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Effect of the addition of coal-ash and cassava peels on the engineering properties of compressed earth blocks

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HIGHLIGHTS

- ▶ We evaluate the use of coal-ash and cassava peels in compressed earth blocks.
- ▶ Compressed earth blocks accomplish the necessities from the eco-construction.
- ▶ The cassava peels and coal-ash can be used as non-tradition stabilizers.

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ABSTRACT

In developing countries, such as Colombia, earth construction is economically the most efficient means to solve housing problem with the least demand of resources. Traditional earth construction techniques such as compressed earth blocks are experiencing a new popularity, taking into account that they constitute green building materials becoming economically competitive. The availability everywhere of soils as raw materials, the low energy consumption and the simplicity of the production process justify their great usage as primary housing material in developing countries. A series of test compressed earth blocks were made using a clay-rich soil, without coal-ash and stabilized with coal-ash, in a Cinva-Ram hydraulic machine. The use of cassava peels as novel organic materials were also introduced in the preparation of the compressed earth blocks. The objective of this study is to investigate the effect of the addition of coal-ash and cassava peels on the engineering properties of compressed earth blocks. The samples were tested for flexion, compression and absorption in order to observe their performance. Results show that the compressive and bending tests reveal that the compressed earth blocks stabilized with coal-ash produced the best results using a dose less than or equal to 5%. However, doses greater than 5% generate more flexible and fragile compressed earth blocks. Adding cassava peels to the clayed soil increases the required water content for extrusion (apparent plasticity).

1. Introduction

Environmentally friendly material recycling and energy saving are very important research fields today [1]. On the other hand, as a result of environmental regulations, the demand for construction ecomaterials is increasing. The utilization of earth in housing construction is one of the oldest and most common methods used. Compressed earth blocks (CEBs) has taken up as the principal building material in ancient cities such as Jericho (Palestine), Atal-Huyuk (Turkey), Harappa (Pakistan), Akhlet-Aton (Egypt), Chan-Chan (Peru), Babylon (Iraq), Duheros (España), among others, as reported in previous studies [2,3]. Over the past 50 years they have developed and been increasingly used, especially in developing countries [4]. Earth can be defined as a clayey soil with variable amount and type of clay minerals, which has been widely used for thousands of years. Considerable variations in the composition of the clayey soil makes the measurement of compressive strength, and other physical characteristics, of CEBs an important quality control measure for manufacturers and builders. CEBs (sun-dried bricks) are one of the oldest identifiable man-made building materials due to their simplicity and low cost, good thermal and acoustic properties, and at the end of a building's life the clay material can easily be reused by grinding, wetting or returned to the ground without any interference with the environment [5]. The use of CEBs in construction accomplishes completely the necessities from the ecodevelopment, because of the great usefulness of the natural

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capability from each region, the lack of transports necessity, the ample availability of raw materials, the lack of specialized labor and the low use of energy. However, there are few undesirable properties such as loss of strength when saturated with water, erosion due to wind or driving rain and poor dimensional stability [6]. Today, this problem can be eliminated significantly by stabilizing the clayed soil with a chemical agent such as lime [7], thereby enhancing many of the engineering properties of the soil and producing an improved construction material [8,9]. The drawback in using lime alone results in durability problems, as reported by other researchers [10]. Works on how to correct the durability of lime-stabilized soil have been conducted by numerous researchers [10–13] and reveal that extensive studies have been published on soil stabilization with Portland cement [5,14–16], lime [7], and other pozzolans like volcanic ash [17,18], fly ash [19], and several ash materials [11,20–22], which can be used as chemical additives. The worldwide development of the agroindustry produces annually large volumes of agricultural wastes and their disposal cause major challenges and serious economic and environmental problems. In the last years, researchers are making effort to reduce their amount by finding alternative uses. Agricultural wastes have been used for animal feed, fertilizer, and fuel for energy production, but little work has been carried out to develop utilization of these wastes in the production of building materials [1]. Several types of organic fibers can be produced from a number of agroindustrial wastes [23–26]. Generally, the inclusion of organic fibers within a mixture is intended to reinforce CEBs, although they do not provide adequate durability [27]. The need to conserve the traditional building materials that are facing depletion has necessitated the search for alternative materials [28]. Cassava processing contributes significantly to environmental pollution. According to Ubalua [29], waste materials from cassava processing are divided into four categories: peels from initial processing, fibrous by-products from crushing and sieving (pulp waste), starch residues after starch settling and waste water (effluent). To our knowledge, no previous effort has been made to use cassava peels as an alternative additive in the preparation of stabilized CEBs. Today, earth building production techniques range from the most rudimentary, manual and craft-based to the most sophisticated, mechanized and industrial [30]. With the 1970s and 1980s there appeared a new generation of manual, mechanical and motor-driven presses, leading to the emergence today of a genuine market for the production and application of CEBs [4]. They have excellent insulating properties - reducing heating and cooling costs. The compressive strengths of the blocks depend on their densities. The compressive strength of a soil can be increased by chemical stabilization. This project was designed to prepare locally available soils, make the building blocks with a block press and test for the engineering properties of CEBs. The objective was to test local soils to see if they could be used for low housing construction. A number of standards have also developed for CEB test procedures [31,32]. However, unlike other masonry units, there is little general consensus on test procedure for CEBs. The main objective of this study is to investigate the effects of the aforementioned types of industrial residues on the properties of CEBS. Results of experimental studies are also presented. The compressive strength of blocks measured by differing tests is also compared with other parameters, such as three-point bending strength.

