Civil Engineering and Architecture 12(3): 1321-1326, 2024 http://www.hrpub.org
DOI: 10.13189/cea.2024.120302

Poured Earth Stabilized with Mineral Wool

Aranda-Jiménez Yolanda, Zuñiga-Leal Carlos, Moreno-Chimely Laura, Robles-Aranda María Emilia*

Faculty of Architecture, Design and Urbanism, Autonomous University of Tamaulipas, México

Received July 19, 2023; Revised December 3, 2023; Accepted January 17, 2024

Cite This Paper in the Following Citation Styles

(a): *[1] Aranda-Jiménez Yolanda, Zuñiga-Leal Carlos, Moreno-Chimely Laura, Robles-Aranda María Emilia , "Poured Earth Stabilized with Mineral Wool," Civil Engineering and Architecture, Vol. 12, No. 3, pp. 1321 - 1326, 2024. DOI: 10.13189/cea.2024.120302.*

(b): *Aranda-Jiménez Yolanda, Zuñiga-Leal Carlos, Moreno-Chimely Laura, Robles-Aranda María Emilia (2024). Poured Earth Stabilized with Mineral Wool. Civil Engineering and Architecture, 12(3), 1321 - 1326. DOI: 10.13189/cea.2024.120302.*

Abstract The stabilizers used in construction with raw earth are very varied, especially in masonry. The construction with earth implies sustainability, therefore under this principle the stabilizers must be chosen. The poured earth, like the rammed earth, are monolithic walls that require formwork or falsework. The objective of this work is to demonstrate if the mineral wool used in the mixture of the poured earth improves the characteristics of the monolithic wall. For this purpose, different percentages of fiber added to the soil used for the dumped earth were analyzed, soil extracted from the bank of material called Champayan, which has clay, silt, sand and stone aggregates, doing tests of resistance to compression, water absorption and thermal transmittance. The purpose of this research was to answer the question: Does the poured earth mix improve its physicochemical properties when mineral wool is added as a stabilizer? The methodology of the experimental part, the soil from the Champayan bank was characterized; Subsequently, three batches of three samples each were made, containing different percentages of mineral fiber. The specimens were subjected to compression, water absorption and thermal transmittance tests. The samples were subjected to three different types of actions, namely compression test, moisture absorption and thermal conduction. In the compression tests, the results of the three samples ranged from 0.678 to 0.923 MPa. In the absorption test, the moisture percentages by weight varied in a range from 12.04 to 13.51%. In the tests carried out to measure its thermal behavior, the range of the thermal conductivity factor was from 0.7407 to 0.8725 W/m*K.

Keywords Architecture with Raw Earth, Improvement of Material Properties, Stabilizers

1. Introduction

There are 12 families of construction systems that make up the architecture with raw earth, these 12 families are divided into: monolithic walls, masonry and structure and in the monolithic wall systems the poured earth is inserted, a system very similar to the rammed earth because it requires a formwork, only it varies because it is an earthen concrete [1].

Poured earth is defined as earthen concrete, fluid, so it cannot be compacted, and has stone aggregate within its composition [2].

Poured earth is a monolithic system of raw earth walls that is not as popular as rammed earth or adobe, so it has been little studied. At the same time, an attempt has been made to stabilize with expensive chemicals that are not very accessible to those who intend to build with this technique, since earth techniques lend themselves to self-construction.

Architecture nowadays demands a more conscious approach, such as a circular design, that is, since the first steps of design, we must think about each and every step of the impact a building will have; from its conception and construction, up until its operational stage, and be mindful of the process, industrial waste generated, viable options to reuse the components used in its construction, and what we are going to do with waste materials [3]. That is why it is essential to resort to sustainable practices both in design and construction and this is where Earth Architecture is inserted, whose main component is clay. This component needs to be stabilized most of the time. A stabilizer is that product that serves to improve soil properties such as:

resistance, durability, plasticity, permeability, density, etc. [4].

In this sense, there are several types of stabilizers that can be classified according to their origin: vegetable, like saps and fibers, of animal origin: as hair and horse manure and those of mineral origin such as: cement, lime and bitumen [5].

The fundamental support of sustainable circular design is reuse and recycling. Earthen architecture could be reused when buildings are demolished, with a minimum impact on the environment, therefore, the stabilizers used must be cheap, natural and easily obtained.

Rock mineral wool is basically extracted from basalt rock of volcanic origin. In addition to being an inorganic, non-hydrophilic material, this means that it does not retain moisture, it is economical, with insulating properties, and since it is a fiber, the impact it presents on the monolithic walls of poured earth was analyzed [6].

