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Physical and mechanical characterization of cement-stabilized compressed earth bricks

Caracterización física y mecánica del ladrillos de tierra comprimida estabilizada con cemento

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Abstract
Soil is the basic material for the manufacture of compressed earth bricks, which is worked without any type of stabilization to obtain the minimum physical and mechanical properties required according to Peruvian standard E.070. The objective of this research is to evaluate the physical and mechanical characteristics of compressed earth bricks stabilized with different dosages of 5, 8, 12, 12, 15 and 18% of cement in dry weight of soil. The tests performed were: absorption, compressive strength, flexural strength per unit of masonry, compressive strength in piles, diagonal compressive strength of walls and the X-ray diffraction test. The results obtained show that with 18% of cement the optimum resistance is obtained, in terms of compressive strength increased by 53.95%, flexural strength by 43%, pile compressive strength by 36.6%, and wall diagonal compressive strength by 41.24%, respectively. The X-ray diffraction test applied to the optimum stabilized compressed earth brick sample shows that its composition is dominated by certain components such as 32.4% calcium silicate, 23.8% aluminum silicate, 17.4% hydrated calcium, 14.2% illite, 6.86% calcium oxide, 3.34% quartz, 1.2% kaolinite and 0.8% goethite. It is concluded that cement-stabilized compressed earth bricks (LTCEC) are a sustainable construction alternative that improves the mechanical properties of earth bricks.

***Keywords:** Soil; cement; bricks; compressive strength; flexural strength.*

Resumen
El suelo es el material básico para la fabricación de ladrillos de tierra comprimida, el cual se trabaja sin ningún tipo de estabilización para obtener las propiedades físicas y mecánicas mínimas requeridas según la norma peruana E.070. El objetivo de esta investigación es evaluar las características físicas y mecánicas de ladrillos de tierra comprimida estabilizados con diferentes dosificaciones de 5, 8, 12, 15 y 18% de cemento en peso seco de suelo. Los ensayos realizados fueron: absorción, resistencia a la compresión, resistencia a la flexión por unidad de mampostería, resistencia a la compresión en pilas, resistencia a la compresión diagonal de muros y el ensayo de difracción de rayos X. Los resultados obtenidos muestran que con 18% de cemento se obtienen la resistencia óptima, en términos de resistencia a la compresión aumenta en un 53.95%, resistencia a la flexión en un 43%, resistencia a la compresión en pilas en un 36.6%, y resistencia a la compresión diagonal de muros en un 41.24%, respectivamente. La prueba de difracción de rayos X aplicada a la muestra óptima de ladrillo de tierra comprimida estabilizada muestra que en su composición predominan ciertos componentes como 32.4% de silicato de calcio, 23.8% de silicato de aluminio, 17.4% de calcio hidratado, 14.2% de illita, 6.86% de óxido de calcio, 3.34% de cuarzo, 1.2% de caolinita y 0.8% de goethita. Se concluye que los ladrillos de tierra comprimida estabilizados con cemento (LTCEC) son una alternativa de construcción sostenible que mejora las propiedades mecánicas de los ladrillos de tierra.

Palabras clave: Suelo; cemento; ladrillos; resistencia a la compresión; resistencia a la flexión.

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1. Introduction

The changes that are continuously occurring in the construction processes in different countries, force civil engineers to search for new materials, traditional construction elements such as concrete block and fire clay bricks, are producing carbon dioxide emission causing environmental pollution, this is becoming a challenge for the community (Shariful Islam et al., 2020). Nowadays there is a lot of demand for housing in developing countries, causing the accelerated urbanization which exerts significant influence on the existing infrastructure from complex to simple construction (Brambilla and Jusselme, 2017).

There is an effort within the construction industry to propose solutions that are technically compliant with building process regulations. Housing must not only be cost-effective, but must offer improved strength and sustainability by incorporating low-cost materials (Bradley et al., 2018). Also, the demands of housing have increased due to the increase in population, the traditional bricks used in construction its elaboration process consumes energy and massive resources generating warming and climate change, also deteriorate and pollute the environment releasing solid waste, a huge amount of dust and gases, to these problems there is a need to provide a solution with the use of sustainable materials, as is the case of rammed earth that has as raw material the natural soil with or without a stabilizer (Khadka, 2019).

Stabilized compressed earth bricks gained popularity in recent times for several reasons, for their strength, acoustic and thermal properties, for their low production cost and for promoting sustainable construction (Jayasinghe and Mallawaarachchi, 2009). The most commonly used stabilizer is cement, which reinforces the soil by improving its strength and water resistance with chemical bonds, while at the same time significantly increasing its embodied energy and reducing its sorption capacity (Medvey and Dobszay, 2020). It should be noted that the strength properties of stabilized bricks vary according to the added percentage of stabilizer and the type of soil. This type of brick is considered as an ecological building material because for its elaboration it is not burned and it is not necessary to have coal or electricity for its elaboration as (Ameen et al., 2020) argues in their research.

