Construction and Building Materials 176 (2018) 566–572

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

A comprehensive study of mechanical properties of compressed earth blocks

Gonzalo Ruiz [a], Xiaoxin Zhang [a,b,*], Walid Fouad Edris [c], Ignacio Cañas [d], Lucía Garijo [a]

[a] ETSI Caminos, C. y P., Universidad de Castilla-La Mancha, Ciudad Real 13071, Spain
[b] State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology, Dalian 116024, China
[c] Hijawi for Engineering and Technology, University of Yarmouk, Irbid 21163, Jordan
[d] ETSI Agrónomos, Universidad Politécnica de Madrid, Madrid 28040, Spain

HIGHLIGHTS

- Advanced mechanical characterization of CEB, including the fracture energy.
- Influence of contact state between specimen and platen on the compressive strength.
- Analysis of the shape and size effects on the compressive strength.
- The characteristic length is 224 mm, obtained for the first time.

ARTICLE INFO

Article history:
Received 29 January 2018
Received in revised form 30 April 2018
Accepted 7 May 2018

Keywords:
CEB
Compressive strength
Mechanical characterization
Capping effect
Shape and size effects

ABSTRACT

Currently, Compressed Earth Blocks (CEBs) are becoming more interesting owing to their sustainability characteristics. However, there is still no consensus on the procedure to measure its mechanical properties. Thus, an advanced study on the measurement of mechanical properties of a type of CEB was conducted. With respect to compressive strength, block units and cubes with different edge lengths, under various contact states were tested. The results show that the whole block capped with rubber is the appropriate procedure to obtain the real compressive strength. Moreover, there exists an abnormal size effect, which could be related to a possible damage of the cubes cut from the blocks.

1. Introduction

Building with Compressed Earth Blocks (CEBs) is becoming more popular due to their environmentally friendly process, low cost and relative abundance of materials at present time. A considerable number of countries currently have earth building standards. Most of them deal with one or, in some cases, more of these three techniques: adobe, rammed earth and CEB. The CEB represents the most studied technique, being present in almost three quarters of the standards under consideration [1].

Most standards of CEB show that the compressive strength is a significant parameter to design constructions. However, these standards [2–32] have notable differences on their procedure to measure the compressive strength [33]. It is worth noting that several variables may influence the obtained results, such as, unit geometry, conditions of specimen surface, moisture and cement contents.

Regarding the geometry of CEB for the compressive test, there are two prevailing ways presented in standards. Firstly, blocks are halved and stacked bonded by using an earth mortar bed joint to double the slenderness ratio of the test specimen as explained in the standards of Colombia [7], France [31], Brazil [22] and the RILEM TC 164 [34]. Secondly, whole blocks are tested directly between platens and following the direction in which they have been pressed during the fabrication. This is also the usual direction in which blocks are placed during construction as presented in the Spanish standard UNE 41410 [6]. Moreover, the experimental results show that there was no parity between the whole block strength and the one in accordance with the RILEM recommendation [35].

Insofar as the state of specimen surface, in general, blocks are not perfectly formed and their bearing surfaces may not be parallel

* Corresponding author at: ETSI Caminos, C. y P., Universidad de Castilla-La Mancha, Ciudad Real 13071, Spain.
E-mail addresses: xiaoxin.zhang@uclm.es, zhangxiaoxinhrb@gmail.com (X. Zhang).

https://doi.org/10.1016/j.conbuildmat.2018.05.077
0950-0618/

and free from surface irregularities. The purpose of capping the bearing surfaces is to assure reasonably that they are parallel and smooth. But, many standards in the compressive test do not even mention this fact. One of the main materials used for solving this problem is plywood sheet, while the thickness of the plywood sheet changes from one to another. The Kenya standard [32] and Walker [36] have proposed to cap the specimens with two 3 mm thick sheets of plywood. According to the Bulletin 5 [37] the thickness of plywood sheets ranges from 4 to 5.5 mm. Walker and Stace [38] adopted 4 mm thick plywood sheets for their tests. Ottazzi et al. [39] used different methods to obtain flat and parallel faces by capping the specimen with a 3 mm thick layer of cement paste with plastic consistency.

As mentioned before, it is obvious that there is still no consensus on the procedure used to measure the compressive strength of this material. Thus, a comprehensive study on the measurement of mechanical properties of a type of CEB was conducted. Once splitting tensile strength, elastic modulus and fracture energy are obtained, the characteristic length will be determined, which is a parameter used to predict the brittleness of a material. As it decreases, brittle nature dominates and vice versa. To our knowledge, it is the first time that the value of the parameter was obtained, which would be helpful for the design of such structure to avoid brittle failure. Regarding the compressive tests, three various capping methods (capping with rubber, plywood and without capping) were adopted. Moreover, the size effect on the compressive strength was studied as well.