Poured earth has properties that are essential to mention; It is important to note that up to now the soil that has been worked with is a soil from the region called Champayan, which has all the required characteristics, that is, clay, sand and the stone aggregate, which is what makes the difference in this earth concrete vs the rammed earth. Until now, the poured earth has been stabilized with 6% cement since the walls of this construction technique have been used as load-bearing walls [7].

Poured earth or earthen concrete is a fast technique in terms of its execution and has thermal characteristics very similar to those of mud. It is a technique that has been little studied in terms of its construction system and its stabilizers.

One of the most important variables to consider in sustainable architecture is thermal behavior [8]. The thermal behavior of poured earth and its ultrasonic characterization have been studied with the addition of the ixtle fiber, but not with the mineral wool fiber [9].

Another way to predict the thermal behavior of poured earth and materials in general, is through mathematical models, theorizing and making projections [10]. Other attempts to use poured earth not stabilized [11] have been directed toward increasing compressive strength using dispersants [12]; however, up to now, mineral wool has not been experimented with, as a type of natural fiber that has very specific characteristics.

The general objective of the present investigation is to demonstrate if the mineral wool used as a stabilizer in the poured earth improves the characteristics of the mixture and of the monolithic wall, having as particular objectives: Characterize the soil from the bank called Champayan, dose different percentages of Mineral wool added to the mix of poured soil stabilized with 6% cement to determine its behavior in terms of compressive strength, water absorption and thermal transmittance.

The importance of this study lies in the fact that until now it has not been tested the stabilization of poured earth with a natural product such as mineral wool and to know if its physical-mechanical characteristics are improved, such as: water absorption, resistance to compression and its thermal conduction capacity.

2. Methodology

In the materials laboratory of the Faculty of Architecture of the Autonomous University of Tamaulipas, 4 groups of 3 samples each were prepared, with the following mixture of soil from the Champayan bank, stabilized with 6% cement. The groups were named A, B, C and D where the amount of fiber was as indicated below:

A is the so-called white or control group without mineral wool.

B Containing 0.025 mineral wool (%w/w)

C Containing 0.050 mineral wool (%w/w)

D Containing 0.075 mineral wool (%w/w)

The dimensions of the cylindrical specimens are 0.15m in diameter and 0.30m high.

2.1. Compression Test

The 3 specimen samples were subjected to this test. Based on the NMX-C-083-ONNCCE-2014 standard [13], an Automax model Controls press was used for the compression test of the specimens with a load application speed of 0.9 kN/s for a nominal area of the specimens of 176.72 cm^2. The compressive strength was determined with the following equation (1), expressing the results in MPa.

$$\boldsymbol{\sigma} = \frac{\boldsymbol{F}}{\boldsymbol{A}} \tag{1}$$

Where:

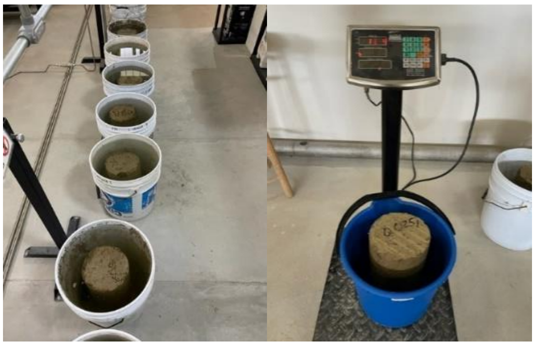
F = maximum applied load up to fracture (kN)

A = nominal area of the specimen (0.017672 m^2)

2.2. Water Absorption Test

For this test, the NMX-C-263-ONNCCE-2010 standard [14] was used. The dry weight of the test tubes was determined, once weighed, they were submerged in water for 24 hours, (Figures 1a, 1b) to later determine the wet weight and take the difference that is equal to the water absorbed by the test tube; the percentage of absorption is represented by the following equation (2):

$$\%\ \boldsymbol{Absorption} = \left(\frac{\boldsymbol{wet\ \ weight - dry\ \ weight}}{\boldsymbol{dry\ \ weight}}\right)\boldsymbol{100} \tag{2}$$



(a) (b)

Figure 1. Absorption test

2.3. Thermal Conductivity Test

It was obtained by the method of temperature difference in a system. Basically, it is intended to determine the capacity of the material for heat transfer, and it can be determined under the following equation (3):

$$\boldsymbol{k} = \frac{\boldsymbol{Q}(\boldsymbol{h})}{\boldsymbol{A}(\Delta \boldsymbol{t})(\boldsymbol{T_c} - \boldsymbol{T_f})} \quad (3)$$