Referring to the mineralogical composition of the soil (Ammari et al., 2017), considers that the component with the highest percentage in their soil sample is quartz with 80% and mentions that the results obtained with stabilization are a function of the mineralogical compositions of the soils to be used, the lack of knowledge of the granular texture and the mineralogical components of the soil can generate a high investment cost in stabilizers.

Regarding the absorption test (Abdullah et al., 2017) in his sample of brick stabilized with 10% cement obtained 14.5% absorption, (Ameen et al., 2020) with 20% cement achieved 21.28% absorption and by the researcher (Nagaraj et al., 2014) with 8% cement his result was 13.5% absorption.

(Sore et al., 2018) studied the compressive strength per unit of brick obtaining an increase of 83.2% with an optimum cement content of 8%, he mentions that the type of soil he used contained 5.4% clay and 63.1% kaolinite, however (Sturm et al., 2014) found an optimum cement percentage of 9% the soil used had less than 5% clay, where he had an increase of 23% of the compressive strength. The bricks obtained met the mechanical characteristics suitable for use as non-structural masonry (Jaramillo et al., 2022). On the other hand, (Khadka, 2019) where his result evidenced that the optimum cement percentage was 5% which originated an increase in compressive strength of 73.3% due to 20% clay content in the soil.

In the flexural strength test researchers (Sitton et al., 2017) with 11.40% cement obtained a 50% increase, (Sore et al., 2018) with 8% cement obtained 80.5% increase, (Sturm et al., 2014) with 9% cement increased by 9% strength.

For the test of compressive strength of piles considered the researchers (Yang and Wang, 2019) with the percentages of 10% and 12.5% cement obtained an increase in strength of 10.32% between both percentages in the case of (Sturm et al., 2014) with 9% cement increased by 61%.

Regarding the diagonal compressive strength test of walls researcher (Sturm et al., 2014) with 9% cement obtained an increase of 10%, (Jayasinghe and Mallawaarachchi, 2009) with 5% cement obtained an increase of 70.5%, and in the case of researcher (Khadka, 2019) with 5% cement obtained a 73% increase in strength.

By indicating the X-ray diffraction test of cement stabilized compressed brick according to (Ammari et al., 2017) mentions with 4% cement the major component is Calcite with 80%, (Sore et al., 2018) with 8% cement indicates the major component is kaolinite with 63.1%, (Chew et al., 2004) with 10% cement obtains 32% calcium silicate, (Mohammad et al., 2022) with 12% cement and (Ji et al., 2022) with 10% cement obtains calcium silicate and aluminum silicate in higher proportion. These tests reveal the presence of quartz, calcite, albite and small amounts of other minerals; on the other hand, cement stabilization increased calcite peaks. Cement stabilization reduces the porosity of the material's microstructure, thus improving the strength and durability properties (Raavi and Tripura, 2020).

The objective of this research was to evaluate the physical and mechanical characteristics of compressed earth bricks stabilized with different dosages of 5, 8, 12, 12, 15 and 18% cement in dry weight of soil. The knowledge gap is the lack of research on absorption tests, compressive strength, flexural strength of both masonry units, compressive strength of piles, diagonal compressive strength of walls and the X-ray diffraction test of bricks in the realization of compressed earth bricks stabilized with cement in the region of Peru, where *mostly constructions in the Peruvian coast, highlands and jungle are carried out. The main findings will serve to guide the society to use this material as an external additive to improve the qualities of the compacted earth brick and can be used in sustainable construction.*

2 Metodology

2.1. Materials

Soil and water

The soil used was extracted from Ferreñafe, Lambayeque, Peru, in a specific area with geographical coordinates S 6°38'03" and W 79°48'11", at a depth of 60 cm below the surface. For the Atterberg limits tests, the ASTM D4318-05 standard was taken into account, obtaining results as shown in Table 1; the water content test was also carried out taking into account the ASTM D4959-16 standard, obtaining as a result 5. 26%; the sample collected according to the SUCS system is considered SP-SC and according to AASHTO: A-2-4, in terms of mineralogical analysis using the X-ray diffraction test, the Ferreñafe soil presented a greater amount of quartz as shown in (Figure 1), the percentages of the components are shown in (Table 2). The soil is identified as an organic soil with clay and sand. Likewise, for a good selection of soil, the gradation of the soil should be taken into account because it has a significant influence on the brick properties (Vinay et al., 2017), and when selecting the type of soil it is important to know the characteristics of each component, a soil with high percentage of sand presents favorable results regarding the behavior of loads and moisture (Acosta, 2001).