2. Materials and methods

2.1. Materials

The materials used for the industrial trial consisted of raw clay-rich material, coal-ash and cassava peels (Fig. 1). The raw clay-rich material used in this study was supplied by ERGO Durán & García Brick Company Ltda., from the brick plant in Girón, Santander (Colombia). The clayed soil forms part of the Fine Member of the Bucaramanga Formation and is currently used by this company to make fired bricks of H7 ($30 \times 7 \times 20$ mm), H10 ($300 \times 100 \times 200$ mm), H12 ($300 \times 120 \times 200$ mm) and H15 ($300 \times 15 \times 20$ mm) types of different shapes and sizes. Dimensional tolerances are conforming to ASTM Standards. However, the clayed soil presents characteristics suitable for the production of CEBs [33]. The coal-ash used in this study as a chemical additive to protect CEBs against moisture decomposition and stabilize them was obtained after combustion of anthracite coal at 800 °C in a brick kiln, which is an energy-intensive process. Peels obtained from cassava (*Manihot esculenta* Crantz) tubers were obtained from the supply and storage center (Centroabastos), Santander (Colombia). The use of the cassava peels should be promoted as an appropriate and alternative low cost but high quality building technology.

2.2. Properties of materials

The chemical composition of the clay-rich material was 49.42% SiO_2, 37.82% Al_2O_3, 0.06% TiO_2, 0.51% Fe_2O_3, 0.07% MgO, 0.35% Na_2O and 0.79% K_2O. The bulk composition of the coal-ash is similar to that of many geologic materials. It is predominantly a inorganic residue, which mostly consists of 52.09% SiO_2, 41.62% Al_2O_3, 0.17% TiO_2, 0,50% Fe_2O_3, 0.39% MgO, 0.15% Na_2O, 0.97% K_2O, 0.51% SO_3 and 0.39% CaO. The combined SiO_2, Al_2O_3 and Fe_2O_3 content is frequently used to provide an indication of its pozzolanic nature due to the capacity to react with $Ca(OH)_2$ and alkali to form C–S–H phases. On the other hand, the CaO content of the coal-ash is also an indicator of its pozzolanic behavior.

Qualitative determination of major crystalline phases present in the clay-rich material and coal-ash was achieved by using a powder X-ray diffractometer (Philips PW1710), operating in Bragg–Brentano geometry with Cu Kα radiation (λ = 1.5406 Å), 40 kV and 40 mA, and secondary monochromation. Data was collected in the 2–70° 2θ range (0.02° step size). The crystalline patterns were compared with the standard line patterns from the Powder Diffraction File database supplied by the International Centre for Diffraction Data (ICDD), with the help of Joint Committee on Powder Diffraction Standards (JCPDS) files for inorganic compounds. The major crystalline phases found in the clay-rich material are quartz, montmorillonite, halloysite, donpeacorite and osbornite (Fig. 2a). As shown in Fig. 2b, the coal-ash is characterized by the occurrence of an amorphous aluminosilicate (see the broad hump at 2θ = 15–35°, having a maximum at 2θ = ~22°). There are peaks indicating the occurrence of quartz and mullite as crystalline phases. The cassava peels represent organic wastes, which are high in soluble carbohydrates and low in fiber with a moderate level of nitrogen. They are characterized by their low digestibility and toxicity from extremely high levels of hydrocyanic acid.

The particle size distribution (the relative content of clay, sand and gravel) of the clay-rich material (Fig. 3a) was obtained by combined sieve and hydrometer analyses according to the standards ASTM C136-06 [34] and ASTM D1140-00 [35]. It is mainly composed of sand (87.80%) particles, with 13.63% of fine particles and few gravel (1.57%) particles, which reveal that the clay-rich material corresponds to a sandy clay soil. The Atterberg's limits (limits of consistency) including liquid and plastic limit tests of the clay-rich material were determined according to the standard ASTM D4318-10 [36], with the following results: liquid limit of 35%, plastic limit of 17% and plasticity index of 18%, as shown in Fig. 3b.

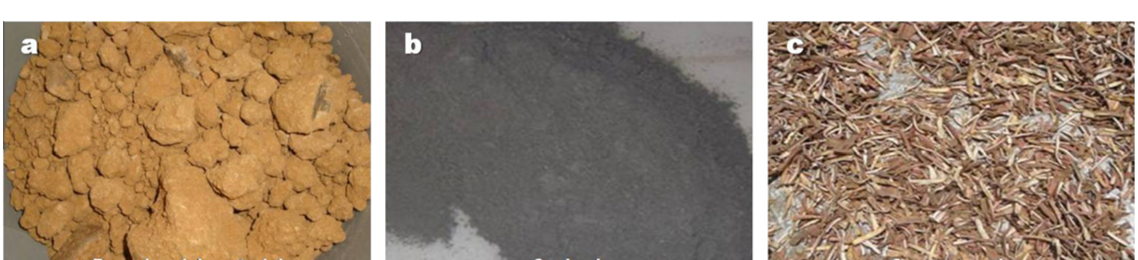

Fig. 1. Starting materials.