Where:
k: Thermal conductivity coefficient
Q: Heat supplied (J)
h: Sample thickness
A: Sample cross section area
Δt: Measurement time
Tc: Hot temperature (K)
Tf: Cold temperature (K)

The heat source was an electric laboratory grill, which was characterized under the following procedure:

1. Approximately 100 g of distilled water was placed in a 250 mL round flat-bottomed flask.
2. The water was heated at a certain level of the laboratory grill and the initial and final temperatures were measured until constant behavior was observed, at intervals of 5 min.
3. The heat emitted by the grill was determined from Equation (4).

$$Q = mC_p\left(T_c - T_f\right) \quad (4)$$

Where:
Q: Heat supplied (J)
m: Mass of water used during the measurement (≈100 g)
Cp: Heat capacity of water (4182 J/kg*K)
Tc: Hot temperature (K)
Tf: Cold temperature (K)

The mass of water of 100.3715 g obtained a constant maximum heat of 23,883.98 J supplied after 2 h of heating. Once the maximum heat supplied by the laboratory grill was known, the samples were subjected to constant heating for 4 h, taking the system in Figure 1a as a representation. The temperatures were measured with THC-4 temperature sensors, recording the hot temperature. (Tc), cold temperature (Tf) and room temperature (Ta) in 5 min intervals. For this purpose, gutters were carved into the bases of each specimen so that the sensor was superficially immersed. During the test, the specimens were kept isolated in a polystyrene container to reduce heat losses in the system (Figure 2). The data obtained were processed for 3 test tubes of each type of mix including an experiment blank and a method blank (concrete cylinder f'c 200 kgf/cm^2, 15x30 cm). All the specimens were heated for a minimum period of 4 h to observe the behavior of the material when applying constant temperature.

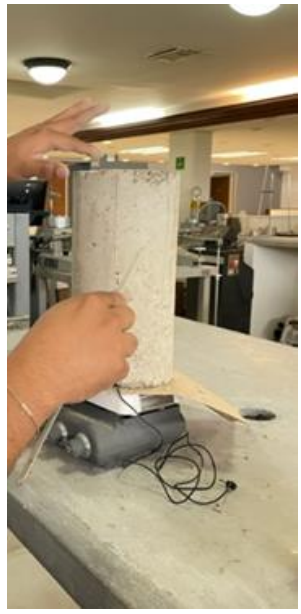


Figure 2. Test tube with sensors attached.

3. Results

Below are the results obtained for each of the most representative tests that were chosen to find out if the characteristics of the poured earth are improved using rock mineral wool as a stabilizer. These tests were:

Compression test, the absorption test, and the heat transfer test. The results are obtained in the determination of the thermal properties of the materials. The presence of mineral wool decreases the coefficient of thermal conductivity with respect to the method target, which is a concrete sample. Naturally, the earth behaves as an insulator, which is demonstrated by the results obtained for Group A that do not contain mineral wool. The expected result for groups B to D was to further decrease this value for the zero percentage, however, the opposite effect is observed. This behavior may be because mineral wool, which is also an insulator (k=0.316 W/m*K), produces a significant difference in heat conduction between the particles within the solid, which requires taking advantage of the available surfaces to dissipate heat from the system. Therefore, as the amount of mineral wool increases, the phenomenon of heat dissipation falls on the soil particles, which increases the global thermal conductivity coefficient. Even with this phenomenon, the materials studied in this are also demonstrated by the behavior observed in Group D (0.075% mineral wool content) as it has a lower thermal resistance and therefore a higher thermal conductance value. However, conducting the experiment for prolonged periods allowed us to determine that the retardation factor, that is, the material's ability to allow the passage of energy in the form of heat, is still 18% higher than the reference value obtained for conventional concrete.

With the results obtained from the compression test to which the specimens were subjected, shown in table 1, and using control group A as a reference, which is a simple concrete sample, it can be inferred that group B had an increase in its load capacity by raising its breaking stress value to 0.886 Mpa, that is, an increase of 8.788% with respect to the control group. Group C reached an average breaking stress value of 0.869 Mpa. which is 6.726% greater than the control group, that is, it is greater than the control group but the increase in the percentage of mineral wool to 0.05% causes the breaking stress to have a small downward variation compared to the group B. Group D behaved in compression with a breaking stress of 0.715 Mpa, which is 12.263% lower than the control group, which is a significant reduction. Given that compression resistance is a very important variable in the load capacity of walls in general and in particular of those made of poured earth, the results indicate that the percentage of mineral wool should be 0.05% maximum to obtain the benefit of an increase in compression load capacity.