Water for the production of bricks was used from the district of Pimentel, Province of Chiclayo, Lambayeque region.

Table 1. *Results of the Atterberg limits test*

Testing	Results (%)
Liquid limit (LL)	25.96
Plastic limit (PL)	17.62
Plasticity index (PI)	8.34

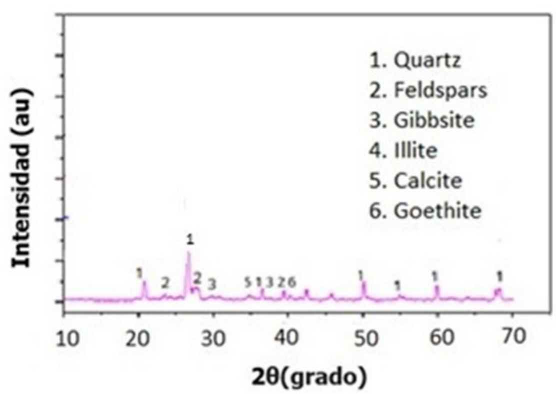

Figure 1. *X-ray diffraction of the soil*

Table 2. *Soil components*

N°	Mineral	%
1	Quartz	32.25
2	Feldspars	25.02
3	Gibbsite	16.08
4	Illite	12.42
5	Calcite	9.12
6	Goethite	6.10

Cement

The cement used for soil stabilization is Portland Type I cement. According to ASTM C150M-12 and NTP 334.009-13, Type I cement has the following characteristics as shown in (Table 3).

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Table 3. *Main chemical constituents of portland cement type I*

Components	Quantities (%)
Lime	60 to 67
Silica	17 to 25
Aluminum	3 to 8
Iron oxide	0.5 to 6
Magnesite	0.1 to 4
Sulfur trioxide	1 to 3
Soda	0.5 to 1.3

2.2. Methods

Stabilized compressed earth brick production process

The cement-stabilized compressed earth bricks were produced according to the parameters of the Spanish standard UNE 41410-2018, as shown in (Figure 2).

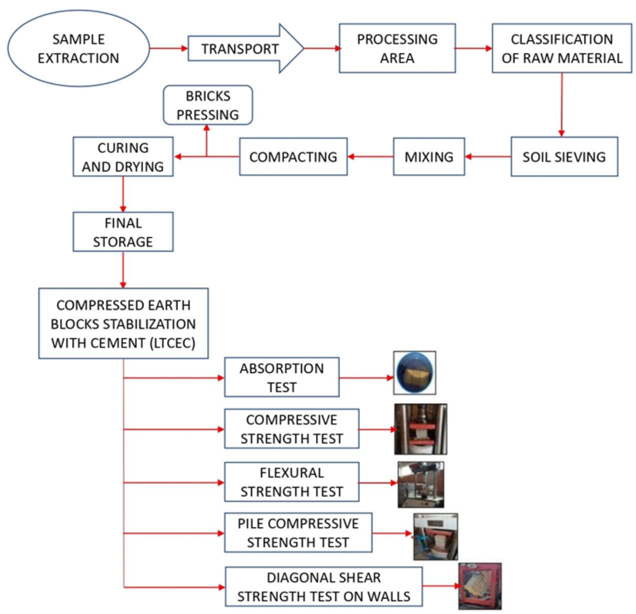

Figure 2. *Stabilized compressed earth bricks manufacturing process.*

Dry blending and wet blending

In this phase, the soil was mixed with the respective cement percentages of 5%, 8%, 12%, 15% and 18% as shown in (Table 4), leaving each sample homogeneous. With respect to the wet mix, the water is incorporated in the right amount and homogeneously as shown in (Figure 3), being a decisive factor for an adequate subsequent pressing. For the preparation of the samples, three basic components must be considered: soil, stabilizer and water.

Table 4. *Soil-cement-water mixture design*

Sample	Soil (kg)	Cement (%)	Water	Design
T1	5	5	1.1	5: 0.25: 1.1
T2	5	8	1.2	5: 0.4: 1.2
T3	5	12	1.3	5: 0.6: 1.3
T4	5	15	1.4	5: 0.75: 1.4
T5	5	18	1.5	5: 0.9: 1.5

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Figure 3. *Mixture of materials in dry and wet state*

Molded and Pressed

To perform the pressing of the sample, a manual press incorporating a hydraulic jack was manufactured as shown in (Figure 4). A force of 2000 kg/cm2 was used to compact the bricks, such samples were manufactured with dimensions of 22.5 x 11.5 x 9.5 cm, by using a pressure 1019.7 kg/cm² is considered a hypercompaction process, because it increases the density of the material and improves the mechanical properties.