The remainder of the paper is structured as follows: the experimental program is described in Section 2; the experimental results are presented and discussed in Section 3; finally, some conclusions are set forth in Section 4.

2. Experimental procedure

2.1. Material characterization

The CEB was fabricated in Madrid, Spain, and stabilized with 6% cement of the total weight. Block dimensions were of 290 mm × 140 mm × 70 mm. The average weight in dry state is 5840 g, corresponding to a dry density of 2055 kg/m^3.

The particle size distribution of the soil used is shown in Fig. 1, the results also indicate that the soil classification is A-1-b according to the standard ASTM D3282 [40]. The liquid and plastic limits of the Atterberg tests are 20.2% and 18.5%, respectively.

The blocks have been produced by a hydraulic press and stored in the ambient laboratory conditions for around one year with the relative humidity of 47% ± 10% and temperature 22 °C ± 5 °C before the testing campaign. In order to eliminate moisture content effect on the mechanical properties, all specimens were placed in an oven at 105 °C for 24 h, and left in the ambient laboratory for approximately 2 h prior to tests according to the Australian Bulletin 5 [37].

Table 1 shows the information of various types of tests for an advanced mechanical characterization of the material, such as compressive strength, splitting tensile strength, elastic modulus, fracture energy and flexural strength. Moreover, cubes were randomly selected from the consignment of units produced from the CEB. Furthermore, length, width, height and weight of the specimens were measured just before tests.

2.2. Tests for measuring mechanical properties of the CEB

2.2.1. Compressive tests for elastic modulus and compressive strength

Compressive tests were carried out on whole blocks and cubes with different edge lengths, 40 mm and 70 mm. For the blocks, the tests were performed by a Servosis servo-hydraulic machine with a capacity of 3 MN, at a loading rate 0.05 MPa/s. For cubes, the tests were conducted by an Instron servo-hydraulic machine with a capacity of 250 kN. The loading rate was 0.05 MPa/s as well, regardless the size of cubes. The displacement between two steel platens was measured through two LVDTs (Linear Variable Differential Transducer), as shown in Fig. 2. Three contact conditions were adopted between the specimen and the steel platen, i.e., specimen capped with two 3 mm thick sheets of plywood, two 3 mm thick sheets of rubber and, without capping.

Compressive tests were also performed on prisms cut from the whole block to measure the elastic modulus. The machine used was the Instron servo-hydraulic machine of 250 kN. The prism was capped with rubber to ensure the uniform distribution of load across the surface of the specimens and avoid the constriction caused by the friction between the steel platens and the specimen

Table 1
Specimens prepared for different types of tests.

Type of test	Mechanical property	Shape and size of the specimen	Number of tests
Compressive test	Compressive strength	Cubes 40 mm in edge length	20
		Cubes 70 mm in edge length	20
		Whole block	37
	Elastic modulus	Prisms 70 × 70 × 140	10
Splitting tensile test	Splitting tensile strength	Cubes 40 mm in edge length	10
		Cubes 70 mm in edge length	10
		Whole block	13
Three-point bending test	Fracture energy Flexural strength	Whole block with a center notch	15

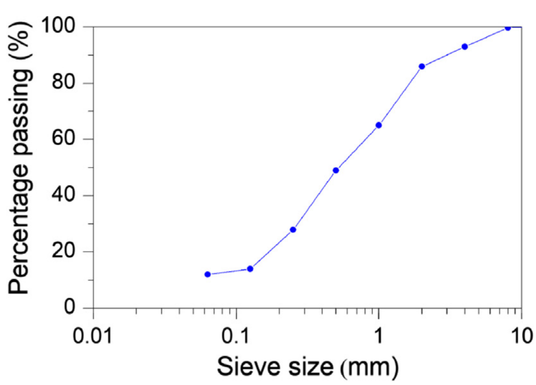

Fig. 1. Particle size distribution of the soil used.

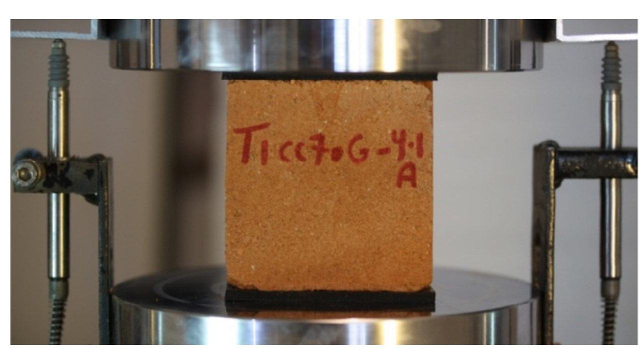

Fig. 2. Compressive test on cube, capped with two 3 mm sheets of rubber.