The results obtained from the absorption test are shown in Table 2, from which it can be deduced that the presence of mineral wool does not have a major impact on water absorption.

Table 1. Compression test results obtained from the compression test for the different groups

	Sample 1		Sample 2		Sample 3		Averages	
	F (KN)	σ (MPa)	F (KN)	σ (MPa)	F (KN)	σ (MPa)	F (KN)	σ (MPa)
Control Group (A)	13.000	0.736	16.240	0.919	13.960	0.789	14.400	0.815
Group 0.025 %(B)	14.010	0.793	16.960	0.960	16.010	0.906	15.660	0.886
Group 0.050% (C)	15.630	0.884	15.950	0.903	14.510	0.821	15.364	0.869
Group 0.075%(D)	14.080	0.797	11.900	0.673	11.910	0.674	12.630	0.715

Table 2. Absorption test results

	Sample	Control (A)	0.025% (B)	0.050% (C)	0.075% (D)
Dry weight	1	9.30	9.50	9.02	9.40
	2	9.35	9.40	9.00	9.60
	3	9.38	9.58	8.86	9.16
Wet weight					
	1	10.58	10.82	10.42	10.72
	2	10.62	10.68	10.36	10.90
	3	10.64	10.88	10.30	10.42
% of Absorption					
	1	12.10	12.20	13.44	12.31
	2	11.96	11.99	13.13	11.93
	3	11.84	11.95	13.98	12.09
	Average	11.97±0.001	12.04±0.001	13.51±0.004	12.11±0.002

Table 3. Thermal conductivity.

PARAMETERS				
	k (W/m*K)	R (m^2*K/W)	C (W/m^2*K)	FR (Adim.)
Group A	0.6425 ± 0.0178	0.4672 ±0.0173	2.1419 ±0.0794	2.7619 ±0.0953
Group B	0.7407 ±0.0008	0.4071 ±0.0014	2.4567 ±0.0086	2.3025 ±0.1867
Group C	0.8089 ±0.0091	0.3685 ±0.0112	2.7151 ±0.0822	2.3454 ±0.0371
Group D	0.8725 ±0.0233	0.2517 ±0.1412	4.7144 ±2.6451	2.0984 ±0.2834
Control of method	1.0165	0.2951	3.3884	1.7737

In Table 3, the average values of the thermal properties of the materials are observed, where k is the coefficient of thermal conductivity, R is thermal resistance, C is thermal conductance, and FR is the retardation factor (dimensionless). Taking the method blank as a reference, which is a concrete sample, it can be observed that the presence of mineral wool decreases the value of the coefficient of thermal conductivity. Comparing the results of Group A, which is a sample of soil stabilized with cement without mineral wool, it follows that the earth is a natural insulator. Regarding groups B, C and D, there is an increase with respect to Group A and a decrease with respect to the method blank. This behavior is probably produced because mineral wool is an insulator (k=0.316 W/m*K), there is an important difference in heat conduction between the particles of the solid, which implies that the available surfaces to dissipate the heat of the system are used. The more the amount of mineral wool, the more heat dissipation falls on the floor and the coefficient of thermal conductivity of the sample increases. The studied specimens show a decrease of 14% with respect to the concrete sample.

4. Conclusions

It is important that the procedure shown here continues to be studied to solve problems that may arise in buildings made of poured earth, using different stabilizers, to improve their behavior.

The results obtained from the thermal properties of the materials allow us to denote that the presence of mineral wool does not have a significant impact on the coefficient of thermal conductivity with respect to the experimental blank (0% mineral wool), however, it continues to maintain a value low compared to conventional concrete. As the dosage of mineral wool increases, the heat conduction of the material also increases, however, the non-retention capacity of this heat remains low compared to traditional concrete. It is advisable to carry out studies with different materials whose thermal properties can be varied, and it is possible to expand this observation with respect to their interaction in a mixture with earth. It can be affirmed that the compressive load capacity is increased with the presence of mineral wool when the percentage oscillates between 0.025% and 0.050%, improves the characteristics of lateral stress resulting from the compression effect and induces that the compressive capacity is increased.

It is not recommended that the percentage of mineral wool reach the percentage of 0.075% because the evidence found reflects a decrease in its load capacity.

With respect to absorption, the data found show that the presence of mineral wool in any of its tested quantities has no influence on water absorption.