Figure 4. *Manual press for brick production*

Drying, curing and storage

Drying has a special importance in the final quality of the blocks as shown in (Figure 5), so it must be done in a controlled manner, in which two stages are differentiated: curing period due to the incorporation of stabilizers and the drying period, to avoid too hasty drying it should be kept sheltered from the sun and wind, if the corresponding care is not taken these types of bricks will crack by shrinkage, generating a deficit in the final strength of the blocks, it is important to take into account the humidity in the bricks because this reduces the load capacity.

After 24 hours the bricks can be handled for placement on pallets, it is recommended that they be packed in plastic in order to maintain the proper humidity conditions for the stabilization used and they can be stored in piles up to 1.5 meters high.

Figure 5. *Drying process of the brick samples*

2. Ressults and discussion

3.1 Absorption test of bricks

The absorption test performed on the CEBSC with 5, 8, 12, 15 and 18%, the results obtained are within the parameters of Standard E.070 "Masonry", for stabilized adobe and compressed earth blocks.

In (Figure 6) in the evaluation of the variable absorption test, the p-value of significance of the one-factor ANOVA test, turned out to be less than 0.05 (p=0.000452<0. 05), i.e., the hypothesis of equality of means was rejected, likewise, the tukey's multiple comparisons test showed that treatments T4 (15% cemente by weight of dry soil) and T5 (18% cemente by weight of dry soil) did not *present significant differences, being also those that allowed maximizing the variable absorption test, whose higher average sample absorption test was presented by treatment T5 (18% cemente by weight of dry soil), whose value was 12.63%.*

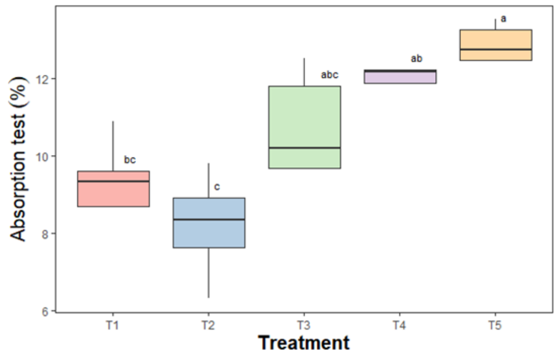

Figure 6. *Results of the percentage of brick absorption*

(Ammari et al., 2017) with 10% cement achieved 14.33% absorption at 28 days, compared to this research with 18% cement 12.63% absorption was obtained, his result shows that his samples have higher absorption percentage, but he points out that cement as a stabilizer originates that the particles reduce their pore size and considers that the addition of cement should be above 4%. In the case of (Abdullah et al., 2017) their samples with 10% cement obtained 14.5 % absorption, it can be evidenced that their value has a similarity with (Ammari et al., 2017), with respect to the results of this research there is a difference of 1.87 % absorption above the present research. On the part of the researchers (Nagaraj et al. 2014) with 8% cement in their bricks, their result was 13.5% absorption compared to the result obtained in this research there is a difference of 0.77% above.

3.2 Compressive strength

This test was carried out at 28 days, the brick samples with 5%, 8% and 12% cement achieved a lower compression than the bricks with 15% and 18% cement, the brick with the optimum percentage was 18%, being considered as type I block according to the parameters of the E.070 Standard as shown in (Table 5).

Table 5. *Classification of bricks according to E.070 Standard*

Sample	f'b (kg/cm^2)	Classification standard E.070
T1	29.61	Block NP*
T2	33.39	Block NP*
T3	40.96	Block NP*
T4	52.90	Type I**
T5	60.45	Type I**

*Note: *NP: Non-bearing block (minimum strength of 20 kg/cm2); ** Category I brick (minimum strength of 50 kg/cm2), according to E.70-2018 standard.*

In (Figure 7) corresponding to the compressive strength variable, the one-factor ANOVA test presented a p-value of significance less than 0.05 (p=6.81e-12<0.05), that is, the null hypothesis of equality of means was rejected, as well as the Tukey's multiple comparisons test, which allowed identifying the T5 treatment (18% cement) as the one that maximizes the response variable, exhibiting an average sample compressive strength of 60.45 kg/cm².

