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Study of compressive strength in artisanal adobe stabilized with cow manure, nopal sap, straw and bull blood

M. Ureña^{1}* , *S. Llumitasig¹* , *A. Siza¹* , *D. Coello-Fiallos¹* 

¹Universidad Técnica de Ambato, Facultad de Ingeniería Civil y Mecánica. Avenida los Chasquis y Río Payamino, C. P. 180207. Ambato, Ecuador.

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*Autor de Contacto: me.urena@uta.edu.ec

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Abstract

Adobe has been used in construction since the first civilizations in the world, and to improve its mechanical properties, organic stabilizers were added. We studied the compressive strength of adobe cubic samples made with soil from the Sierra Region of Ecuador and organic stabilizers. Four organic stabilizers were studied: cow manure, nopal sap, straw and bull blood, which were added in specific percentages individually and in combination. Field and laboratory tests were carried out according to "Proyecto de actualización – versión 1 de la Norma Peruana E.080 de Noviembre 2013". The results showed that the four organic stabilizers improve the compressive strength, having an increase from 0.5 to 13.1%. By using 10% of cow manure with 20% of bull blood the adobe compressive strength increased 13.1% in relation to the basic adobe.

Keywords: Compressive strength; Adobe; Organic stabilizers.

Estudio de la resistencia a la compresión de adobe artesanal utilizando estabilizadores orgánicos: estiércol de vaca, savia de nopal, paja y sangre de toro

Resumen

El adobe ha sido usado en la construcción desde las primeras civilizaciones del mundo, para mejorar sus propiedades mecánicas, se adiciona estabilizadores orgánicos. Estudiamos la resistencia a compresión de muestras cúbicas de adobe, elaboradas a base de suelo de la Sierra ecuatoriana y estabilizadores orgánicos. Se estudiaron 4 estabilizadores: estiércol vacuno, savia de nopal, paja y sangre de toro, mismos que fueron añadidos en porcentajes específicos de forma individual y combinada. Los ensayos de campo y laboratorio se realizaron según el "Proyecto de actualización – versión 1 de la Norma Peruana E.080 de Noviembre 2013". Los resultados muestran que los cuatro estabilizadores orgánicos mejoran la resistencia a la compresión, teniendo un incremento del 0.5 a 13.1 %. Al usar 10% de estiércol vacuno con 20% de sangre de toro la resistencia a la compresión del adobe incrementó 13.1% en relación al adobe básico.

Palabras clave: Resistencia a la compresión; Adobe; Estabilizadores orgánicos.

Introduction

Earth is one the oldest and most common building material in the world, The Wall of Jericho in Palestine, of which there are still remains, it is known as the first evidence of construction with adobe since 9.000 years B.C [1]. Over the years, some structures of great religious importance, especially in the dome shape and traditional houses, have been built with earth [2]. In addition, adobe has been used in the construction of shelters for thousands of years, and approximately 30% of the current population in the world still live in structures built with this material [2,3]. This is due the earth is a construction material respectful of the environment, abundantly available and with basic construction technology [4-7]. Currently, a rich cultural heritage of earth construction can be found in Africa, Iran, Afghanistan, Yemen, Iraq, Syria, Spain, Germany, England, France, Portugal, Italy, Denmark and Sweden [2]. In India, according to the 1971 Census, 73% of all buildings are made of earth. In Perú, 60% of the houses are built with adobe or tapial. In general, this type of construction has been used mainly by the rural population of low economic resources [8].

The basic adobe brick is made of a mixture of earth and water, this is put in molds and left drying in the open air, even direct to the sun [4]. This material has excellent thermal and acoustic properties [8,9], but it can also present some disadvantages such as its moderately low compressive strength, low tensile strength, and low water resistance. To overcome these problems, certain additives called stabilizers must be added, these components improve the basic adobe properties such as compressive strength, tensile strength, abrasion resistance, density, porosity, impermeability and hardness [4].