Regarding the thermal properties, it is observed that, with respect to the white model, the presence of mineral wool does not significantly alter the coefficient of thermal conductivity, but it does with respect to the common concrete model. With larger amounts of mineral wool, the heat conduction of the material increases, but the fact is that it does not retain heat maintains low values with respect to concrete.

Acknowledgements

The authors thank the FADU Research Center, especially Dr. Josué Sánchez

REFERENCES

[1] Houben, Hugo, and Hubert Guillaud. "Construction methods", Earth construction: a comprehensive guide. (4th Edition), ITDG Publishing, 1994, pp. 163-190.

[2] Doat P, Hays A., et al. "Vigniey: An experimental construction with rammed earth in the Isere", Building with earth Vol. I (1st Edition), Fondo Rotatorio Editorial, 1990, pp. 110-115.

[3] Kozminska, U. "Circular design: reused materials and the future reuse of building elements in architecture. Process, challenges and case studies", IOP Conference Series: Earth and Environmental Science vol. 225, 2019, IOP Publishing.

[4] Rivera, J. F., Aguirre A., Gutierrez R., Orobio A. "Chemical Stabilization of Soils-Conventional and Alkaline Activated Materials (Review)." Informador técnico, vol. 84, no. 2, pp. 202-226, 2020. https://revistas.sena.edu.co/index.php/inf_tec/article/view/

2530/3417 (accessed August 23, 2023).

[5] Minke G. "Improving the earth's characteristics by special treatment or additives", Building with earth (Third Edition). Birkhauser. Germany. 2001, pp. 38-40.

[6] Hou, Y., Pojtanabuntoeng, T., Iannuzzi, M. "Use of electrochemical current noise method to monitor carbon steel corrosion under mineral wool insulation". npj Materials Degradation, Vol. 4, no. 39, pp. 1-7, 2020. Doi: 10.1038/s41529-020-00144-3

[7] Aranda, Y., Espuna J., Suárez, E. "Structural and Thermal Monitoring of Sustainable Housing with Poured Earth Walls". International Journal of Scientific Research Engineering & Technology, vol. 5, no. 1, 2016. https://www.researchgate.net/publication/320867631_Structural_and_Thermal_Monitoring_of_Sustainable_Housing_with_Poured_Earth_Walls

[8] Adrian, Z. M.., Hien, N., Marcel, I., Kardinal, S. "Predicting the envelope performance of commercial office buildings in Singapore". Energy and Buildings. vol. 66, pp. 66-76, 2013. https://ideaslab.io/publication/pdf/chong-201366.pdf

[9] Suárez E., Aranda Y., Fuentes C., Zúñiga C. "Behavior of the heat capacity and ultrasonic characterization for poured earth". IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), vol. 14, no. 6, pp 18-22, 2017. https://www.researchgate.net/profile/Edgardo-Suarez-Dominguez/publication/324273451_Behavior_of_the_heat_capacity_and_ultrasonic_characterization_for_poured_earth/links/5ac86cc94585151e80a55fb2/Behavior-of-the-heat-capacity-and-ultrasonic-characterization-for-poured-earth.pdf

[10] Suárez E., Aranda Y., Palacio A., Izquierdo E. "Mathematical model for the description of heat transfer for poured earth". Nova scientia, vol. 6, no. 12, pp. 379-390, 2014. https://www.scielo.org.mx/pdf/ns/v6n12/v6n12a19.pdf

[11] Ardant, D, Brumaud C. "The slower it is, the stronger it will be: How to improve poured earth strength without stabilization", 8th International Conference on Building with earth. Proceedings (Switzerland), LEHM, 2020, pp. 1-4. https://www.dachverband-lehm.de/lehm2020_online/pdf/lehm2020_p_ardant-brumaud-habert_en.pdf

[12] Romero, J., & Barbeta, G. "Stabilisation of earthen surfaces using carob (Ceratonia siliqua L.)", Vernacular and Earthen Architecture: Conservation and Sustainability, (1st Edition), CRC Press, 2017, pp. 789-795.

[13] Mexican Standard NMX-C-083-ONNCCE-2014, pp.9, 2014. https://onncce.org.mx/images/CatalogoNormas/CDN35.pdf

[14] Mexican Standard NMX-C-263-ONNCCE-2010 https://onncce.org.mx/images/CatalogoNormas/CDN35.pdf alcalinamente, Informe Técnico, pp. 10, 2010. https://revistas.sena.edu.co/index.php/inf_tec/article/view/2530/3417