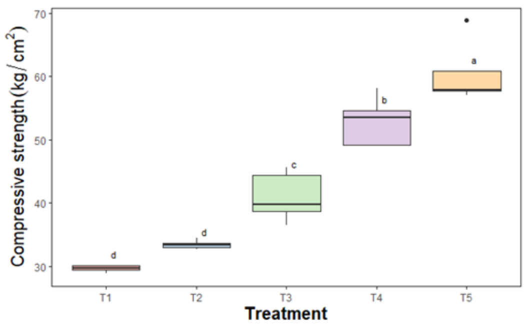

Figure 7. *Compression test results of the masonry unit*

In the research of (Sore et al., (2018) made brick samples with 8% cement in relation to the weight of the soil, obtained as a result 82.60 kg/cm² comparing with the result obtained in this research of 60.45 kg/cm² with 18% cement, an increase of 26.82% can be appreciated by the research of (Sore, 2018). Similarly (Sturm et al., 2014) used a percentage of 9% cement and their result was 36.71 kg/cm²,in this case an increase of 39.3% can be appreciated with respect to this research, and (Khadka, 2019) elaborates samples with 5% cement which obtained as a result a resistance of 66.41 kg/cm², comparing with the result obtained in this research with 18% cement, this exceeds by 8.97% of compressive strength, the above mentioned researchers have studied the improvement of mechanical properties by the addition of cement and agree that this improvement can be attributed to the creation of bonds between soil particles and hydrates formed during cement hydration.

3.3 Flexural strength

In this test, bricks with cement percentages of 5%, 8%, 12%, 15% and 18% were considered, obtaining 18% cement as the optimum result. With respect to (Figure 8), in reference to the flexural strength variable, the p-value of significance of the one-factor ANOVA test, reached a value less than 0.05 (p=6.65e-08<0. 05), i.e., there is a significant difference in at least two treatments, which based on the tukey's multiple comparisons test, we can know that treatments T4 (15% cement) and T5 (18% cement), were those that allowed maximizing the response variable, highlighting treatment T5 (18% cement), as the one that presented the highest sample average flexural strength, with a value of 9.42 kg/cm².

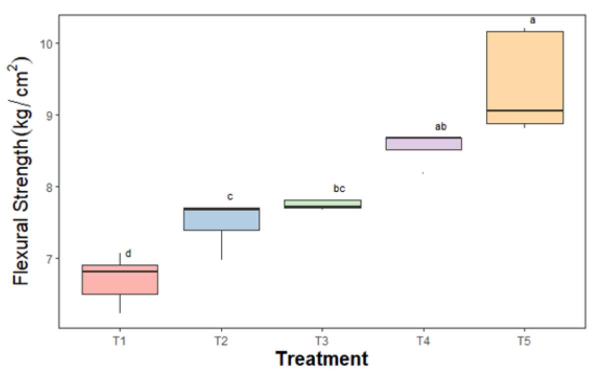

Figure 8. *Flexural test results*

According to (Sitton et al., 2017) considers in his test a sample with a percentage of 10.91% cement, in which he obtains an average flexural strength of 16.92 kg/cm² and making a comparison with the result of 9.42 kg/cm² with 18% cement, the result of the researcher (Sitton et al., 2017) is higher by 44.33% than the result of this research. In the case of (Sore et al., 2018) with a cement percentage of 8% obtains 22.43 kg/cm², it shows that its obtained value is higher than the result of this research by 58%, but the researcher (Sturm et al., 2014) with 9% cement obtained 2.14 kg/cm², the result obtained in the present research is higher by 77.28%; the researchers mention that this result can be attributed to the hydrates formed during the hydration of cement, these hydrates are generally formed in contact zones of clay and sand.

3.4 Compression test of piles

For this test, an optimum result of 41.95 kg/cm² of resistance was obtained, as shown in (Figure 9), in reference to the variable resistance to compression in piles, the p-value of significance of the one-factor ANOVA test was less than 0.05 (p=2.51e-15<0. 05), i.e., the hypothesis of equal means was rejected. Likewise, the tukey multiple comparisons test determined that treatment T5 (18% cement) was the treatment that managed to maximize the response variable, with a sample average compressive strength in piles of 41.96 kg/cm².

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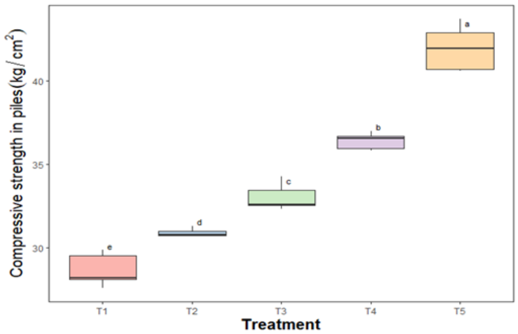

Figure 9. *Pile Compression Test Results*

Likewise, (Yang and Wang, 2019) in their two types of samples tested with 10% and 12.5% cement, their results were 5.30 kg/cm² and 5.91 kg/cm², it is observed that the resistances are lower than the results obtained in the present research with 18% cement and a resistance of 9.42 kg/cm², in which there would be an increase of 37.26% by this research. As for (Sturm et al., 2014) in their brick sample considered 10% cement, from which they obtained a result of 8.9 kg/cm² which is higher compared to the result obtained by (Yang and Wang, 2019), but lower than the result of the present research by 5.5%; likewise the researchers mention that their results obtained are low in resistance and suggest that it be taken as a reference to the upcoming studies.

