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Compaction effect on the compressive strength and durability of stabilized earth blocks

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HIGHLIGHTS

- There is a strong dependence between the CEB strength and the granulometry.
- 10% of the stabilized lime or OPC is sufficient to develop non-structural CEB.
- The compaction forces increase the compressive stress when OPC is used as stabilizer.
- The 5% and 10% stabilizers reduced the anisotropy of the compressive strength.
- The microstructure is related to the durability coefficients.
- For the same amount of binder, the compressive stress increased more than 200% by changing the mesh distribution.

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ABSTRACT

This work aims to investigate the design of clay matrices with optimum granulometry for their use in compressed earth blocks with and without stabilizers. The results and discussion focus on the mechanical properties, compressive strength anisotropy according to the compaction direction, and durability tests such as abrasion and absorption coefficients. The results show that the granulometry is an important aspect for matrices without stabilizers, as well as the applied compaction forces, obtaining values greater than 2 MPa with compaction forces of 1.96 kN. The clay-sand microstructure matrices are densified when the stabilizers are added, which causes a change in the failure mechanism due to the stiffening of the matrix.

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1. Introduction

Construction procedures have a great impact on the environment. This deterioration occurs not only by the modification of the environment, but also by the materials that are used in it [1]. In the countries with the highest population growth, there is a great demand for low-rise dwellings. This demand cannot be reached even by traditional low-rise construction methods [2], which also generate a large amount of waste and emissions during the extraction, manufacture, transfer, use, and disposal typical of the linear economy. One possible solution to this problem is construction with compressed earth blocks (CEBs) [3]. These construction materials allow building with low technology in an economical, sustainable way, and use materials of the environment. Construction with earth has its origins in ancient civilizations, and even today a large part of the world's low-rise dwellings are built with simple technologies that use earth as the building material [4]. However, construction with earth has different problems in its manufacture and performance, as has been observed in history [5]; it is still a challenge to improve the properties and service life of these materials [6–8]. Therefore, the extensive use of soil-based construction can be feasible if construction processes become standardized, efficient, effective, and easily reproduced using knowledge of the climatic conditions of each region [9].

The Cinva Ram was the first of the instruments that pushed this type of construction procedure [10]. In addition, the performance of CEB, rammed earth, adobe, and cob has been constantly evaluated in order to identify their performance under conditions where their properties are compromised [11–17]. Construction with CEB uses the soil according to granulometry distributions and mix proportions of silica sand and clay. These materials mixed in the

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appropriate amount with water will develop binder properties. The workable mixture is compressed into blocks, generally parallelepipeds, which develop their resistance as a function of the compaction force and amount of clay. However, because these blocks have compressive strength between 1 and 7 MPa, they fail easily under inclement weather conditions [18–20]. Therefore, it is necessary to add different materials to stabilize their performance [21,22]. The stabilization may be mechanical or chemical, and will depend on the type of stabilizing agent and amount added.

The most common stabilizers are Portland cement and lime. Other materials that have been tested as stabilizers are synthetic compounds, supplementary materials, residues, fibers, and alkaline activated materials, among others [23,24]; even materials with high salt content have been used [25]. The quantity and type of addition will depend on the characteristics of the soil type and the expected performance of the manufactured compressed earth stabilized block (CESB). Thus, the focus on these materials is the response of their durability and the correlation with the manufacturing characteristics of these elements [26–28]. Currently, research is underway to change from the simple stabilization of CEB to the manufacture of soil construction materials with a technology similar to concrete, in which through additives it is possible to control the behavior in a plastic state and achieve high resistance in short production times. However, the debate on how to achieve better performance of these materials and their contribution to reduce the environmental impact of buildings remains open [29].

The aim of this study was to determine the effect on compressed earth blocks of different granulometric distributions with and without stabilizers, and their relationship with different compaction forces and durability. Compaction forces and a suitable particle size distribution will help to reduce the anisotropy of the properties and the consumption of stabilizers used in the compressed earth blocks. In the initial part of this study, the design of sand-clay mixtures was carried out with four different distribution particle sizes for testing without stabilizers. In this part, the effect of different compaction forces on the compressive strength was analyzed to determine the granulometry distribution that produces the highest compressive strength without stabilizers. A reduced test specimen was used considering the restrictions of the sample block size aspect factor (longer size/shorter size) reported in other investigations [30,31]. After the granulometric distribution that produces the highest resistance were selected, two stabilizers were added in three different percentages to determine the effect along with the compaction forces, and analyze the stabilizer content in the performance regarding the resistance as a function of the compaction direction [32] and durability tests, such as coefficients of abrasion (Ca) (33) and absorption coefficient (Cb) [34]. The results are discussed in terms of regulations related to this type of product [33–35].