Common additives are divided into three categories: mineral, synthetic and organic. Two sources of organic materials are known; a vegetable source such as straw, palm leaves, rice husks, and nopal sap; and an animal source such as hair, excrement and animal blood [4, 10]. On the other hand, sand is considered like an excellent mineral stabilizer that reduces shrinkage and swelling of the soil used to make mud, improving its properties [4]. The amount of sand and clay is very important for the adobe elaboration process if there is not enough of clay, the mixture does not achieve the necessary cohesion to support the actions of external agents, and hence adobe blocks can fall apart. On the contrary, if there is not an adequate amount of sand, cracking occurs due to shrinkage of the clay during the drying process [11].

The amount and type of stabilizer used in several researchs depends of the characteristics of soil. Several researches report that cow manure is a stabilizer that provides cohesion and plasticity to the soil, reducing the expansion and contraction, providing strength and hardness. In India, traditionally this organic stabilizer

is mixed with water and five portions of soil by weight and applied to fill surface cracks [4]. Straw which is a vegetable fiber provides tensile strength, reduces cracking, decreases density and accelerates drying [4,6,7,12,13], the nopal sap provides durability against external agents [4,14], as well as hardness and improve the compression strength, waterproofing and density. Furthermore, animal blood mixed with soil attributes, as animal manure, provides hardness and water resistance [4]. In 2012, the British architect Jack Munro used animal blood to make bricks as an innovative project, due to the water scarcity in rural areas of Egypt. So, he proposed to replace water with animal blood, because it was a widely wasted substance in ancient times and he used it as a natural glue and agglutinating to solidify the soil, creating a new waterproof construction material of high cohesion [4,15]. Some organic stabilizers are widely available and can be obtained at low cost or not cover.

In this study, the adobe compressive strength of cubic samples adding organic stabilizers were analyzed. We use cow manure, nopal sap, straw and bull blood, which were added individually and in combination (up to 3 stabilizers at a time) in certain percentages in relation to total weight, obtaining 10 total combination.

Materials and Methods

The materials used in this study were soil extracted from Latacunga-Ecuador, drinking water (for the mud mixture) and 4 organic stabilizers (o.s). The solid o.s were straw (s) and cow manure (cm), the liquid o.s were bull blood (bb) and nopal sap (ns). The o.s used in this study were prepared previously, according to the literature [4,14,15-18]. The nopal was cut into small pieces and it was immersed in water for 5 days to obtain the main substance. Equal weight proportions of nopal and water were used, the cow manure was left to stand for 4 days. On the other hand, the straw was dried, and it was cut into pieces of 5cm in length, and finally, the bull blood used was fresh and it was treated with anticoagulant (DAFLON 500mg), and a preservative - antibacterial (Mentilparabeno). The anticoagulant was added in amount of 10% by weight of blood and the Mentilparabeno was added in the amount of 5 g/ liter of blood [15].

The standar used for this work was "El proyecto de actualización - versión 1 de la Norma Peruana E.080" "Construcción con tierra" de noviembre 2013 [19] because the "Norma Ecuatoriana de la Construcción 2015" (NEC 2015), references it to establish requirements, technical design and construction criteria for earth buildings [20]. In the same context, another standard that regulates earth structures is ASTM E2392 / E2392M - 10 (2016), it is a Standard Guide for Design of Earthen Wall Building Systems; it contains some similar topics to E.080.

The first process to make the adobe cubes was to

verify the adequate amount of clay in the soil, carrying out two field tests called "Cinta de Barro" y "Resistencia Seca", as established the Peruvian standard [19]. According to the Unified Soil Classification System (USCS), the soil had 71% of material passing the No. 200 sieve (particle sizes $\geq 0.075\text{mm}$) and 29% of material retained the No. 200 sieve (particle sizes $< 0.075\text{mm}$). The liquid limit was 26.3%, plastic limit 33.1% and the plasticity index was 6.8%. Therefore, the classification of the soil is CL-ML (silty clay with sand).

So "the mud" (fresh mixture of clay, sand and water) was elaborated according to E.080 and left to stand under shade for 48 hours, acquiring the denomination of "resting mud" (RM) [16]. After, half part of water was mixed for every five parts of RM to obtain the called "activated mud" (AM) [16], it was cured at room temperature for 30 days, taking the name of basic adobe (BA), after this process we can performed the destructive test.