3.5 Compression test of diagonal walls

According to (Figure 10), for the variable diagonal compressive strength of walls, the one-factor ANOVA test showed a p-value of significance less than 0.05 (p=1.69e-06<0.05). 05), that is, there is a significant difference in at least two treatments, likewise, the post hoc Tukey test showed that treatments T4 (15% cement) and T5 (18% cement) did not present significant differences (both presented the letter "a" in common in their box and whisker diagrams), being also the treatments that managed to maximize the response variable, where it was treatment T5 (18% cement), which presented the highest sample average diagonal compressive strength of walls, with a value of 6.91 kg/cm².

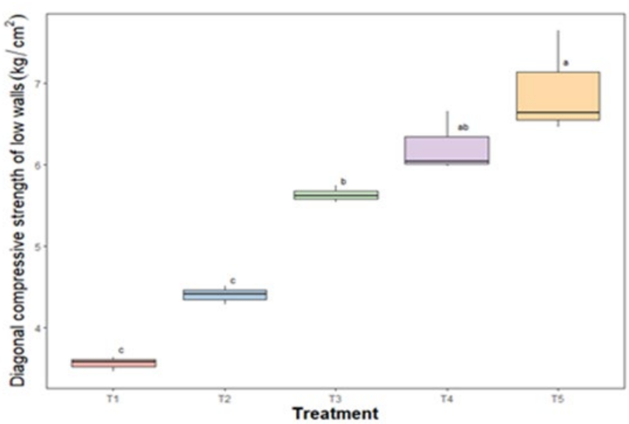

Figure 10. *Results of diagonal compression test of walls*

With respect to (Sturm et al., 2014) considered as optimal 10% cement and obtained as a result 5.4 kg/cm², making the comparison of results with this research of 18% cement and a resistance of 6.91 kg/cm², there is an increase of 21.85% in favor of the result of this research, in the case of (Jayasinghe and Mallawaarachchi, 2009) performs samples of rammed earth walls stabilized with 5% cement, their tests indicated results of 4. 7 kg/cm², this value is lower than that obtained in the present research by 31.98% with respect to 18% cement, by the researcher (Khadka, 2019) with 5% cement obtained a resistance of 55.35 kg/cm², this result is higher than that obtained in this research by 87.5%.

3.6 X-ray diffraction testing of cement stabilized compressed brick

For the mineralogical analysis of the compressed brick stabilized with 18% cement at 28 days, the X-ray diffraction test was performed as shown in (Figure 11), in which a higher proportion of calcium silicate 32.4% was obtained as shown in (Table 6), according to the researcher (Chew et al., 2004) in their mineralogical analysis of their soil sample stabilized with 10% cement there is a similarity of 32% in calcium silicate with respect to this research that considered a percentage of 18% cement.

(Mohammad et al., 2022), in their research carried out the mineralogical analysis of a soil stabilized with 3,6,9 and 12% cement, in which they obtained the formation of hydration gels such as calcium silicate and aluminum silicate in high percentage; in comparison with this research it can be noted that these components also exist in high quantities. In the case of the researchers (Ji et al., 2022) in their sample of soil stabilized with 10% cement and with the curing period of 28 days, they point out the appearance of calcium silicate in high percentage, the same happens in this research.

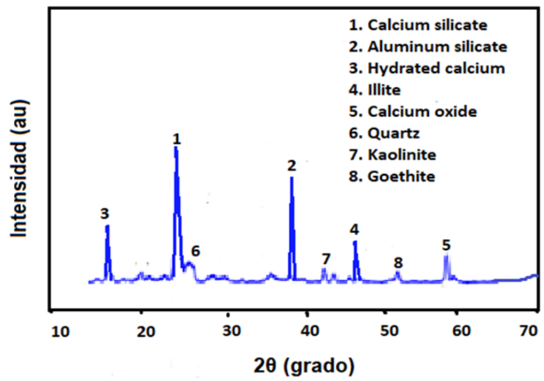

Figure 11. *X-ray diffraction diagram of brick*

Table 6. *Components of cement-stabilized bricks*

N°	Mineral	%
1	Calcium silicate	32.4
2	Aluminum silicate	23.8
3	Hydrated calcium	17.4
4	Illite	14.2
5	Calcium oxide	6.86
6	Quartz	3.34
7	Kaolinite	1.2
8	Goethite	0.8

4. Conclusion

The production of BCESC shows good resistance, its manufacturing process does not generate environmental pollution, it does not require firing for mass production and it is an alternative material for construction. The following conclusions can be drawn from this study:

1. According to the Masonry Standard E.070-2018, treated samples T1, T2 and T3 can be used for non-bearing walls in the case of perimeter walls and in the case of samples T4 and T5 they meet the minimum strength parameters required by said standard for load-bearing block and can be used as load-bearing walls for dwellings up to two floors.