2. Materials and methods

2.1. Characterization of materials and manufacturing blocks

The CEBs were manufactured with silica and clay. First, the granulometry of these materials was determined by a sieve method and by laser diffraction with a Malvern Zeta sizer 2000. The surface area was determined by nitrogen physisorption with a BET method. The use of the surface area indicates the ideal area relation between mix materials. The morphology of the materials was also characterized by scanning electron microscopy (SEM), and the chemical composition by X-ray fluorescence with a Panalytical Epsilon 3 device. The CEBs were manufactured using four different sand distribution granulometries. The selection of granulometry was based on first determining the amount of clay, which determines the binding characteristics and the water content necessary to achieve the compressive resistance properties [36]. In this work, the granulometries recommended by the guidelines were taken as a reference, being an important factor in the performance that the CEB with or without stabilizers will develop [37,38]. Even though these guidelines are a good indicator for the feasibility of soil, they do not indicate the impact that the different granulometries have on the final compressive strength of the CEB. Therefore, the selection was based on the evaluation of the compressive strength development of each of the proposed distributions. After the granulometries to be used were established (see Table 1), three specimens were tested to determine the simple compressive stress. Silica sand with a dry density of 2.60 g/cm^3 was used along with 20% of the mixture with clay of kaolinite origin. According to the classification parameters of Atterberg, it has a liquid limit of 33.46%, a plastic limit of 21.82%, a plasticity index of 11.64, and a dry density of 2.63 g/cm^3 with an average size of 23.71 μm. The sand-clay and water mixes were compacted with forces of 0.49, 0.98, and 1.96 kN applied to a constant area to make the specimens.

The manufacture of the specimens tested in this research required a 4.75-l capacity mixer with the characteristics described in standard ASTM C305, a steel mold with interior dimensions of 30 mm × 40 mm x 200 mm, and a hydraulic press with control of the load application during the complete manufacturing cycle. Mixtures were produced in 3-kg batches, homogenizing all dry materials for 3 min at a speed of 140 rpm. While the equipment was still running, water was added for 30 s. Subsequently, the material was mixed for 5:30 min more. The compaction force required to achieve a certain compressive stress is higher in poorly graded soils than well-graded soils. However, it is unknown to what extent this fact affects the homogeneity of the properties. For that reason, it was decided to conduct a series of tests in two different directions, to establish an anisotropy measure of this property [39]. After that, the granulometry distribution to be used during the remaining experimentation was definitively selected. The manual methodology used a Cinva-Ram press [10], whereby pulling a lever activates a piston, which pushes the material to be compressed between steel plates, forming a parallelepiped. This action generates a compaction force of approximately 0.45 kN when making either CEBs or CESBs.

The second manufacturing methodology used a 200 K Tinius Olsen model super L hydraulic press, which generally applies forces between 0.39 and 1.96 kN or more. In this work, three compaction forces were used to evaluate their effect on CEBs and CESBs. The evaluated forces were 0.49, 0.98, and 1.96 kN, and the results obtained by applying different compaction forces and the resulting block properties can justify the compaction force applied [40]. Because each stabilization variable has a specific process of property development, it was necessary to treat each type differently, dividing them in two groups: the specimens without stabilizers and those stabilized. Resistance in soils that use only clay as a material must undergo a process of moisture loss. Therefore, the specimens of CEB were oven dried for only 24 h at 100 ± 5 °C. The CESBs with added lime and ordinary Portland cement (OPC) were cured in the laboratory for 28 days at a room temperature of 25 ± 5 °C and a relative humidity of 30 ± 5%.

2.2. Mechanical testing and durability of CEB and CESB

The compressive stress measurement of the CEB or CESB is a test that is normally specified in the manufacturing guidelines. In this case, because of the high compaction forces used, the force induces an anisotropic behavior of the element. Therefore, the specimens were tested in two different directions: normal to the compaction load (RCV) and parallel to the compaction direction

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