TURK-COSE 2020

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Abstract: The proposals for the construction of sustainable and eco-friendly housing require an exhaustive study of its mechanical properties and structural system. Several researches around the world agree on the use of chemical stabilizers during the production enhance significantly the compressive strength of earthen blocks. The most common stabilizer used for this purpose is cement; however, the production of this material is responsible for the emission of tons of CO2 per year. The objective of this research is to evaluate the mechanical properties of Compressed Earth Blocks (CEB) stabilized with less pollutant's materials like pozzolana or lime. The results indicate that the compressive strength of specimens grow up in two times or more with the chemical stabilization. However, the stabilization which presents best results in terms on high strength values and low variability is the combine addition of cement (7.5%) and lime (2.5%).
Keywords: Earthen blocks, Cement stabilization, Lime stabilization, Pozzolana, Mechanical characterization.

1. Introduction

Masonry made by Compressed Earth Blocks (CEB) is a construction technique that is being researched and implemented in different countries and codes around the world [1-4]. This system is an economic constructive method that has adequate strength and durability properties [5]. On the other hand, several investigations on CEB agree on the soil (raw material) must fulfill certain requirements like be non-expansive material, has low or non-organic compositions, and avoid clay with high plasticity [6]. On the other hand, according to the Australian code HB195 [7] and the African code ARS674 [8], the compressive strength of stabilized rectangular blocks should be 2 MPa or more (slenderness ratio of 0.50). Since rammed earth does not always accomplished the suggested strength, chemical stabilization emerges as a good option to increase the mechanical properties of CEB [9]. According to [10], it is required that the raw soil and the stabilizer conform a good matrix among time, therefore the quantity of lime and clay is relevant since it provides cohesion. However, this in presence of water those materials may create cracks and affect the behavior of the structural system. One of the stabilizers most widely defused and relative cheap is the cement. Many authors agree that cement increases significantly the mechanical behavior of CEBs, this increment is directly proportional to the curing age of the specimens and also to the amount of cement [11-12]. According to [11], the optimum percentage of clay on the raw material must be between 10% to 14%, this fact takes to the maximum strength if the percentage of cement is between 4 to 10%. A negative effect of cement stabilization of CEBs is that its thermal properties fall down since the formed matrix usually presents an elevated thermal conductivity, which may be a problem in extreme weather [13]. In addition, cement production is one of the industries responsible for tons of CO2 per year. On the other hand, lime is natural binder that could be used as a stabilizer for CEB. With this material the degree of water absorption can be reduced, so it can make the soil less sensitive to moisture changes, improving its workability [13]. In addition, lime allows control of swelling and shrinking of expansive soils [14]. In [14], lime was added in the CEB as a stabilizing agent forming a lime-clay gel, which allowed obtaining blocks more resistant to compression in the long term. In addition, pozzolana in conjunction with other materials could also be used as a stabilizer of CEBs. [15] Showed that pozzolana increased in around 25% the compressive strength at the 28 days of CEBs.

2. Experimental campaign

Description of the raw materials

The origin of the soil corresponds to the district of Ventanilla located in Callao - Lima and it was classified as a clay soil with a minimum percentage of organic materials. In order to improve the physical properties of this soil and to meet the requirements given by [4] the raw material was sieved by the mesh #4. Well graded sand was added in a percentage of 15% by weight. The final result of this soil is called Better Soil (BS). According to XRF analysis, SiO2 is the main mineral that composes this soil which indicates that the soil may be a low plasticity clay [4]. The Cement (Ce) used for the stabilization correspond to a Portland cement type I. The hydraulic lime (Ca) is a composition of crushed limestone and 3% to 15% of Ca(OH)2. The third stabilizer is pozzolana (Pz) which has an 11.2 µm grain size and a specific weight of 2.78 gr/cm³. Figure 1 shows the specimens during the curing age.

Figure 1. Production and curing pf cylindrical

Description of the experimental campaign

The experimental campaign was made taking in consideration two mechanical test: uniaxial compressive test and split test. Furthermore, different dosages were considered to check which one provides the best requirement. For the compressive test specimens were tested at the ages of 7, 14, and 28 days (5 specimens per day), for each dosage. While for the spit test the only the 28 day of curing age was considered. Table 1, shows the detailed dosage for each sample.