The o.s were incorporated in a specific type of mud to make the adobe cubes. In AM sample were adding only solid o.s, while in RM both liquid and solid o.s were added individually and combined. Table 1 shows the percentages used for dosing (by weight) of the organic stabilizers used. For convenience of identification we assigned a code por each combination.

Table 1. Percentages by weight of the organic stabilizers added to elaborate the cubic samples

TYPE OF MUD	ORGANIC STABILIZERS (%)				CODE	#(*)
	bb	ns	cm	s		
AM	-	-	-	-	BA	1
	-	-	-	3	A-1s	2
	-	-	10	-	A-2cm	3
	20	-	-	-	R-1bb	4
	20	-	-	3	R-2bb	5
	20	-	10	-	R-3bb	6
RM	-	28	-	-	R-1ns	7
	-	28	-	3	R-2ns	8
	-	28	10	-	R-3ns	9
	-	28	10	3	R-4ns	10

*Correspondence with the images of Figure 2.

Six adobe test samples were prepared for each type of combination (total 60), but only the four best compressive strength were considered as established by the Peruvian standards. The samples had a cubed-shaped of 0.10m of edge [19]. For the destructive test, a CONTROLS concrete compression machine was used, it has a maximum load capacity of 2000KN and a maximum calibration tolerance of 200KN (Figure 1).

In Figure 2, we present photographs of the different mixtures proposed for this study. The photograph 1 shows activated mud without stabilizers, photographs 2 and 3 show activated mud with straw and cow manure respectively. Photographs 4 to 10 show the mixtures of resting mud with the different stabilizers in the proportions established in the Table 1.



Figure 1. Standardized adobe samples for the test in the compression machine.



Figure 2. Mixtures with the different organic stabilizers

Results and Discussion

Figure 3 shows the average compressive strength and the standard deviations of the adobes made from combinations proposed. The standard deviations are very small, the minimum and the maximum standard deviation value are 0.005 and 0.022 MPa respectively, it means that the data are closely distributed (instead of widely spread) around the mean value, indicating accuracy in the preparation of the samples in each combination, as well as a close monitoring of the compression test.

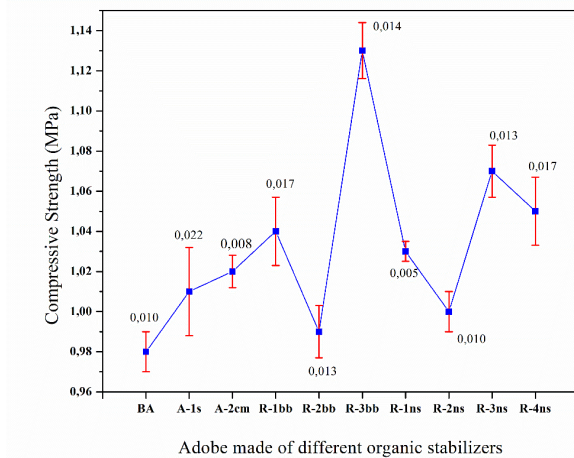


Figure 3. Standard deviation of adobe compressive strength values for each combination.

In this study we obtained a compressive strength of 0.98 MPa in the BA, this value is 2% less than the one specified by the Peruvian standard (1 MPa), may be due to the fact that we used as a reference as a standard that does not correspond to the country where the clay was extracted. Therefore, we can take that value only as a reference.

However, is evident that the addition of the different stabilizers proposed increases the compressive strength of the BA and in many cases exceeds the resistance established in this standard. Table 2 shows the 4 highest values of compressive strength of the 10 proposed combinations, their average and rate of increase in each case.

The common solid organic stabilizer in R-3bb, R-3ns and R-4ns combinations was cow manure, obtaining the highest values of compressive strength: 1.13 MPa, 1.07 MPa and 1.05 MPa respectively, it means to a rate of increase of 13.1%, 8.0% and 6.2% respectively in relation to the BA (see Figure 4). The combination R-3bb reached the greater compressive strength (1.13MPa), it is equivalent to a compressive force of 11300N, while the (BA) reached a compressive strength of 0.98 MPa being equivalent to a compressive force of 9800N. So, R-3bb resists 1500 N additional compared to the traditional adobe BA.

