components of industrialized origin and associated with current conventional building technology.

The use of impervious resources as surface protection of old buildings leads to the migration of salts, moisture condensation, encapsulation in substrates, exfoliation, and, in extreme cases, the collapse of construction components by disintegration or dissolution (Mattone et al. 2005). The traditional construction of stone, brick, wood, but above all that of earth, requires the daily exchange of air and water vapor in its construction components to maintain its structural stability.

The earth coverings have proven to be highly effective for millennia, as evidenced by very ancient archaeological remains located in different world regions. However, almost all were applied by procedures and combinations with substances whose origin has been lost. There is scarce information about how to land coverings could be made that could remain in an adequate state of conservation despite local weather conditions and the passage of time (Guerrero, 2015).

At present, it is required to develop experiments that allow replicating or at least try to explain the behavior of plasters that offer protection against deterioration agents to the walls and roofs of old buildings. In this line of work, for several years, experiments have been carried out in Mexico to evaluate the use of mucilage from vegetables as stabilizing substances in soil plasters. The results obtained so far are adequate but are not easily replicable in different geographical conditions due to the unique needs of the plant material from which they come.

Given this limitation, the use of glycerol as a product available in many parts of the world has been proven with a remarkable level of success, which gives coatings made with soil highly favorable properties for surface protection not only of historical structures made with soil but also of other construction materials (Guerrero, 2016).

The tests reviewed in this test showed that by using glycerol solutions of only 1% concentration as part of the mixing water of earth mortars applied as coatings, it is possible to retard their drying, which results in more homogeneous, dense, and resistant to the impact of various deterioration agents. Once applied and hardened, these coatings have a partially water-repellent performance that makes them less vulnerable to clays by slowing down the entry of water between their micelles, thus retaining it for less time, avoiding its change in volume and subsequent retraction and disintegration. The use of glycerol also helps reduce the importance of water required for mixing. Above all, they do not alter the natural permeability properties of the soil, which, as is known, are closely related to its hygrothermal qualities.

Glycerol is an industrial by-product whose production reaches surplus levels, making it a potential contaminating waste. Its use as a stabilization component of earth building materials can be positive, both in ecological architecture and conservation—sustainable cultural heritage from the economic, ecological, and socio-cultural point of view.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Ávila, E., & Guerrero, L. (2018). El mucílago de Opuntia Ficus como estabilizante en recubrimientos de tierra. Memorias del SIACOT 2018, Antigua Guatemala: PROTERRA, 115-126.

Betancourt, C., de Melo Prado, R., Castellanos, L., & Silva, C. (2016). Caracteristicas de la glicerina generada en la producción de biodiesel, aplicaciones generales y su uso en el suelo. México: Ediciones INCA, Instituto Nacional de Ciencias Agrícolas, 7-14.

Guerrero, L. (2007). Arquitectura de tierra, hacia la recuperación de una cultura constructiva. Apuntes, 182-201.

Guerrero, L. (2015). Recubrimientos de tierra compactada para la conservación del patrimonio arqueológico de México y el Salvador. Memorias del SIACOT 2015, Cuenca, Ecuador: PROTERRA, 233-244.

Guerrero, L. (2016). El papel de la humedad y la compactación en la elaboración de recubrimientos de tierra. Construcción con tierra CT7, 11-22, Buenos Aires: Universidad de Buenos Aires.

Kita, Y., A. Daneels, y A. Romo De Vivar. (2013). Chemical analysis to identify organic compounds in pre-Colombian monumental earthen architecture. TOJSAT, 3 (1):39–45.

Lafuente, G. (2017). Glicerol: Síntesis y Aplicaciones. Madrid: UNED Facultad de Ciencias.

Mattone, M., et Al. (2005). Uso de productos naturales para mejorar el comportamiento al agua de revoques a base de tierra, en Terra em Seminário 2005, Lisboa: Argumentum, 266–69.

Mattone, M. et al. (2016). Stabilization of earthen plasters: Exchange of knowledge and experiences between Italy and Morocco. Journal of Materials and Environmental Science, 7 (10):3647–55.

Mattone, M. et al. (2017). Experimentation of Earth-Gypsum Plasters for the Conservation of Earthen Constructions. International Journal of Architectural Heritage Conservation, Analysis, and Restoration, 11:6, 763-772, DOI:10.1080/15583058.2017.1290850.

Minke, G. (2005). Manual de construcción en tierra, Uruguay: Fin de Siglo.

Minke, G. (2013). Revoques de barro, mezclas, aplicaciones y tratamientos. Bariloche, Argentina: Icaria editorial.

Normal 11/85 (1985). Assorbimento d'acqua per capillarità –Coeficiente di assorbimento capillare. Italia: CNR-ICR.

Pérez, A.; Guerrero, L.; González, J. y Prado, R. (2017). Nopal mucilage as hydration agent for quicklime; extraction methods, Ge-conservación, 11: pp. 189-195.

Pérez, N. (2009). Formulación de un mortero de inyección con mucílago de nopal para restauración de pintura mural. Tesis para la obtención del grado de Maestría. Tlaquepaque, Jalisco: Instituto Tecnológico y de Estudios Superiores de Occidente.

Pérez, N. (2016). Los adobes arqueológicos de la Gran pirámide de Cholula. Tesis Doctoral de Ciencia e Ingeniería de los Materiales. México: UNAM.

Stazi, F., A. Nacci, F. Tittarelli, E. Pasqualini, and P. Munafò. (2016). An experimental study on earthen plasters for earthen building protection: The effect of different admixtures and surface treatments. Journal of Cultural Heritage, 17:27–41. doi:10.1016/j.culher.2015.07.009.

Torres, P., et. al. (2015). La baba y el mucílago de nopal, una alternativa natural para la conservación de acabados arquitectónicos de tierra. Revista Interdisciplinaria, INAH, 99: pp. 93-114. UNE-EN-16302

Warren J. (1999). Conservation of earth structures. Oxford: Butterworth Heinemann.