Table 1 Detailed composition of each type of dosage

N°	Type	Dosage by weight (%)				w (%)	w/c
		BS (%)	Ce (%)	Ca (%)	Pz (%)		
1	BS	100	-	-	-	12 - 14%	-
2	BS + Ce10%	90	10	-	-	9 - 10%	0.9 - 1.0
3	BS + Ce 9.0% + Ca 1.0%	90	9	1	-	8 - 9%	0.9 - 1.0
4	BS + Ce 7.5% + Ca 2.5%	90	7.5	2.5	-	9 - 10%	1.2 - 1.3
5	BS + Ce 5.0% + Ca 5.0%	90	5	5	-	8 - 9%	1.6 - 1.8
6	BS + Ce 9% + Pz 1%	90	9	-	1	9 - 10%	1.0 - 1.1
7	BS + Ce 8% + Pz 2%	90	8	-	2	9 - 10%	1.1 - 1.3
8	BS + Ce 7% + Pz 3%	90	7	-	3	9 - 10%	1.3 - 1.4

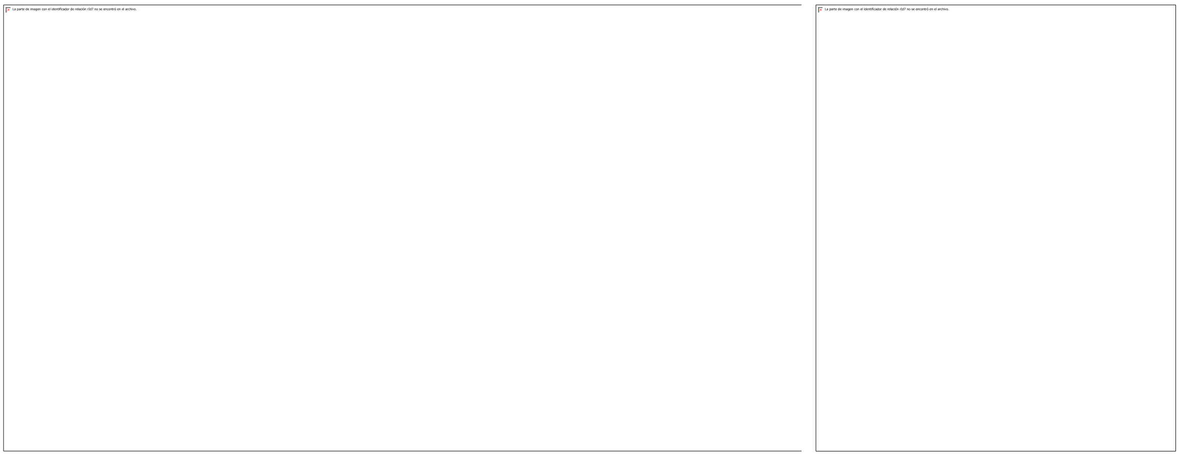
The first test corresponds to the uniaxial compressive test on cylindrical specimens ASTM C39 [16]. For this purpose, a universal electro-mechanic testing machine MTS Exceed 45.105 controlled by displacement was employed. The vertical load was applied at a constant velocity of 0.5 mm/min. The dimension of the cylindrical specimens was 50 mm in diameter and 75 mm tall obtaining a slenderness value of 1.5. Compressive strength was calculated as a division of the maximum load and the nominal cross section area of the specimen. Figure 2 shows the test configuration.

(a) (b)

Figure. 2. Uniaxial compression test on cylinders: (a) scheme and (b) specimen test

The second mechanical test corresponds to the split test con cylinders as it is indicated on ASTM C496 (2017) [17]. The specimens used for this test have the same geometry and production explained previously. Also the same machine frame was used to generate the diametric compression. However, due to the behavior in tension of this material, the compression speed in this case was settled at 0.1 mm/min. In addition, small wooden pieces were used as capping at the top and at the bottom of the specimens. The indirect tensile strength of each sample was calculated using Eq.1. where P is the maximum load, d is the diameter and L is the total length of the specimen. Figure 3 shows and scheme of this test and a specimen after applying the load.

$$f_{it} = \frac{P}{\pi d L} \qquad \text{Eq. 1}$$



(a) (b)

Figure. 3. Split test on cylinders: (a) scheme and (b) specimen after the test.

3. Discussion of results

The results of the uniaxial compression tests are summarized on Figure 4. This figure shows the evolution of the compressive strength of all the stabilized specimens in comparison to the non-stabilized specimens. In general stabilization always provides an increment of the compressive strength no matter the curing age. It should be noted that cement stabilization (Ce) gives the greater values of compressive strength, and also the mayor standard deviation (see Figure 4-a). This stabilization also shows that the compressive strength at 7 days is greater than results at 14, 21 or 28 days. This may occurred due to the high variation associated with this stabilization. Dosage which includes lime (Ca), also present high values of compressive strength, however, this stabilization shows even more variation of Ce. On the other hand, dosage with cement and lime present good results in terms of compressive strength with low variability (Figure 4-b). In addition, pozzolana stabilization is the one that provides the lower enhancement on strength (Figure 4-c). The summary of the best results is presented in Figure 4-d where the dosage #4 (BS + Ce7.5 + Cal2.5) present the better results.

(a) (b)

(c) (d)

Figure. 4. Evolution of the compressive strength of different dosages.