2. The absorption test shows to be within the maximum admissible parameter, showing in the treated samples that the lower the amount of cement, the lower the absorption.

3. The mineralogical analysis shows that the components obtained in the optimum treatment T5, the components with the highest percentage of content were calcium silicate, aluminum silicate and hydrated calcium, some of these components improve the resistance, others the plasticity and other properties that improve the behavior of the brick, that is why it is very important to know the mineralogical composition.

4. The findings of the study show that the use of compressed earth bricks at 18% of cement in dry weight of soil, shows to be efficient, sustainable and with better properties than other conventional earth bricks, integrating this engineering methodology in sustainable earth constructions.

7. References

Abdullah, A. H.; Nagapan, S.; Antonyova, A.; Rasiah, K.; Yunus, R.; Sohu, S. (2017). *Comparison of Strength Between Laterite Soil and Clay Compressed Stabilized Earth Bricks (CSEBs). International Symposium on Civil and*

Environmental Engineering 2016 (ISCEE 2016). 103, p. 01029. MATEC Web of Conferences. doi:10.1051/matecconf/201710301029

Acosta Valle, C. (2001). *Durabilidad de ladrillos prensados de suelo-cemento. Materiales de construcción, 51(262), 15-21. Retrieved from https://digital.csic.es/bitstream/10261/84729/1/23-10-2013-dos.pdf*

Agostino, W. B.; Domenico, G.; Céline Perlot, J. M. (2017). *Mechanical behaviour of hypercompacted earth for building construction. Materials and Structures, 50(160), 160. doi:10.1617/s11527-017-1027**-5***

Ahire, N. A.; Kothawade, R. S.; Chavan, A. B.; Mahale, A. L. (2019). *Replacement of Cement by Lime and Other Materials in Compressed Stabilized Earth Blocks. Construction and Building Materials Engineering, 5(1), 24-29. Obtenido de http://matjournals.in/index.php/JOCBME/article/view/3672/0*

Ameen Saeed, I.; Jasim Mohammed, T.; Abd-Alkarem Jihad, S. (2020). *Production of Earth Units Compressed and Stabilized by Using cement and pozzolana. Materials Science and Engineering, 745, 012126. doi:10.1088/1757-899X/745/1/012126*

Ammari, A.; Bouassria, K.; Cherraj, M.; Bouabid, H.; Charif D'ouazzane, S. (2017). *Combined effect of mineralogy and granular texture on the technico-economic optimum of the adobe and compressed earth blocks. Case studies in construction materials, 7, 240-248. doi:10.1016/j.cscm.2017.08.004*

Bradley, A.; Gohnert, M.; Fitchett, A. (2018). *Guidelines to Mitigate Cracking in Compressed Stabilized Earth Brick Shells. American Society of Civil Engineers, 32(3), 04018018. doi:10.1061/(ASCE)CF.1943-5509.0001170.*

Brambilla, A.; Jusselme, T. (2017). *Preventig overheating in offices through thermal inertial properties of compressed earth bricks: A study on a real scale prototype. Energy and Buildings, 156(1), 281-292. doi:10.1016/j.enbuild.2017.09.070*

Chen, R. (2020). *Mechanical and Thermal Behaviors of Cement Stabilized Compressed earth bricks. Construccions and design, 474(6), 072090. doi:10.1088/1755-1315/474/7/072090*

Chew, S. H.; Kamruzzaman, A. H.; Lee, F. H. (2004). *Physicochemical and Engineering Behavior of Cement Treated Clays. Journal of Geotechnical and Geoenvironmental Engineering, 130(7). doi:10.1061/(ASCE)1090-0241*

Claude Morel, J.; Pkla, Á.; Walker, P. (2005). *Compressive strength testing of compressed earth blocks. Construction and Building Materials, 21(2), 303-309. doi:10.1016/j.conbuildmat.2005.08.021*

Jaramillo, H. Y.; Suárez Castrillón, S. A.; Gomez Camperos, J. A. (2022). *Mechanical Properties of an Earth Block Compressed with Cementitious Material. Civil Engineering and Architecture, 10(7), 2858 - 2865. doi:10.13189/cea.2022.100706*

Jayasinghe, C.; Mallawaarachchi, R. (2009). *Flexural strength of compressed stabilized earth masonry materials. Materials and Design, 30(9), 3859-3868. doi:10.1016/j.matdes.2009.01.029*