Table 2. Data of the compression test of the adobe cubes made of different stabilizers and muds

#(*)	Code	Compressive Strength (MPa)					\bar{x} (MPa)	Increment (%)
1	BA	0.99	0.99	0.97	0.98	0.98	0.98	--
2	A-1s	0.98	1.02	1.00	1.03	1.01	1.01	2.5
3	A-2cm	1.03	1.01	1.02	1.02	1.02	1.02	3.7
4	R-1bb	1.04	1.03	1.02	1.06	1.04	1.04	5.3
5	R-2bb	0.99	0.99	1.00	0.97	0.99	0.99	0.5
6	R-3bb	1.12	1.15	1.13	1.12	1.13	1.13	13.1
7	R-1ns	1.03	1.03	1.02	1.03	1.03	1.03	4.4
8	R-2ns	0.99	1.00	0.99	1.01	1.00	1.00	1.5
9	R-3ns	1.05	1.07	1.07	1.08	1.07	1.07	8.0
10	R-4ns	1.07	1.03	1.05	1.04	1.05	1.05	6.2

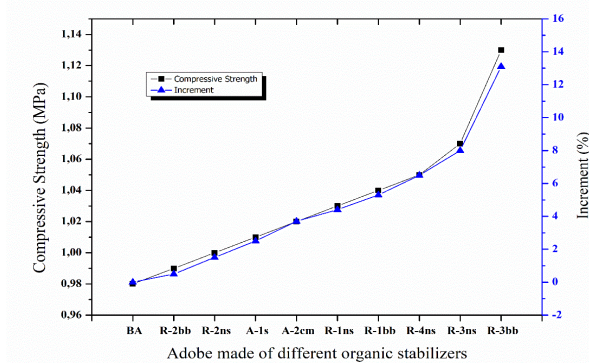


Figure 4. Graph in increasing order of the compressive strength and its rate of increase in relation to the basic adobe by each type of adobe.

The mixture of bull blood and the cow manure adding to the resting mud (R-3bb) to make adobe had the highest average compressive strength (1.13 MPa). This could be due to the bull blood when is incorporated and compacted with the soil is able to form a material of great hardness and cohesion making it sustainable and safe for residential construction, this criteria is also reported by J. Munro [15]. The cow manure contributed to the adobe compressive strength because it contains fibrous material, phosphoric acid and potassium improving the material behavior [4,18].

The adobe cubes that contains straw A-1s, R-2bb and R-2ns with the exception of the R-4ns, achieved a lower rate of increase in compressive strength, 0.5%, 1.5% and 2.5% respectively, this performance is mainly due to the plant fiber only increase the tensile strength [4,6,7,12]. Previous studies have shown that the fibers decrease the compressive strength because when they are wet are susceptible to rotting, affecting its durability [4, 13].

The mixture of nopal sap with cow manure (R-3ns) in the adobe exceeds the compressive strength of BA by 8.0%, reaching the second highest strength (1.07MPa) in this study, this is because when the sap is mixed with the RM gives a good compressive strength.

Conclusions

In this study we used four organic stabilizers to elaborate adobe sample and reached increase of compressive strength, the percentage increase was of 0.5% to 13.1% in relation to adobe without organic stabilizer. The combination of cow manure and bull's blood adding to make adobe present the best compression behavior, reaching the higher increase in relation to adobe without organic stabilizer.

The gather results can be considered as a precedent for future research in order to evaluate other mechanical properties of the adobe using the proposed stabilizers, due in most of the regions this is a type of construction that is clearly artisanal, where the organic stabilizers are incorporated without any technical knowledge. On the other hand, this research will also encourage to build more earth buildings due to the easy affordability of the materials and stabilizers used in this type of construction. Finally, these stabilizers are highly recommended to improve the structural behavior of buildings made of earth.

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