Table 2 presents the results of the indirect tensile strength. The result of this test also shows that the addition of stabilizers always provides an increment of the mechanical properties of the specimen. pozzolana stabilization provides the higher variability, on its results and moreover the lower increment of strength. Lime stabilization in particular dosages #3 and #4, presents the higher increment on indirect tensile strength and an acceptable variation: 4.1% and 13.2%, respectively. Therefore, dosage with cement and lime remains as the better stabilizer in this experimental campaign.

Table 2 Results of the split test

#	Dosage type	$f_{it,prom}$ 28d (MPa)	Desv. Std (MPa)	CV (%)
1	BS	0.026	0.005	19.8
2	BS + Ce 10%	0.114	0.006	5.1
3	BS + Ce 9.0% + Ca 1.0%	0.205	0.010	4.1
4	BS + Ce 7.5% + Ca 2.5%	0.206	0.027	13.2
5	BS + Ce 5.0% + Ca 5.0%	0.056	0.017	30.7
6	BS + Ce 9% + Pz 1%	0.066	0.028	43.0
7	BS + Ce 8% + Pz 2%	0.071	0.020	28.8
8	BS + Ce 7% + Pz 3%	0.091	0.009	9.5

4. Conclusions

In this research several dosages were made in order to find out which one provides the best mechanical results of compressed earth blocks. The mechanical characterization was performed con cylindrical specimens on both, compressive test and split test. Even though, all the stabilizers add a significant enhancement of strength on the specimens, the results shows that the stabilization with cement and lime provides high values of strength with the lowest variability. Furthermore, this stabilization also present a good curing behavior since from 7 to 28 days the compressive strength grow up from 0.9 MPa to 1.6 MPa on average. In conclusion, the dosage which provides the greater results is dosage #4

Acknowledgement

This investigation was sponsored by FONDCYT PERU under the project: ‘‘BTC Ensamble: Implementación de lineamientos para la construcción de edificaciones con bloques ensamblables de tierra comprimida que sirvan como una solución de construcción económica y segura para las viviendas localizadas en regiones de alta sismicidad” (Contract No. 130-2018- FONDECYT).

References

- L. Ramos, T. Sturm, D. Gomes, P. Mendonça, R. Eires, A. Camões, & P. Lourenço, Hilotech - Self-building Manual for Sustainable Housing (2014)
- IS 1725. Specification for Soil Based Blocks used in General Building Construction, India: BIS (Bureau of Indian Standards) (1982)
- NZD4298. Materials and Workmanship for Earth Buildings (1998)
- UNE 41410. Bloques de tierra comprimida para muros y tabiques. Definiciones específicas y métodos de ensayo. España: AENOR (2008)
- M. Ghrici, S. Kenai, & E. Meziane, Mechanical and durability properties of cement mortar with Algerian natural pozzolana. Journal of Materials Science, 41(21), 6965-6972 (2006)
- H. Nagaraj, A. Rajesh, & M. Sravan, Influence of soil gradation, proportion and combination of admixtures on the properties and durability of CSEBs. Construction and Building Materials, 110, 135–144. (2016)
- HB195, The Australian Earth Building Handbook. Standards Australia International, Sydney. (2002)
- ARS674, Compressed Earth Blocks - Technical Specifications for Ordinary Compressed Earth Blocks. African Regional Standards for compressed earth blocks, CDI Guides ‘Technologies Series, 11. (1996)
- J. Cid, F. Ruiz, & L. Cañas, Las normativas de construcción con tierra en el mundo. Informes de la construcción revista de información técnica, 63(523), 159-169. (2011).
- B. Venkatarama & P. Prasanna, Cement stabilised rammed earth. Part A-compaction characteristics and physical properties of compacted cement stabilised soils. Materials and Structures, (2011), 44:681–693. (2011)
- T. Sturm, L. Ramos, & P. Lourenço, Characterization of dry-stack interlocking compressed earth blocks. Materials and Structures, 48(9), 3059-3074. (2015)

- R. Eires, T. Sturm, A. Camões, & L. Ramos, Study of a new interlocking stabilised compressed earth masonry block. In XIth International Conference on the Study and Conservation of Earthen Architectural Heritage, Terra 2012 (pp. 1-10). (2012)
- E. Adam & A. Agib, Compressed Stabilised Earth Block Manufacture in Sudan. UNESCO. (2001)
- B. Venkatarama, Stabilised soil blocks for structural masonry in earth construction. Modern Earth Buildings Materials, Engineering, Constructions and Applications (2012), 13: 324-362. (2012)
- C. Shon, D. Saylak, & D. Zollinger, Potential use of stockpiled circulating fluidized bed combustion ashes in manufacturing compressed earth bricks. Construction and Building Materials, 23(5), 2062-2071. (2009)
- ASTM C39/C39M-18 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (2018)
- ASTM C496/C496M-17 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens (2017)