Ji, E.; Xu, F.; Wei, H.; Qian, W.; He, Y.; Zhu, P. (2022). *An Investion on Mineral Dissolution and Precipitation in Cement-Stabilized Soils: Thermodynamic Modeling and Experimental Analysis. Applied sciences, 14, 6843. doi:10.3390/app12146843*

Khadka, B. (2019). *Rammed earth, as a sustainable and structurally safe green building: a housing solution in the era of global warming and climate change. Asian journal of civil engineering, 21(1), 119-136. doi:10.1007/s42107-019-00202-5*

Medvey, B.; Dobszay, G. (2020). *Durability of Stabilized Earthen Constructions: A Review. Geotechnical and Geological Engineering , 38, 2403–2425. doi:10.1007/s10706-020-01208-**6***

Mohammad Jawed, R.; Ahmad Safuan, B.; Muhammad Azril, B.; Mohammad Nazir, N.; Siti Norafda, B.; Sakina, Tamassoki; Roslizayati Razali. (2022). *Evaluation of cement stabilised residual soil on macro and micro scale for road construction. Journal of Engineering and Applied Science, 69(109), 1-22. doi:10.1186/s44147-022-00165-6*

Nagaraj, H. B.; Sravan, M. V.; Arun, T. G.; Jagadish, K. S. (2014). *Role of lime with cement in long-term strength of Compressed Stabilized Earth Blocks. International Journal of Sustainable Built Enviroment, 3(1), 54-61. doi:10.1016/j.ijsbe.2014.03.001*

Raavi, S. S.; Tripura, D. D. (2020). *Predicting and evaluating the engineering properties of unstabilized and cement stabilized fibre reinforced rammed earth blocks. nstruction and Building Materials, 262, 120845. doi:10.1016/j.conbuildmat.2020.120845*

Seick, O. S.; Adamah, M.; Elodie, P.; Gilles, E.; Francois, T. (2018). *Stabilization of compressed earth blocks (CEBs) by geopolymer binder based on local materials from Burkina Faso. Construction and building materials, 165(1), 333-345. doi:10.1016/j.conbuildmat.2018.01.051*

Shariful Islam, M.; Tausif E-Elahi, Rafat; Shahriar, A.; Kamrun, Nahar; Reza Hossain, T. (2020). *Strength and durability characteristics of cement-sand stabilized earth blocks. Journal of Materials in Civil Engineering, 32(5), 04020087. doi:10.1061/(ASCE)MT.1943-5533.0003176.*

Sitton, J. D.; Zeinali, Y.; Heidarian, W. H.; Story, B. A. (2017). *Effect of mis design on compressed earth block strength. Construction and Building Materials, 158, 124-131. doi:10.1016/j.conbuildmat.2017.10.005*

Sore, S.; Messan, A.; Prud'homme, E.; Escadeillas, G.; Tsobnang, F. (2018). *Stabilization of compressed earth blocks*

(CEBs) by geopolymer binder based on local materials from Burkina Faso. Construction and Building Materials, 165, 333 - 345. https://doi.org/10.1016/j.conbuildmat.2018.01.051

Sturm, T.; Ramos, L. F.; Lourenco, P. B. (2014). *Characterization of dry-stack interlocking compressed earth blocks. Materials and Sctrutures, 48(9), 3059-3074. doi:10.1617/s11527-014-0379-3*

Temitope Kolawole, J.; Beniito Olalusi, O.; Johnson Orimogunje, A. (2019). *Adhesive bond potential of compressed stabilised earth brick. Structures, 23, 812-820. doi:10.1016/j.istruc.2019.12.024*

Tripura, D. D.; Gupta, S.; Debbarma, B.; Deep, R. S. (2020). *Flexural strength and failure trend of bamboo and coir reinforced cement stabilized rammed earth wallettes. Construction and Building Materials, 242, 117986. doi:10.1016/j.conbuildmat.2019.117986*

UNE 41410. (2008, Diciembre). *Bloques de tierra comprimida para muros y tabiques definiciones, especificaciones y método de ensayo. In U. 41410, Bloques de tierra comprimida para muros y tabiques definiciones, especificaciones y método de ensayo (pp. 1-26). Madrid, España: AENOR. Retrieved from http://www.bioarkiteco.com/uploads/1/1/3/2/11328176/une_414102008.pdf*

Vinay Kumar, B. M.; Ananthan, H.; Balaji, K. V. (2017). *Experimental studies on cement stabilized masonry blocks prepared from brick powder, fine recycled concrete aggregate and puzzolanic materials. Building Engineering, 10, 80-88. doi:10.1016/j.jobe.2017.02.007*

Yang, X.; Wang, H. (2019). *Strength of hollow compressed stabilized earth-block mansory prisms. Hindawi, 2019, 1-8. doi:10.1155/2019/7854721*